HEALTH EFFECTS OF IONIZING RADIATION ON DIAGNOSTIC PROFESSIONAL RADIATION WORKERS IN SOME SELECTED HEALTH INSTITUTIONS IN SOUTHERN NIGERIA

BY

OMITA, EFE (B.Sc. UNN, M.Sc. RSU)

REG NO: 20174082668

A DISSERTATION SUBMITTED TO THE DEPARTMENT OF PHYSICS, POST GRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D.) DEGREE IN RADIATION AND HEALTH PHYSICS.

OCTOBER, 2023.

CERTIFICATION

This is to certify that the work described in this thesis was carried out by, OMITA EFE (Reg. No: 20174082668) a student of the Department of Physics, Federal University of Technology Owerri.

Prof C.E Orji
Supervisor

03 - 10 - 2023
Date

Dr. K.B. Okeoma
Co-Supervisor

03-10-2023
Date

Dr. C. Iroegbu
Co-Supervisor

03.10.23
Date

Dr. K.B. Okeoma

Head, Department of Physics

03-10-2023
Date

Prof. C.E Ogukwe

Dean, School of Physical Sciences

04/10/2023
Date

Prof. B. O. Esonu

Dean, Postgraduate School

Date

Prof C.O. Awosika

External Examiner

Date

Dedication

This work is dedicated to my lovely husband, Mr. Daniel Omita and my children Zino Daniel Omita and Uzezi Daniella Omita.

Acknowledgements

First and foremost I would like to thank God Almighty who made all things possible for me.

My gratitude goes to my family, my Husband Mr. Daniel Omita, my children Zino Omita and Uzezi Daniella Omita, my Parents Mr. and Mrs. Ohwekevwo and all my siblings for their spiritual, financial and physical support to the success of this project work.

My deepest and heartfelt appreciation goes to my supervisors, Prof C.E. Orji and Dr. K.B. Okeoma, and Dr. **C**. Iroegbu whose directives, guidance and constructive criticism led to the production of this work. I will also like to thank the Post graduate school, the Dean, Prof. B. O. Esonu, the Associate Dean and all the members of staff of the school for their supports and contributions to the success of this degree.

I wish to appreciate Dr. C. Aborisade, Dr. L. Rilwan and Mr. Peter Ojike for his invaluable guidance, constructive and thorough comments on this work. I will like to extend my appreciation to Mr. Michael Ogolodom and Mr. Amakom Michael Chijioke, Mr. Amstrong and Mr. Onuk Orji Galadima for their assistance towards the success of this research work. My gratitude also goes to Dr. O.K Echendu and Dr. A. Ohajianya, our PG coordinators for his understanding, support and Patience during this project work.

I am grateful to my friends and colleagues, amongst who are, Mrs Charles Miebaka, Mr. Akin Daniel, Mr. Obetta Thaddeus and Mrs. Blessing Enyinnaya, for their guidance and assistance to the success of this work.

Finally, I would like to thank everyone who contributed to the successful realization of this dissertation.

Table of Contents

ABBREVIATIONS

ALARA	**As Low as Reasonable Achievable**
APD	**Avalanche Photodiode**
BASO	**Basophil**
CBC	**Complete Blood Count**
CT	**Computed Tomography**
DELSUTH	**Delta State University Teaching Hospital**
DNA	**Deoxyribonucleic Acid**
EDTA	**Ethylendiaminetetraacetic acid**
EOS	**Eosinophil**
EQA	**External Quality Assessment**
FMC	**Federal Medical Centre**
Gy	**Gray**
Hgb/HGB	**Hemoglobin**
Hct/HCT	**Hematocrit**
IDC	**Image Diagnostic Centre**
IER	**Ionizing Electromagnetic Radiation**
IQC	**Internal Quality Control**
IR	**Ionizing Radiation**
ICRP	**International Commission on Radiological Protection**
LiF	**Lithium fluoride**
LNT	**Linear No-Threshold**
MCH	**Mean Cell Hemoglobin**
MCHC	**Mean Cell Hemoglobin Concentration**
MCV	**Mean Cell Volume**
mGy	**mili Gray**
MONO	**Monocyte**
MPV	**Mean Platelet Volume**

mSv	**mili Sievert**
NDUTH	**Niger Delta University Teaching Hospital**
NUET	**Neutrophil**
OEL	**Occupational Exposed Limit**
PCT	**Platelet Concentrate**
PDW	**Platelet Distribution Width**
P-LCR	**Platelet Large Cell Ratio**
Plt/PLT	**Platelet**
PMP	**Photo Multiplier Tubes**
RBC	**Red Blood Cell**
RD	**Radiograph**
RDW	**Red Cell Distribution Width**
RRBN	**Radiographer Registration Board of Nigeria**
SOP	**Standard Operating Procedure**
SPSS	**Statistical Package for Social Sciences**
Sv	**Sievert**
PPE	**Personal Protective Equipment**
TLD	**Thermo luminescent Dosimeter**
UPTH	**University of Port Harcourt Hospital**
WBC	**White Blood Cell**
W H O	**World Health Organization**

List of Tables

List of Figures

ABSTRACT

This study was designed to evaluate the effects of regular low-level ionizing radiation on the hematological parameter of occupational radiation workers. This experimental study was carried out in southern Nigeria among 202 samples, which include 101 occupationally exposed workers and 101 non-occupational exposed workers (control).The exposed subjects were selected from Radiology Departments and Radio diagnostic centers with large number of referral cases who were chronically exposed to low doses of ionizing radiation. Selected controls workers in the same hospitals and center without being exposed to any kind of radiation doses. All exposed and control subjects match gender, age and occupational records (±3 years). They were categorized based on the duration of exposure as group 1 (<10 years) and group 2 (≥10 years). A Physical Dosimetry was carried out by measuring their occupational exposure to ionizing radiation is routinely monitored by personal exposure measurement devices (Thermoluminiscent dosimeter).This monitoring was carried out for at least two years and a Biological Dosimetry was also carried out using Full Blood Count to ascertain the biological effect of low ionizing radiation. Data such as gender, age, full blood count parameters as well as the radiation doses received by the radiation workers were collected using data capture sheet. All results were compared to the standard values. Out of 101 radiation workers, the majority 70.3% (n=71) were medical radiographers and the least 1.98% (n=2) were medical physicists. There is a statistically significant mean difference between the standard dose and radiation doses received by radiation workers with the mean cumulative dose of 1.67mSv which is below the recommended dose of 20mSv by the ICRP (t= -234.6, p= 0.00). There were statistically significant mean difference between blood parameters of radiation workers (BPRW) and standard full blood count limits(SFBCL) are WBC (BPRW = 5.19 and SFBCL mid-point = 7.00- 10 x 10^9), RBC (BPRW = 4.08 and SFBCL = 4.50-5.50 x 10^{12}), Platelets (BPRW = 228.22 and SFBCL = 200 x 10^9) and MCV (BPRW = 80.51 and 80-100), with values of WBC (t= 12.16, p = 0.00), RBC (t= 4.09, p =0.00), Platelets (t= 3.57, p = 0.001) and MCV (t= -8.76, p = 0.00). The analysis of variance (ANOVA) results revealed that there were statistically significant different in the radiation effects on the blood parameters such as WBC (F= 2.326, p = 0.025), RBC (F = 3.969, p= 0.000), Platelets (F=6.060, p = 0.000), MCH (F=4.898, p = 0.000), HCT (F=4.060, p = 0.000) and MCHC (F=5.377, p =0.000). There were no statistically significant different in the effect of radiations on Hb (F=1.690, p=0.111) and MCV (F=1.502, p = 0.167). The average annual effective radiation dose was below the limits advised by the International Commission on Padiological Protection, there was also some evidence that low ionizing radiation exposures affect some hematological parameters of radiation workers. Despite this, there is no established threshold for initiation of biologic alterations brought on by exposure to low doses of radiation.

Keywords: Ionizing radiation, Radiation workers, complete blood count, low-dose, Thermoluminiscent dosimeter, Hematological parameters, Physical Dosimetry, Biological Dosimetry.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Radiation is the emission or transmission of energy as wave or particles through space or material medium. (Weisstein, 2014). Radiation consist of electromagnetic radiation which includes radio waves, microwaves, infrared, visible light, ultraviolet, x-ray and gamma ray, particle radiation (alpha, beta and neutron particle and acoustic radiation (ultrasound and seismic). Radiation is frequently categorized as ionizing and non-ionizing, ionizing radiation carries more than 10 eV, which is sufficient to break the chemical bonds in atoms and molecules. This is a significant distinction due to the large differences in how harmful ionizing radiations are to living things.

In order for an atom to become charged or ionized, ionizing radiation must have sufficient energy to remove closely bound electrons from the atom's orbit (WHO, 2020). The energetic end of the electromagnetic spectrum, such as X-rays and gamma rays, as well as subatomic particles like electrons, neutrons, and alpha particles are all included in ionizing radiation. (Land, 2007).

One of the latest advancement in technology is the utilization of ionizing electromagnetic radiation in various fields ranging from science to industry and medical application (Banik, Bandyopadhyay, & Ganguly, 2003; Abdolmaleki et al., 2012). Ionizing radiation (IR) mostly X-rays and those emitted by radioactive substances, play a significant role in diagnostic and therapeutic medicine (Calabrese, Dhawan, & Kapoor, 2014; & Puthran, Sudha, Gayathri, & Shetty, 2009). Despite this vital role, ionizing radiation is globally known as an occupational hazard in the work place due to its potential biological damage. (Feinerdegent, Brooks, & Morgan, 2011).

Negative biological consequences may occur if an individual is exposed at a level above the occupEation exposure limit (OEL) recommended by the International Commission on Radiological Protection (ICRP, 2007). These limits are 20 mSv per annual averaged over a period of five-year periods, with a maximum of 50 mSv effective dose in any one year. Equivalent dose for skin, hand and feet at 500 mSv per year and 20 mSv to the lens of the eye average over a defined period of five years with no single year exceeding 50 mSv per year. Even when they are wearing the proper personal protective equipment (PPE), medical radiation workers are inevitably exposed to long-term low-dose ionizing radiation (Cengiz et al., 2003). Ionizing radiation is used in two-thirds of radiological operations for medical imaging equipment. (Roobottom, Mitchell, & Morgan-Hughes, 2010).

According to the ICRP (2007), the incidence of "Stochastic" effects may increase at low radiation doses (below approximately 100mSv per year) with a small probability and proportion to increase in radiation dose over the background dose. Randomly occurring effects like cancer or genetic harm are included in these stochastic effects. These stochastic effects cannot be entirely avoided at the current state of scientific knowledge, and there is no radiation dose threshold that can be used ti account for them.

However, low-dose radiation is exposed during clinical diagnosis, such as with X-ray radiography and computed tomography (CT), ongoing nuclear operations, or following a nuclear disaster (Maqsudur, Latha, Arwa, Naima, & Hanna, 2019). Ionizing radiation with a low dose is that with less than 100mSv. As exposure to radiation at doses utilized in medical imaging has been connected to the development of malignancies, radiation is dangerous in all dosages (Smith et al., 2009; Aborisade**,** Famurewa, Ibitoye & Balogun, 2019; Nwodo et al., 2020; Aborisade, 2021). Ionizing radiation has the potential to cause chromosomal aberration to occur more frequently among other types of cell damage. Several earlier investigations have established the cytotoxic effects of low-dose ionizing radiation in occupationally exposed radiation professionals (Zakeri, Hirobe, & Noghabi, 2010).

Ionizing radiation is recognized to have harmful effects on health that depend on the dose and length of exposure, but there is no level of ionizing radiation that is considered safe. A few years after ionizing radiation was discovered, its effects started to become clear. This scenario illustrates the fact that if radiation safety regulations are not upheld, radiological environments

where machines are employed may be threatened by secondary (scatter and leakage) radiation. (ICRP, 2007).

Data from the Cancer Registries throughout Nigeria, as documented by the Nigeria National System of Cancer Registries (NSCR) from 2009 to 2016, indicates that Nigeria ranks among the countries with the highest occurrences of cancer and associated fatalities worldwide. Given that ionizing radiation is a known factor contributing to cancer, there is a pressing need to oversee the well-being of individuals exposed to radiation. Those professionals who dedicate their entire working lives to daily activities in radiation facilities emerge as significant victims of the eventual consequences of ionizing radiation (Shrader-frechette, 2007).

There are already more than 4,000 X-ray machines in operation in Nigeria (Akpochafor Omojola, Adeneye, Aweda, & Ajayi, 2016). It is impossible to avoid ionizing radiation exposure in medical imaging facilities, despite the fact that the radiation dose is modest during diagnostic operations. Therefore, care should be taken to reduce unneeded radiation exposure for both public and occupational radiation people (Brigg-kamara, Okoye & Omubo-Ppple, 2013). The Nigerian Nuclear Regulatory Authority (NNRA) is the federal agency in charge of overseeing nuclear safety and radiological protection in order to protect people, property, and the environment from the potentially dangerous effects of ionizing radiation. (Eze, Abonyi, Njoku, Irurhe, & Olowu, 2013).

In order to ensure that the acceptable limits are not exceeded, occupational radiation professionals could be routinely observed using radiation Dosimetry, which is primarily used to protect against ionizing radiation (ICRP, 2007; Aya, 2018). It can also be applied to industrial and medical radiation monitoring, including radon monitoring in buildings and radiotherapy. (Izewska & Rajan, 2012).

Ionizing radiation dosimeters are instruments, detectors, and devices that may measure directly or indirectly the amounts of exposure received in terms of dosage or dose equivalent (Singh, Managanvi, Bihari, & Bhat, 2013). Dosimeters are primarily used for human ionizing radiation monitoring and for assessing absorbed dosage in industrial and medical radiography. Finger dosimeters and work environment dosimeters are just two examples of the electronic personal dosimeters that are available (Seco, Clasie, & Partridge, 2013). Lummis the Instadose (Digital dosimeter) and the Thermoluninescene dosimeter are the two most widely used personal radiation dosimeters in Nigeria (Yahaya et al., 2019).

According to Garzón, Khoury, Ovalle, & Medeiros (2018), the Instadose (Digital dosimeter) is a compact, reliable dosimeter that uses direct ion storage technology. A memory chip incorporated into the Novel technology stores each user's identity using a special serial code that is provided to them (Miron, 2018). From a computer with internet connectivity, users can examine the results of their radiation dose at any time. A detector that is compatible with the universal serial bus enables readings through a laptop. In order to utilize Instadose, a user must first register at www.instdose, after which the device's drivers and clients are installed on the user's computer. When a user needs a reading, all they have to do is log into their account, connect Instadose to a USB port, and select "Read Device." The Instadose stored dose is processed using an algorithm. The procedure is automated, which lessens the possibility of human error and misidentification. After the procedure is complete, a visual showing the current dose will load on the screen (Ginjaume, 2011). The advantages of the Instadose dosimeter are its tiny, lightweight design, USB-compatible detector, and user-performed online dose readout. Users only need to log in to their accounts, connect Instadose to a USB port, and click whenever they want to get a reading.

Thermoluninescene dosimeter (TLD), on the other hand, combines four Thermoluminiscent detectors with anodized aluminum foil (Covens, Berus, Buls, Clerinx, & Vanhavere 2007). The typical components of TLD are lithium fluoride activated with magnesium and calcium fluoride activated with manganese (Singh et al., 2013). Ionizing radiation energy is stored in the dosimeter (Seco et al., 2014). TLD is typically heated to a temperature of 300^{o} C, releasing the energy held in the form of light, in order to measure the amount of radiation received by the device. The radiation dose each detector receives determines how much light is emitted. (Bappah et al., 2019). The main advantages of TLD are its affordability, good tissue equivalent, simplicity of use, sensitivity, and accuracy. It is reusable and independent of environmental factors. (Furetta & Weng, 1997; Koguchi et al., 2010) and TLD was chosen as the dosimeter for this study because to the aforementioned benefits.

The biological effects of X-rays and gamma rays are harmful because they can cause chromosomal abnormality, destroy living cells, and have a carcinogenic effect when they penetrate living tissue (Adhikari, 2012). During radiological operations, medical radiation technicians are exposed to low-dose ionizing radiation. Hematological, biochemical, and cytogenic markers have been used in various studies over the past ten years to assess the biological effects of ionizing radiation. Several prior investigations also found cytotoxic effects of low ionizing radiation in occupationally exposed professionals (Zakeri et al., 2010).

In routine medical examinations, analyses of hematological parameters like the total blood cell count are often used. The most vulnerable human cells to ionizing radiation are hematological cells, and prolonged exposure to low doses of ionizing radiation can have a significant negative impact on human cells, particularly the peripheral blood cell count. The complete blood count (CBC) examination, a straightforward, affordable point-of-care test, is helpful for diagnosing a variety of disorders in their early stages. Additionally, the complete blood count (CBC) gives doctors the ability to make a wide range of differential diagnoses (Tavakoli et al., 2012).

Periodic medical examinations of radiation workers are routinely conducted in many countries. Although it is not anticipated that low dose radiation (LDR) will have a substantial impact on blood count, the periodic checkup typically entails reviewing work history, general medical history, a physical examination, and blood collection. The lymphocytes are the most sensitive blood parameter to ionizing radiation and in Iran, radiation workers, even those who work in diagnostic radiology departments, are regularly examined for blood count changes. (Zare & Mortazavi, 2019)

1.2. Problem Statement

Ionizing radiation is one the causes of cancers and deaths. Nigeria has one of the highest cancer cases resulting to death, and this has attracted much global concern (Sowunmi et al., 2018). Ionizing radiation is one of the serious factor in the work place that seriously harm professional radiation workers resulting to both permanent and irreparable damage to biological tissues. Medical radiation Professionals who are exposed to secondary ionizing radiation while performing their duties are likely to acquire radiation related illnesses especially those associated with hematopoietic cells such as cancers.

1.3 Aim of this Study

The aim of this study is to determine the health impact of low ionizing radiation on Professional radiation workers in some selected tertiary hospitals in south-south and south Eastern Nigeria

1.4 The Objectives of this Research Work are to:

I. Determine the dose equivalent of occupational radiation workers from the selected tertiary health institutions and compare it with the standard value of 20mSv given by the International Commission on Radiological Protection (ICRP) using the t-test.

II. Evaluate the hematological parameters of occupational radiation professional and compare them with the standard Complete Blood Count Reference Limits using the t-test.

III. Measure and compare the hematological parameters of Healthy occupational radiation workers with healthy non-radiation workers in the same Hospital or radio diagnostic centers using t-test.

IV. Determine the effects of ionizing radiation dose on the hematological parameters of radiation workers using simple Regression (with the absorbed dose of radiation as the independent variable and the hematological parameter as the dependent variable.

V. Compare the hematological parameters of male and female radiation workers using the t-test method.

1.5 Research Questions

1. Why is radiation monitoring of occupational radiation workers not mandatory in Nigeria?
2. Why is biological monitoring of radiation professionals not done in Nigeria?
3. Why is there Lack of radiation protection compliance among occupational radiation personnel?

1.6 Hypothesis

1. Ho: There is no significant difference between the standard dose and radiation doses received by radiation workers

   Hi: There is significant difference between the standard dose and radiation doses received by radiation workers

2. Ho: There is no significant difference between the blood parameters of radiation workers and standard full blood count limits.

   Hi: There is significant difference between the blood parameters of radiation workers and standard full blood count limits.

3. Ho: There is no significant difference in the blood parameters of radiation workers and non-radiation workers

   Hi: There is significant difference in the blood parameters of radiation workers and non-radiation workers.

4. Ho: There is no statistical difference in the radiation effects on the blood parameters of radiation workers across the hospitals.

   Hi: There is statistical difference in the radiation effects on the blood parameters of radiation workers across the hospitals.

5. Ho: There is no significant impact of the cumulative absorbed dose by radiation workers on their blood parameters

   Hi: There is significant impact of the cumulative absorbed dose by radiation workers on their blood parameters

6 Ho: There is no significant difference in the hematological parameters of male and female radiation workers.

   Hi: There is significant difference in the hematological parameters of male and female radiation workers.

1.7 Significance of Study

Several older radiographers and medical radiation workers have died from different forms of cancers from my several years of working in the radiology department (Linet et al., 2010). Also from the literature review carried out, it was observed that no work have been carried out on this topics from these regions and the radiation workers may be suffering because of no standard here to compare. This study will help Professional radiation workers to know their health status as regard to their exposure to long term low ionizing radiation by:

I. Knowing the amount of absorbed dose of radiation from the Thermoluminiscent dosimeter readings.
II. Knowing the effects of ionizing radiation on their hematological parameters through the results from the automated Complete Blood Count Analyzer.
III. The results of the Thermoluminence dosimeter from this study will help the individual radiation worker to take precautionary measures while working with ionizing radiation.
IV. The outcome of the study will assist the management of Radiology department/ Centre and hospitals where the radiation workers works to have a data base thereby making proper planning in respect to radiation protection monitoring procedures.

1.8 Scope of the Study

This study is focused on assessing the health impacts of low-dose ionizing radiation on radiation workers in selected tertiary health institutions across six states in south-eastern and south-south Nigeria, encompassing Rivers, Bayelsa, Delta, Enugu, Abia, and Imo. The study involves radiation professionals, including Radiologists, Radiographers, Medical Physicists, and Resident doctors in Radiology, recruited from institutions such as the University of Port Harcourt Teaching Hospital, Federal Medical Center Yenagoa, and others. Dosimetry, both physical (using Thermoluminescent dosimeter) and biological, is employed to evaluate radiation exposure, with a focus on comparing hematological parameters of radiation professionals to non-radiation workers and assessing adherence to international safety standards.

CHAPTER TWO

2.0 Literature Review

The literature review of this work will be done using the theoretical review and Empirical review. The theoretical review will examine some of the theories involved in radiation protection and effects of ionizing radiation on radiation professionals.

2.1 Theoretical Review

Ionizing radiation (IR) is high-energy radiation that has enough energy to liberate electrons from atoms and cause breaks in chemical bond. It causes DNA strand breaks, leading to mutation and resulting in cell death. The major types of IR exposures are from background, external, internal and medical sources and include nuclear radiation, X-rays and gamma rays. Medical exposure occur through X-rays, CT scans, and cancer radiotherapy.

2.1.1 Discovery of Ionizing Radiation

During the late part of the nineteenth century, Scientists actually started making advances in their understanding of atomic structures and radiation. In 1869, Dmitri Mendeleev proposed the periodic system of elements. Wilhelm Roentgen, who had captured an x-ray image of the woman's hand in December 1895, made a curious discovery about X-ray properties (Rai, 2019). As a result, further information has emerged about the properties of ionizing radiation as well as their potential to be used in medicine.

Radiation-generating machines, such as medical X-ray machines, produce ionizing radiation electronically and stop producing radiation when turned off. Equipment that contains

radioactive material, such as some industrial radiography equipment, cannot be turned off because the radioactive source emits ionizing radiation. These sources must be shielded (i.e., surrounded by a material that can block radiation) to prevent or reduce radiation exposure.

2.1.2 Types of Ionizing Radiation

Particulate radiation: Sub-atomic particles with mass such as Alpha and Beta particles, electrons and neutrons.

Alpha particles: Positively charge particle

Electromagnetic Radiation: Gamma rays and X-rays, has no mass and no charge

1. **Alpha particles (α)**

Positively charged particles consisting of two protons and two neutrons emitted from the nucleus of some radioactive atoms. An alpha particle is the nucleus of a helium atom.

Unstable atoms with a low neutron-to-proton ratio may emit alpha particles.

Radionuclides that emit alpha particles include:

I. Uranium-238 (U-238), U-234, U-235
II. Radium-226 (Ra-226), Ra-223, Ra-224, (decay products of uranium)
III. Radon-222 (Rn-222), Rn-219, Rn-220 (decay products of radium)
IV. Thorium-230 (Th-230), Th-227, Th-228
V. Americium-241 (Am-241)
VI. Polonium-210 (Po-210)

2. **Beta particles (β-) and Positrons (β+)**
    a. **Beta particles (β-)**

Negatively-charged, fast-moving electrons emitted from the nucleus of various radionuclides. Unstable atoms with a high neutron-to-proton ratio emit negatively-charged beta particles.

Beta particles (β-)

Some radionuclides that emit beta particles include:

I. Strontium-90 (Sr-90)
II. Phosphorus-32 (P-32)

III. Carbon-14 (C-1

b. Positrons (β+)

Positively-charged, fast-moving electrons emitted from the nucleus of certain radionuclides. Unstable atoms with a low neutron-to-proton ratio can emit positrons.

Positrons (β+)

Fluorine-18 (F-18) is an example of a positron-emitting radionuclide that is commonly used in medical facilities for positron emission tomography (PET) scanning.

An F-18 atom has nine protons and nine neutrons, and is unstable (i.e., radioactive). To become more stable, the F-18 atom releases radiation by turning a proton into a neutron and ejecting a positron. Having gained a neutron and lost a proton, the radioactive F-18 atom becomes stable oxygen-18 (O-18), with eight protons and 10 neutrons.

3. **Neutron particles**

Neutral (i.e., having no electric charge) particles that can be emitted from the nuclei of various unstable radionuclides. Neutrons are high-speed nuclear particles that are the only type of ionizing radiation that can make objects radioactive.

Nuclear fission and fusion reactions, as well as neutron sources (e.g., Cf-252, AmBe), neutron generators, and some particle accelerators, produce neutrons. For example, neutrons would be produced from the detonation of a fissile nuclear weapon, such as an improvised nuclear device (IND)

4. **Gamma rays (γ)**

High-energy electromagnetic photons emitted from the nucleus of an unstable, excited atom. Gamma rays are pure energy and can travel great distances at high speed.

Some radionuclides that emit gamma rays include:

I. Iodine-131 (I-131)
II. Cesium-137 (Cs-137)
III. Cobalt-60 (Co-60), cobalt-57 (Co-57)
IV. Gallium-67 (G-67)

V. Technetium-99m (Tc-99m)
VI. Iridium-192 (Ir-192)

Gamma rays are often emitted along with alpha or beta particles during radioactive decay (e.g., Co-60, Ir-192).

5. **X-rays**

High-energy electromagnetic photons emitted from outside the nucleus. The primary difference between X-rays and gamma rays is that X-rays are emitted from processes outside the nucleus, but gamma rays originate inside the nucleus.

Some radionuclides that emit X-rays include:

Iodine-125 (I-125)

Iron-55 (Fe-55)

Machines containing an X-ray tube also electronically produce X-rays.

2.1.3 Production of X-rays

There are three mechanisms for x-rays production

I. The acceleration of charged particles
II. Atomic transition between discrete energy level
III. The radioactive decay of some atomic nuclei

Each of these mechanism result to a characteristic spectrum of x-ray radiation.

In classical electromagnetic theory, accelerating electric charge emit electromagnetic waves. The most common source of x-rays, which is the x-ray machine. In x-ray tube, a high-energy electrons beam strike on a target. The fast moving electrons in the beam interact with the electrons and nuclei of the target atom. They are deflected repeated and slowed down. During the sudden deceleration, the beam emit braking radiation called bremsstrahlung which is a continuous spectrum of electromagnetic radiation with a peak intensity in the x-ray region. Most of the energy emitted in the x-ray tube is in the spectrum.

Along with the continuous spectrum of radiation that the accelerating electrons release, an X-ray tube also emits a spectrum of discrete X-ray emission lines that are characteristic to the

target material. This “characteristic radiation” results from the excitation of the target atoms by collisions with the fast-moving electrons. Most frequently, a collision first results in the ejection from the atom of a securely bound inner-shell electron, and a loosely bound outer-shell electron then fills the empty space in the inner shell. A single photon with an energy equal to the difference between the inner-shell and outer-shell vacancy states is released by the atom during the process. Typically, this energy disparity correlates to photon wavelengths in the X-ray spectrum. When a target material is exposed to a primary X-ray beam, characteristic X-ray radiation can also be generated from that material. In this instance, a series of electron transitions are initiated by the primary X-ray photons, and they eventually lead to the emission of secondary X-ray photons.

I. The X-ray Production Process

The tungsten filament becomes heated as a result as a current flowing through it. Thermionic emission, a process that releases electrons from the filament as it heats up, is made possible by the increased energy. The tube potential (voltage) controls how strongly the electrons are drawn to the positively charged anode and how strongly they strike the tungsten target. Bremsstrahlung and other characteristic interactions occur as the electrons bombard the target, converting energy into heat (99%) and x-ray photons (1%), respectively. The x-ray photons, which are the building blocks of x-ray image formation, are released from the tube's window in a beam with a variety of energies (the x-ray spectrum).

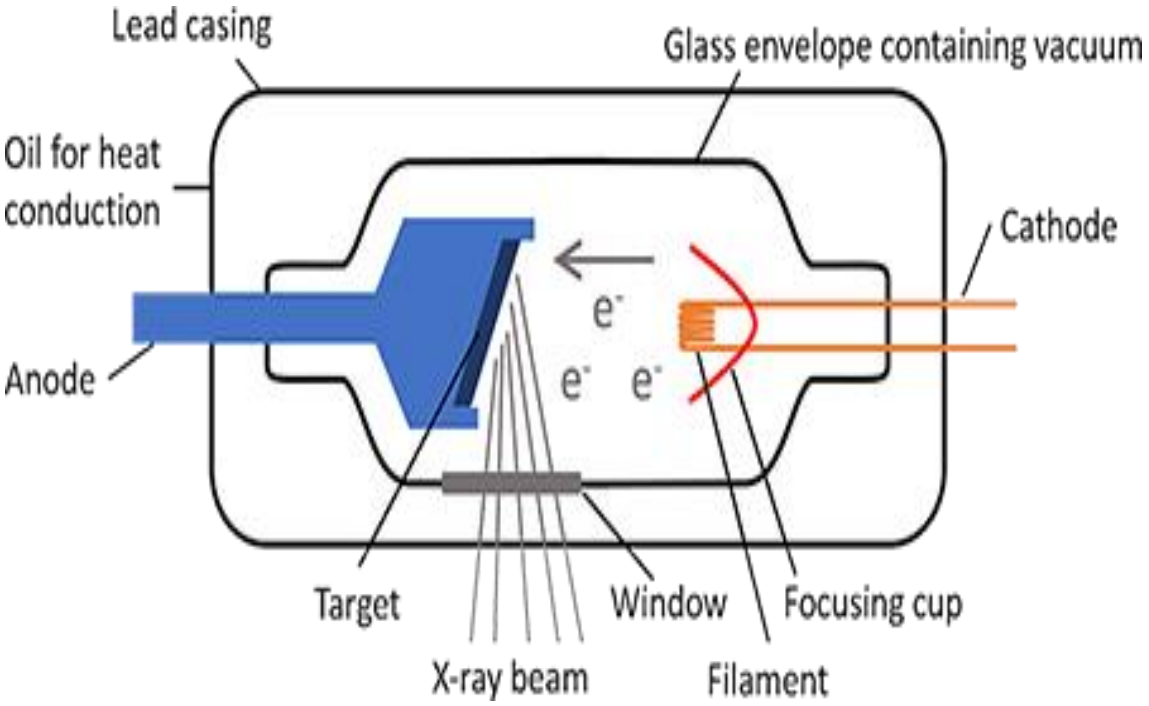


Fig. 2.1 Diagram of the X-ray Tube (Clarke, 2011)

II. Cathode:

Filament: Made of thin tungsten wire of 0.2mm with high atomic number (A 184, Z 74). It is a good thermionic emitter (good at emitting electrons) and has high melting point with temperature (3422^0c).

The focal spot size is related to the filament's size. Some cathodes have two filaments for fine and broad focusing.

Focusing Cup: It is made up of molybdenum with high melting point, poor thermionic emitter so electrons are not emitted to interfere with electron beam from filament. The focusing cup is negatively charged in other to focus the electrons towards the anode and to stop spatial spreading.

III Anode: The anode is made of tungsten as the filament but rhenium is added the tungsten to prevent cracking of the anode at high temperature and usage and set into an anode disk of molybdenum with stem. It is positively charged to attract electrons and set at angle to direct x-ray photon beam down towards patient, usually at an angle of $5^0 – 15^{0.}$

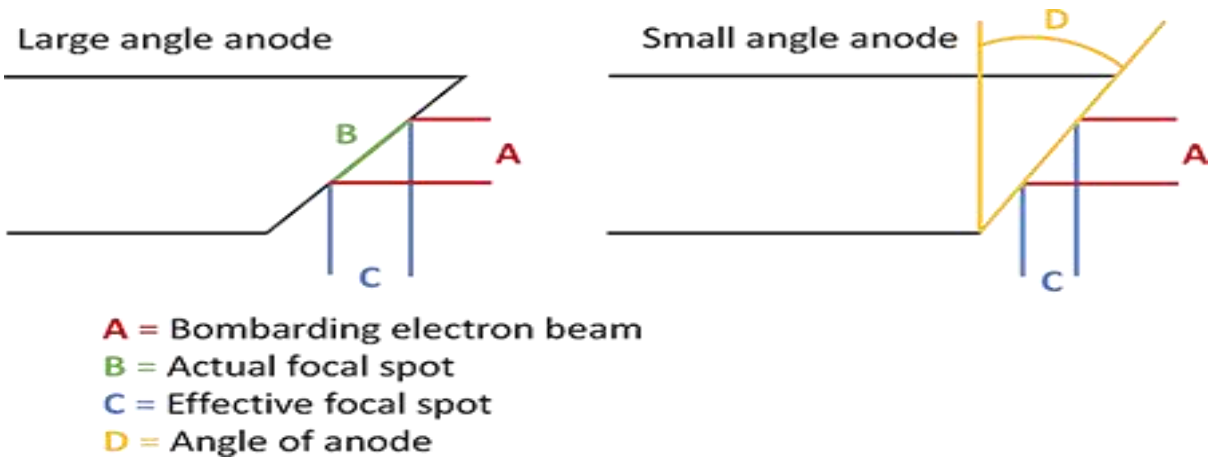


Fig.2.2. Anode Angles and Definitions (Clarke, 2011)

Heating of the Anode is a major limitation of X-ray production. Heat is normally removed from the anode by radiation through the vacuum and into the conducting oil outside the glass envelope. The Molybdenum stem conducts very little heat to prevent damaging the metal bearings.

Heat (J) = keV x mAs (2.1)

keV = Effective Kilo electron volts

MAs = Current exposure time product

IV. The Anode heel Effect

An X-ray beam gets attenuated on the way out by the target material itself causing increase intensity gradually from the cathode to anode direction as there is more of target material to travel through. Therefore, the cathode side should be placed over the area of greatest density as this is the side with the most penetrating beam. Decreasing the anode heel effect results in a less uniform and more attenuated beam.

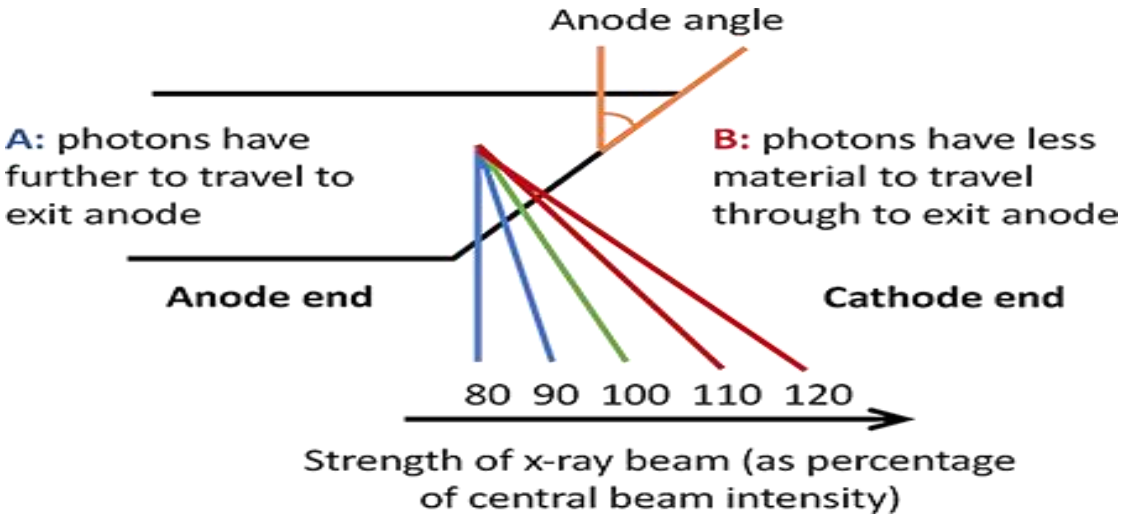


Fig.2.3. Anode heel Effect (Clarke, 2011)

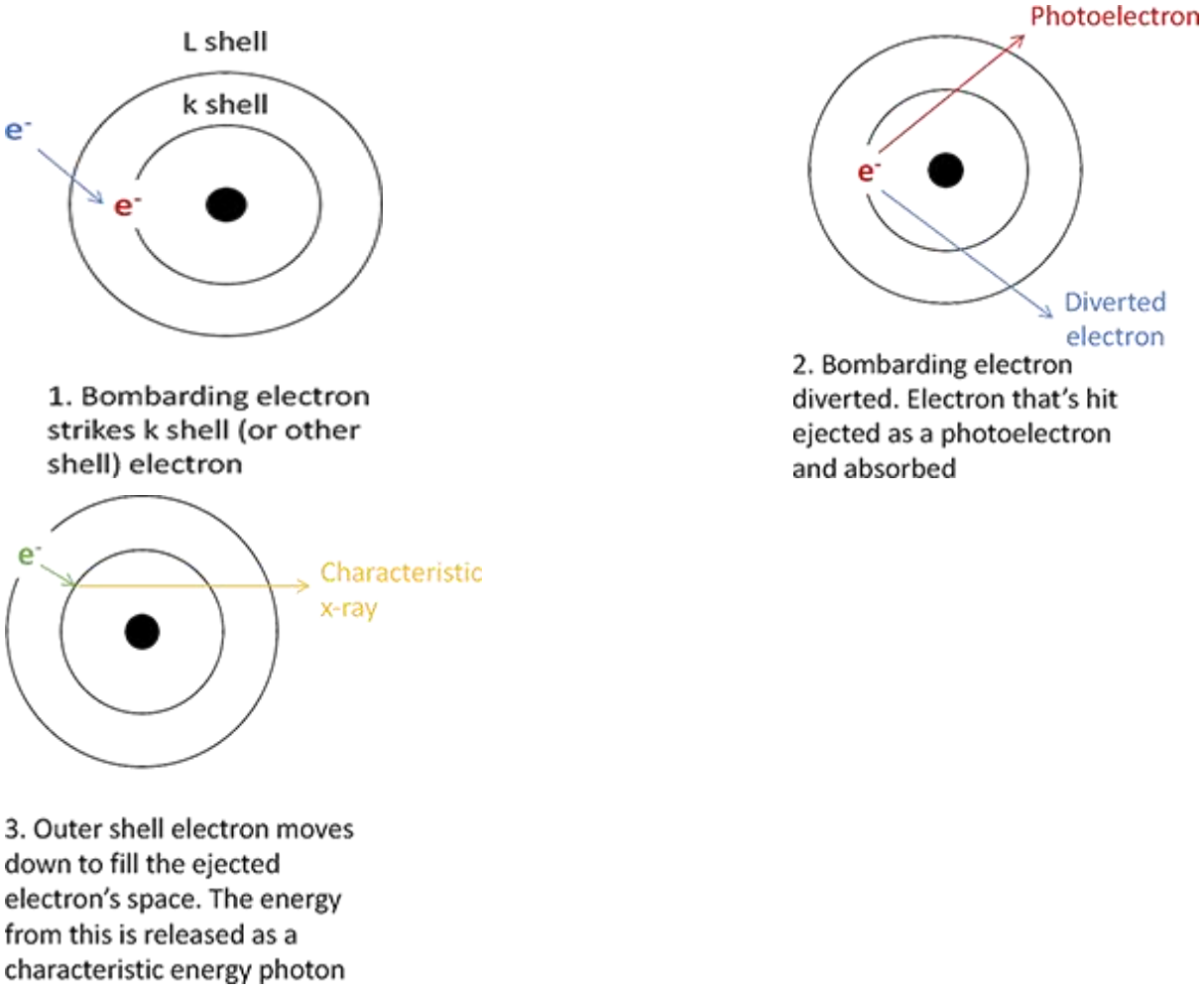


Fig.2.4 Characteristics Radiation (Clarke, 2011)

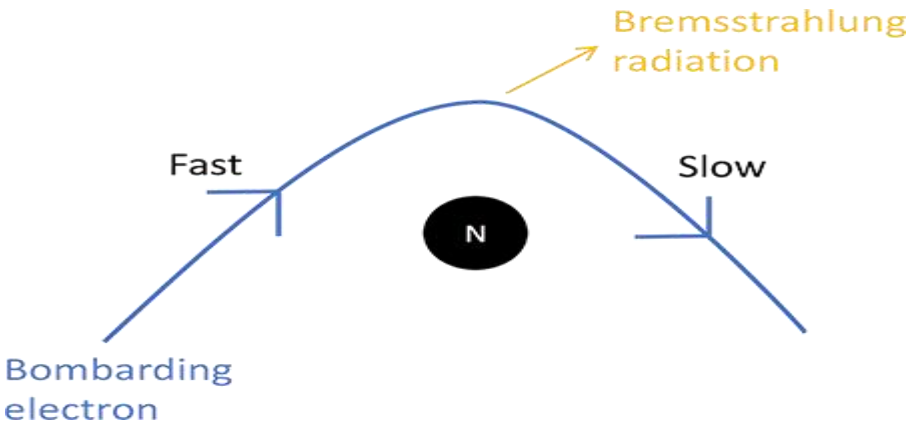


Fig. 2.5 Bremsstrahlung Radiation (Clarke, 2011)

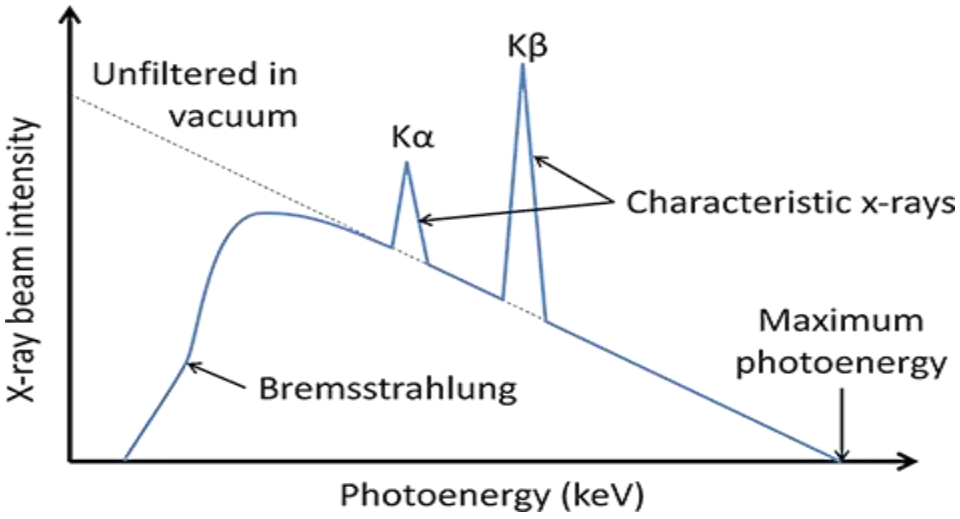


Fig.2.6 X-rays Energy Spectrum (Clarke, 2011)

2.1.4 Medical uses of X-rays

Medical uses of X-rays can either be diagnostic or therapeutic. X-rays are used in Medical imaging, numerous medical disorders in both children and adults can now be diagnosed and treated more accurately. Medical imaging processes come in a variety of forms, or modalities, and each one employs a unique set of tools and methods. Ionizing radiation is used to create images of the body in computed tomography (CT), fluoroscopy, and radiography (sometimes

known as "conventional X-ray" and including mammography). The risk of acquiring cancer throughout the course of one's lifetime may increase if an individual is exposed to ionizing radiation. The same basic idea underpins CT, radiography, and fluoroscopy: an X-ray beam is directed through the body, where some of the X-rays are either absorbed or dispersed by the internal structures, and the remaining X-ray pattern is delivered to a detector.

The fundamental principles of CT, radiography, and fluoroscopy are all similar. Mammograms, dental x-rays, and medical x-rays all use relatively small amount of radiation. CT scans and fluoroscopic procedures expose patients to higher radiation doses due to the requirement for repeated pictures and/or a longer exposure duration. However, medical imaging is a very powerful and valuable technique that can provide important and lifesaving information.

1. Diagnostic uses of X-rays

X-rays radiography are used to detect bone fractures, certain tumors and other abnormal masses, pneumonia, some types of injuries, calcifications, foreign objects, or dental problems.

X-ray images of breast tissue, known as mammograms, are employed for the detection of breast cancer. Mammograms come in two varieties: screening and diagnostic. Screening mammograms are used to check healthy women with no signs of disease. Very low amounts of x-ray radiation are used in screening mammography. When there are any signs of breast cancer, diagnostic mammography can be beneficial. Multiple x-rays are frequently used in diagnostic mammography.

Computed tomography scans are x-ray procedures that create cross-sectional views and three-dimensional images of a patient's internal organs. A CT scan involves numerous x-rays being taken almost simultaneously, internal organ images from CT scans are incredibly detailed. Doctors can diagnose internal health issues like tumors or organ damage with the help of these in-depth images.

X-rays are used in fluoroscopy to visualize movement in real time. It can depict the motion of a body part, such as the heart beating, or the path that a medical device or contrast agent takes as it takes as it travels through the body. Fluoroscopy, as opposed to standard x-rays, passes a pulsed, intermittent x-ray beam through the body. Doctors can see the body part and its motion in real time by sending the images to a monitor. The amount of time spent performing the fluoroscopic procedure and how frequently the x-ray beam is used determine the overall radiation exposure.

2. Therapeutic use of X-rays

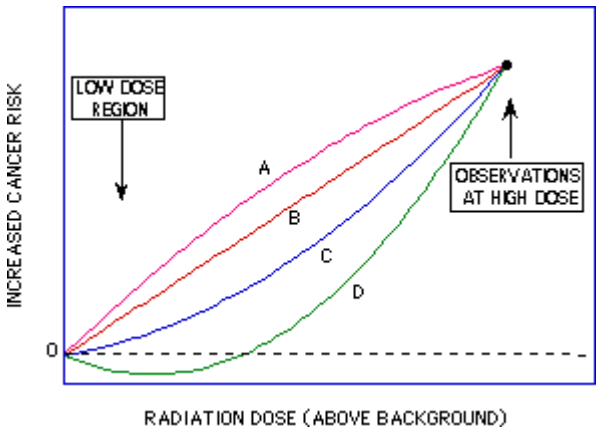
Radiation therapy is used to treat cancer. Cancerous tumors and cells can be eliminated by destroying their DNA using X-rays and other high-energy radiation sources. The radiation dose utilized for treating cancer is much higher than the radiation dose for diagnostic imaging.

Many studies have shown that radiation workers are at the risk of health effects due to their involvement in the use of ionizing radiation in carrying out their duties (Richardson et al., 2015). To reduce this effect of radiation, the ALARA principle (As Low as Reasonably Achievable) must be adhered to at all times. (Wilson-Stewart et al, 2018). The international Commission on Radiation Protection (ICRP) recommends that occupational radiation dose should be enforced to prevent radiation workers from being over exposed to ionizing radiation. For occupational radiation workers, the recommended effective dose limit for the eye lens is 5mSv/year, as well as 20mSv/year for skin dosage and 500mSv/year for hands (ICRP, 2017).

Ionizing radiation is a well-known carcinogen and research on adults show that the connection between IR and cancer is best explained by a linear no-threshold model (LNT).

The linear no-threshold (LNT) model of ionizing radiation-induced cancer assumes that any increase in radiation dose, however small, results in an increase in cancer risk in humans. The linear no-threshold model is currently the most widely used model for assessing radiation risk (Shore et al., 2019). This model, was adopted in late 1950s in the wake of massive government investments in science.

Solid tumors are frequently not statistically significant in studies with modest doses (less than 100mG), which are virtually always accompanied by relatively low statistical results for radiation. The consistency and validity of the findings may be weakened by sampling errors, other exposures including smoking, and lifestyle factors in studies. According to Shore et al (2017), the majority of high-quality low-dose studies show positive risk coefficients. Low doses may have cancer-causing effects, which is compatible with the LNT model's applicability for radiation protection but does not necessarily prove it. However, it should be highlighted that there is little chance of cancer from modest doses.



(Berkeley, 2000)

Fig.2.7 Different assumptions on the extrapolation of the cancer risk vs. radiation dose to low-dose levels, given a known risk at a high dose:

(A) supra-linearity, (B) linear

(C) linear-quadratic, (D) hormesis

The validity of the LNT model is not applicable in all cases and other model exits like the Threshold model. In mathematical or statistical modeling a threshold model is any model where a threshold value, or set of threshold values, is used to distinguish ranges of values where the behavior predicted by the model varies in some important way. The Threshold model assumes that very small exposures are harmless, and this is the radiation Hormesis model. According to the theory of "radiation hormesis," low doses of ionizing radiation that are in the region of and just above natural background level" are advantageous because they stimulate the activation of disease-preventive repair mechanisms that are dormant in the absence of ionizing radiation. Radiation hormesis model asserts that radiation can have positive effect at very low doses, and the supra-linear model based on observation data. (Goffman, 1996). The public is still largely unaware of hormesis

Stochastic effects are those that happen by chance and may not have a dosage threshold. The likelihood of an event occurring is inversely related to the dose, while the severity is dose-independent. Cancer is the main stochastic impact in the context of radiation protection. The LNT model implies a linear relationship between the stochastic health impact and dose and that there is no lower threshold beyond which stochastic effect occurs.

The LNT model presupposes that radiation can potentially affect people at any dosage level, no matter how little the dose, and that the accumulation of many small exposures is likely to

have the same stochastic health effects as a single large exposure with an identical dose value (Sacks et al., 2016). The effects of low-level radiation are very difficult to observe because the baseline of cancer rate is already very high and the risk of developing caner fluctuate 40% due to individual lifestyle and environmental impacts (Parkin et al, 2011). A 100 millisieverts acute effective dose may raise cancer risk by 0.8%. Although background radiation levels from both natural and artificial sources (under 4 mSv cumulative with 1 mSv being the average annual dose from terrestrial and cosmic radiation, excluding radon which primarily doses the lung) are increasing for childhood leukemia and other cancers, children are particularly sensitive to radioactivity. (Spycher et al, 2015). In view of the most recent radio biologic research, it is not justified to use only the LNT to calculate the carcinogenic effect at doses lower than 20msv. They believe there are multiple dose-effect relationships, not just one, and that each of these relationships depends on a variety of factors, including the target tissue, the radiation dose, the dose rate, and the individual sensitivity factors. They ask for more research to be done on low doses (less than 100 mSv) and very low doses (less than 10 mSv), as well as the effects of age and tissue type. The LNT model, according to the Academy, is only useful for regulatory purposes because it makes the administrative process simpler.

Deterministic health effects, such as acute radiation syndrome, are radiation-induced side effects brought on by tissue damage. Over a threshold dose, deterministic effects typically manifest, and as the dose rises, the severity of the impact increases (Christensen et al., 2014). Linear non-thread hold is not a model for deterministic effect as a result of these distinctions. Linear non-thread hold model is frequently used to estimate the likelihood of radiation-induced cancer at higher doses, where epidemiology studies support its application, but controversially even at lower doses, where there is less predictive statistical significance (Sack et al., 2016). To counteract stochastic health consequences, as shown in public health policy, regulatory agencies frequently employ LNT to regulate dose limits. For this present study the LNT model is applied because it is used by most regulatory bodies and also taking into consideration the lifestyle factors that predispose people to cancer and the biological Dosimetry is done to evaluate the impact of the absorbed radiation dose on the blood parameters of the individual

radiation worker. The method of obtaining data for this research work is the physical and biological Dosimetry. The physical Dosimetry involves the use of Thermoluminiscent dosimeter to measure the effective radiation dose in mSv of the radiation workers while the biological Dosimetry has to do with the laboratory complete blood count test of the hematological parameters of all the participants in this study. The methods used for interpretation and analysis of data for this research work includes t-test, simple regression and simple Anova.

2.1.6 Interaction of Electromagnetic radiation with Matter

When a photon beam enters a person body, the interaction process will most likely depends on the energy of the photon (€) and the atomic number (Z) of the material it interacts with. There are three types of interactions of radiation with matter. These includes photoelectric effect, pair production and Compton Effect. Photoelectric effect occurs at low (diagnostic) energies while pair production and Compton Effect become dominant at high megavoltage energies. For radiotherapy treatment energies, the most significant interaction is Compton Effect. The photon (hv) disappears and the electron (called a photoelectron) is released with the remaining energy of the photon after subtracting the required binding energy (EB) to break free from the nucleus.

I. Photoelectric Effect

In a photoelectric effect, a photon interacts with and transfers its entire energy to an electron that is bound to an inner shell. The energy causes the electron to be released from the atom, allowing it to travel through the surrounding material. However, the electron quickly loses its energy and travels a relatively small distance from its starting point. As a result, the energy of the photon is transferred to nearby material during the photoelectric interaction. The transfer of energy occurs in two stages. In the first stage, known as photoelectric interaction, a photon gives its energy to an electron. The second stage involves the electron depositing this energy into the surrounding matter.

Photoelectric interactions primarily take place with electrons that are strongly bound to the atom, specifically those with a relatively strong attachment. These types of interactions are most likely to occur when there is only a minimal difference between the electron's binding energy and the photon's energy. If the binding energy is higher than the photon's energy,

photoelectric interaction is not feasible. This interaction can only happen if the photon carries enough energy to surpass the binding energy and remove the electron from its atom.

II. Compton Interaction

A Compton interaction occurs when some of the energy is absorbed and a lower-energy photon is generated. The resulting photon travels away from the original direction of the interaction. Due to the alteration in the path of photons, this particular type of interaction is categorized as a scattering phenomenon. Essentially, some of the incident radiation is reflected or scattered by the material. This can be important in certain instances because the material that is exposed to the primary x-ray beam can then emit secondary radiation. The primary contributor to scattered radiation during an x-ray procedure is typically the patient's body. The section of the patient's body that is exposed to the primary x-ray beam produces scattered radiation, which has two negative effects. First, it lowers the quality (contrast) of the captured image by reaching the image receptor in a forward direction. Second, this scattered radiation from the patient is the primary cause of radiation exposure for personnel performing the examination.

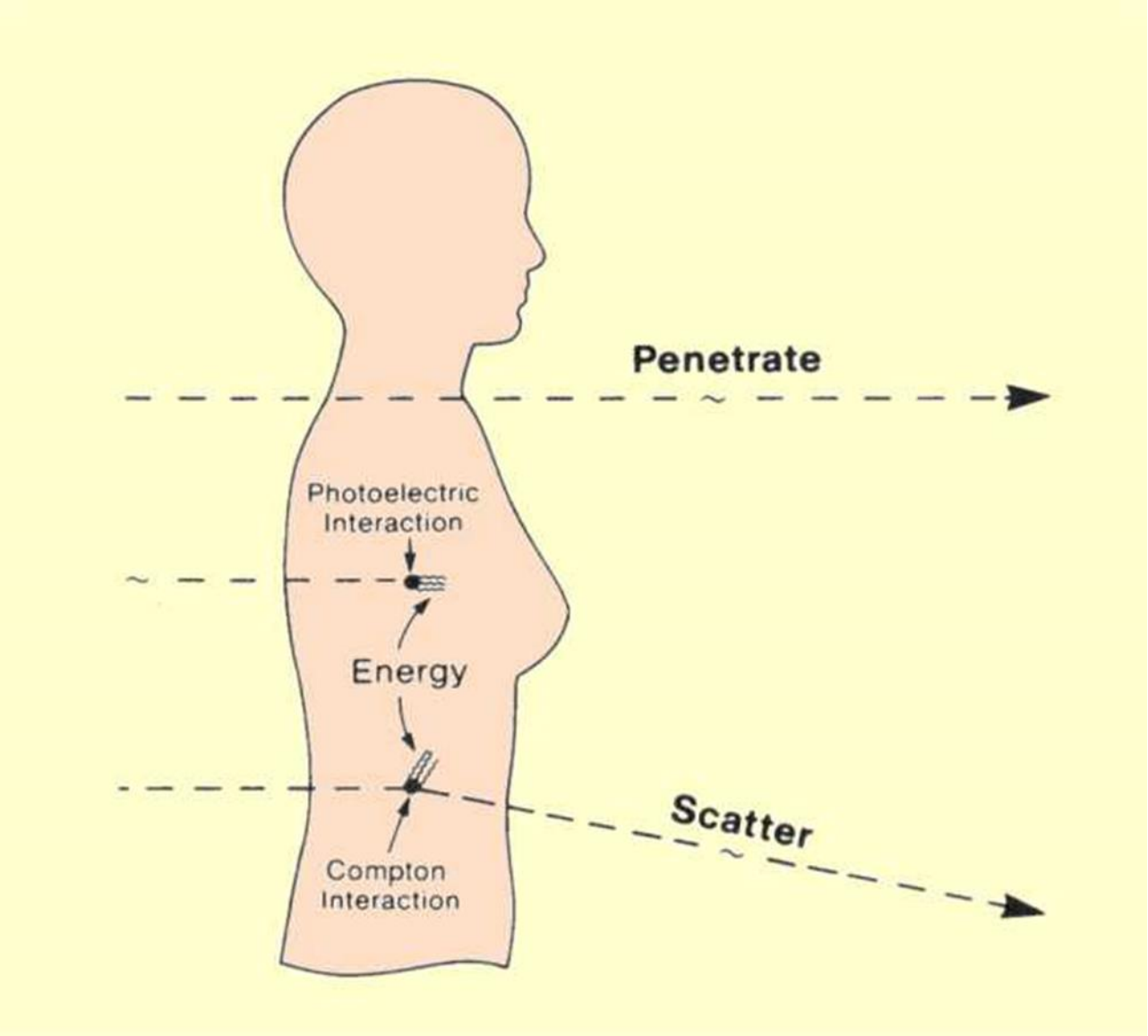


Fig 2.8. Photons Entering the Human Body Will Either Penetrate, Be Absorbed, or Produce Scattered Radiation (Sprawls, 1995)

III. Pair Production

Pair production is a type of interaction between photons and matter that is not typically seen in diagnostic techniques. It can only occur when the photon has a high energy of at least 1.02 MeV. During this interaction, the photon interacts with the nucleus and its energy is converted into matter, resulting in the creation of an electron and a positively charged positron. Both particles have equal mass, equivalent to 0.51 MeV of rest mass energy each.

2.1.6 Principle of Thermoluminiscent Dosimeter Operation

Thermoluninescene Dosimetry is based on imperfect crystals' capacity to absorb and store the energy of ionizing radiation, which, when heated, is re-emitted as electromagnetic radiation, primarily with visible wavelengths. The absorbed dose received by the thermoluninescene material like the Lithium fluoride (LiF) or Calcium fluoride (CaF) is then measured and correlated to the light that was emitted.

Thermoluminiscent dosimeter (TLD) is a passive radiation dosimeter that measures ionizing radiation exposure by measuring the intensity of the visible light emitted from the sensitive crystal in the detector when heated. The light intensity is measured by the TLD reader and this is dependent on the radiation exposure. Thermoluminiscent dosimeters were invented by Professor Farrington Daniels of the University of Wisconsin-Madison in 1954 (Lamarsh, 1983).

Thermoluminiscent dosimeter crystals are generally non-conducting (conduction band in the band model of crystals is empty) at ambient temperature, all electrons are confined to the valance band. When the crystals are exposed to ionizing radiation, some of the electrons acquire enough energy to move to the conduction band (Fig. 2.8).

A conduction band is energy band that comprises of free electrons that are responsible for conduction. The electrons that get moved out from the valance band by experiencing external force reaches the higher energy band in order to support conduction. This band is above the Fermi energy level (higher energy state). Valance band (VB) is defined as the energy band that consist of valance electrons present in the outermost shell of an atomic structure. These valance electrons, when given enough energy, can change into free electrons and move to the conductivity. Valance band is at a lower energy level than the conduction band in the energy level diagram. The two bands are separated by a certain amount of energy called forbidden energy gap. The energy gap depends on the kind of material (Conductor, insulator or semi-conductor). In conductors, the two bands overlap and thus the electrons present in the lower energy band can easily move to the conduction band. In semiconductor, a sufficient energy gap exit between the two bands, therefore external energy is needed to free the valance electrons. While for insulator the band gap is very large and this extremely large energy is required to make the valance electron a free electron.

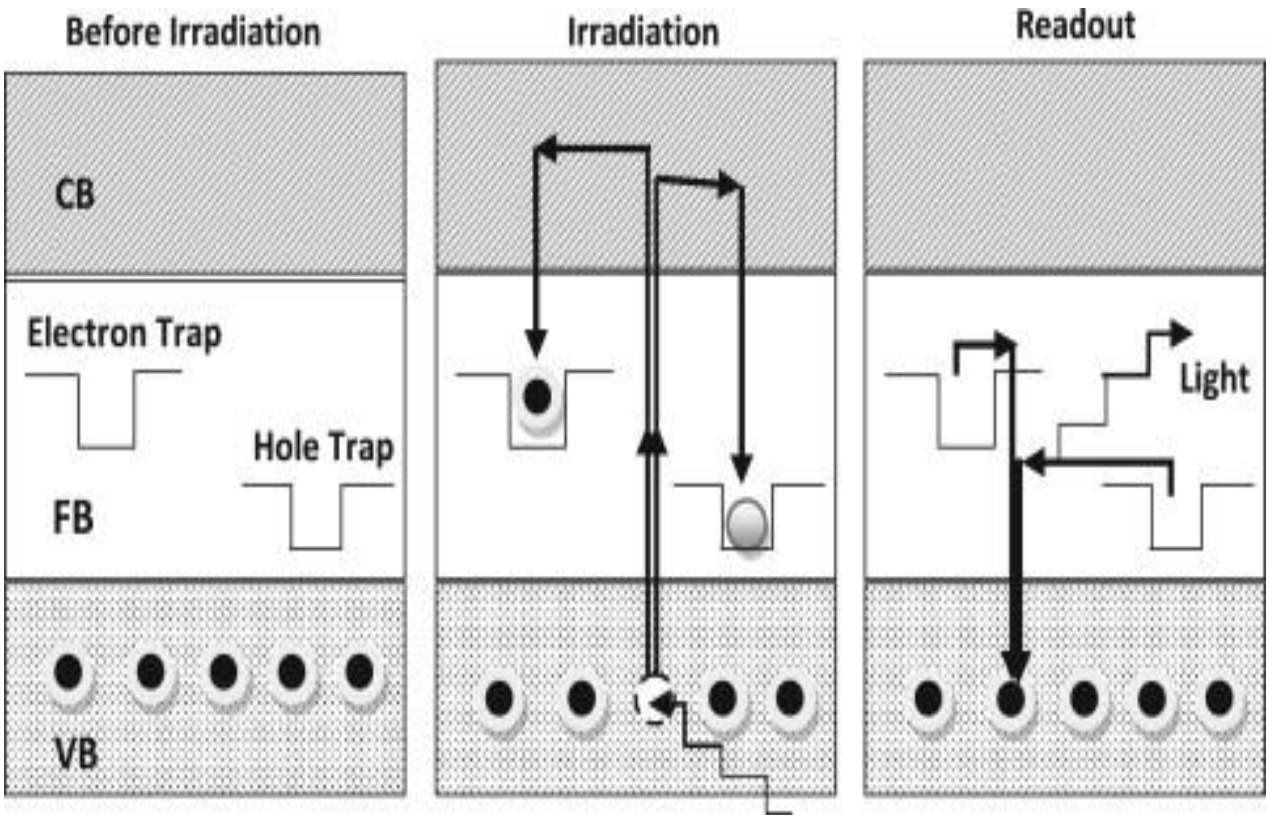


Fig.2.8: Mechanism for thermoluninescence Principle. CB- Conduction band, VB- valance band, FB- Forbidden Band. (Rivera, 2012).

In the Thermoluninescent materials, there are a number of impurities (Manganese and Titanium in the crystal which can trap electrons from the conduction band at an energy state. This energy level is between the conduction and valance band. The energy gaps between conduction band and trap is of a few electronvolts and the quantity of electrons trapped is a function of the intensity of the incident radiation.

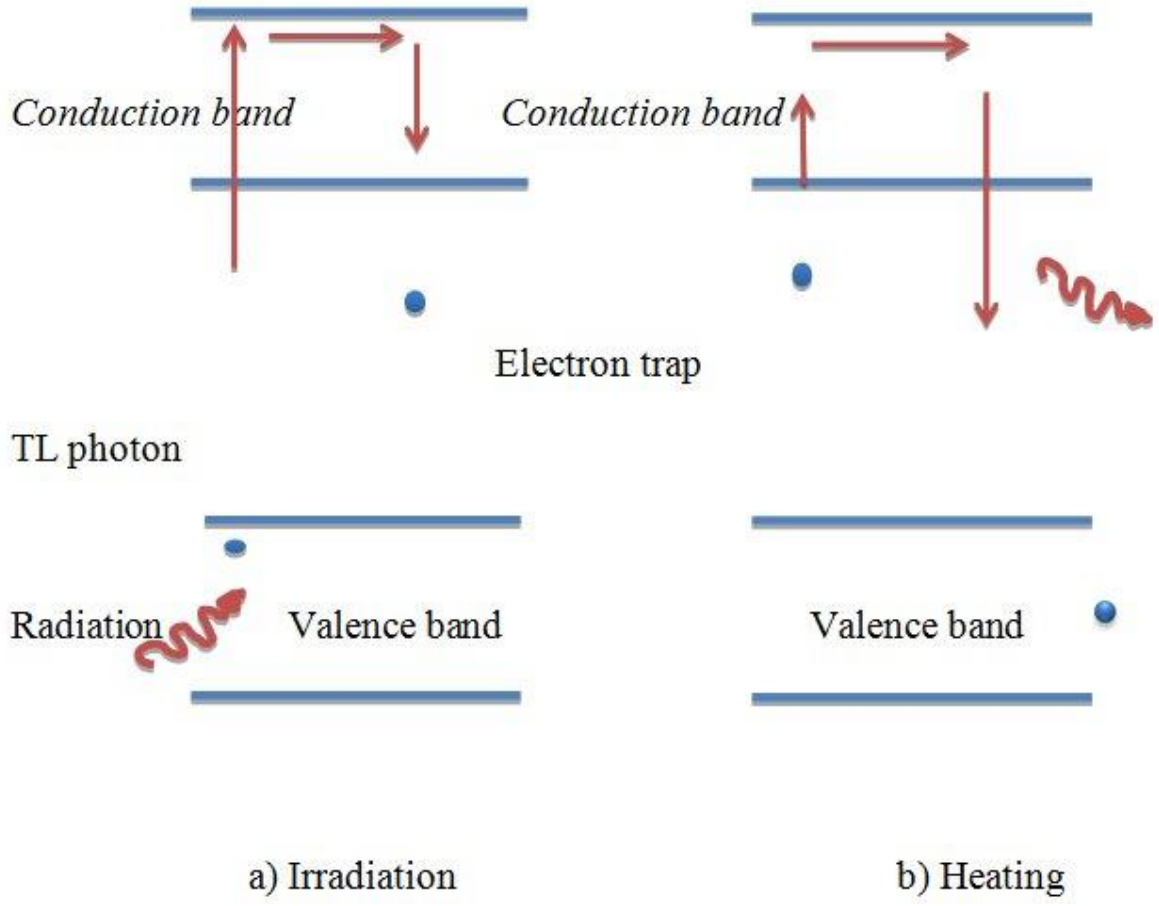


Fig. 2.9 Energy Level Diagram Illustrating the Principle of TLD (Nabil et al, 2020)

Thermoluninescence (TL) or thermally stimulated luminescence (TSL) is the emission of light during heating from phosphor, a material with a large band gap that has already been subjected to ionizing radiation. Irradiation causes the phosphor stores energy to be released as visible light when heated. The Photo-multiplier tubes (PMT) are used to detect light. In the thermoluninescene phenomenon, temperature acts as the motivating factor. As a result, when unexposed phosphor is heated, it will not emit any light (except than infrared and black body radiation). The phosphor must therefore be expose to ionizing radiation exposure prior to receiving TL signal, a band gap is the necessary condition for a material to display TL, hence metals do not show TL signal. The wavelength that the phosphor emits occurs in the infrared and ultraviolet regions.

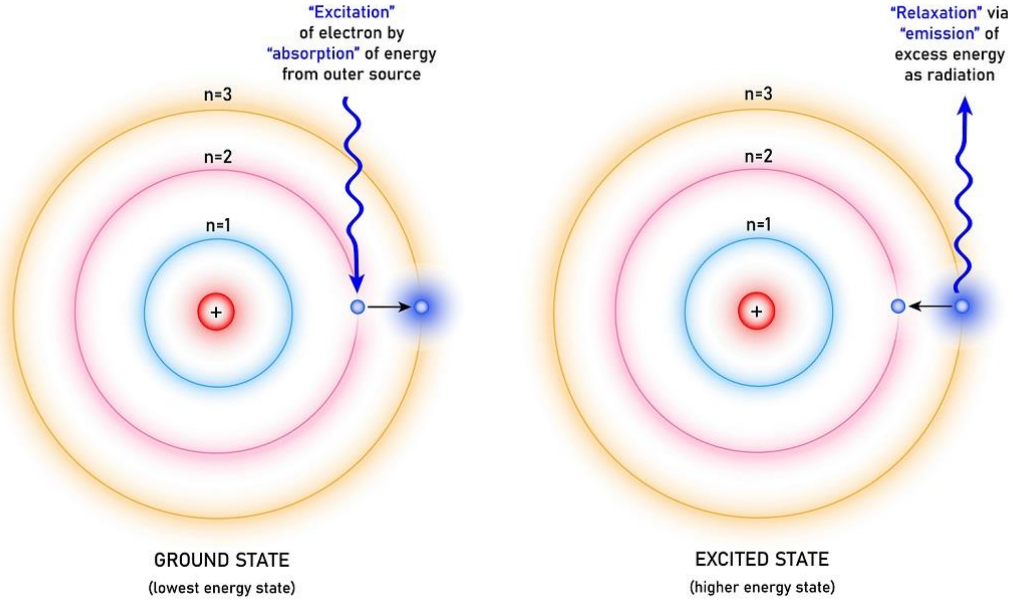


Fig. 2.10 Two different concepts for energy levels have been proposed (Niels & Erwin, 2022)

When phosphor is exposed to radiation, electron-hole pairs are created. As these pairs move through the phosphor, they may become stuck at the metastable energy levels that are present in the forbidden gap due to vacancies, defects, or the presence of impurities. It should be noted that electron traps typically lack negative charge, such as a negative ion vacancy also known as an F center. The +ve charge is insufficient in the traps for holes. At room temperature, the traps can hold onto the caught electrons and holes for a long time. It takes energy to release the carriers from the traps, which is provided by heating the phosphor. The recombination of electrons and holes takes place as a result of the charge carriers being freed from the traps during heating, which results in the emission of light in the form of TL.

Based on a model that presumes a free particle inside a potential well known as the trap, Randall and Wilkins first developed a theoretical formula for TL.

The energy distribution of the trapped particles, whether electrons or holes, complies with Boltzmann's law. The particles that reach the well's top are predicted to leave the well at a frequency that is about equal to their vibrational frequency, which would clearly depend on temperature. The "attempt to escape frequency," denoted by the letter s in s-1, is that frequency.

Therefore,

$$p = s \exp(-E/kT) \qquad (2.2)$$

Where E is the well (trap) depth in eV

T is the temperature in K, is the formula for the probability of a charged particle escaping from a trap.

K the Boltzmann constant (J/K) (Sunta et al., 2006.)

In response to the heating effect, the confined electrons in the metastable energy states receive enough thermal energy to break free and the conduction band once more, where they are once again free to move and experience the same three probable outcomes:

Either they will become stuck in impurities

Or enter the valence band and mix with holes either radioactively or non-radioactively

Or recombine radioactively at a luminous center that is activated by a hole

2.1.7 Dosimetric quantities

The International Commission on Radiological Protection (ICRP) created the International System of Radiological Protection, which serve as the global standard for radiological protection laws, regulations, programs, and practices. (ICRP 103, 2007). The ICRP is an independent, international organization with experts representing the world's leading scientists and policy makers in the field of radiological protection. The ICRP methodology is based on a number of characteristics of the radiation(s) involved, the exposed organs or tissues, and the pathways that lead to exposure. It estimates the dose of ionizing radiation received by particular organs or tissues.

I. Absorbed Dose (D_T)

This is the fundamental dosimetric quantity used by the ICRP. The International System (SI) unit of absorbed dose is the gray (Gy), defined as an energy deposition of 1 joule/kilogram, for the purpose of dose reconstruction, its value is obtained as an average over the mass of a specific tissue or organ, recognizing that it is impractical to specify the relevant physical processes at a microscopic level (ICRP 103, 2007). Radiation weighting factors account for differences in distribution of energy deposited in microscopic regions of the particular tissue or organ.

For the purpose of defining the overall risk of specific harms, such as cancer, developing in the tissue or organ as a result of an exposure, this average dose is thought to be an accurate representation. Calculations are done on the homogeneity of the exposure and the penetration range of the radiation incident on the body for radiation exposures resulting from sources outside the body.

II. Equivalent dose (H_T) and radiation weighting factors (W_R)

Effective Dose (H_T) is a concept used in radiological protection to quantify the potential biological harm resulting from exposure to ionizing radiation. It represents a way to express the overall risk associated with exposure to different types of ionizing radiation, taking into account the varying sensitivities of different tissues and organs in the human body. The various absorbed dose estimates for each radiation type must be combined if a tissue is exposed to more than one radiation source. To do this, it is necessary to multiply the absorbed dose of each type of radiation by a radiation weighting factor, as advised by the ICRP, which reflects the radiation's propensity for harm. The equivalent dose is the result of multiplying the absorbed dose by the radiation weighting factor. The Sievert (Sv) is the equivalent dose unit in SI units. The radiation weighting factor is assigned a factor of 1 for gamma and x-rays and the values for other types of radiation are related to this in accordance with their ionizing densities. The ionization density of beta radiation is similar to that of gamma and x-rays, so its weighting factor is also 1. Radiation weighting factors for neutrons are energy-dependent and range from 2.5 to 20. Alpha particles are assigned a radiation weighting factor of 20. This makes it possible to calculate the cumulative equivalent dose, which represents the total amount of ionizing radiation that a specific organ or tissue has received from external sources, internal sources or both.

Equivalent dose (H_T) = D_T x W_R (2.3)

D_T = Absorbed dose

W_R = Radiation weighting factor

III. Effective dose (E.D) and tissue weighting factors

The effective dose is determined by multiplying the equivalent doses by the weighting factor for each tissue or organ and adding the results to determine exposure to the entire body or to

different tissues or organs. For various radiation types and energies, the ICRP has recommended tissue and organ weighting factors (ICRP 103, 2007). The Sievert (Sv) is also the SI unit for effective dose.

The absorbed dose in a given tissue is a quantity that can, at least in theory, be measured by a radiation detector like the TLD, whereas equivalent dose and the effective dose, then, incorporate weighting factors based on data from animal and epidemiological studies of particular health outcomes.

E.D (Sv) = $\sum (W_R \times HT)$ (2.4)

= $\sum$ (Tissue weighting factor X Equivalent dose)

Methods for calculating an effective dose when the whole body is evenly exposed to 1 mGy of x-ray irradiation and an effective dose when only the head is exposed to 1 mGy of x-ray irradiation are compared. Since the radiation weighting factor (W_R) for x-rays is 1, the whole body being evenly exposed to 1 mGy means that the whole body is evenly exposed to 1 mSv (1 gray × 1 (W_R) = 1 millisieverts). That is, equivalent doses are 1 mSv for all organs and tissues. To calculate effective doses, the equivalent doses for individual tissues are multiplied by their respective tissue weighting factors and the products are summed. In order to account for the high risk of radiation-induced fatal cancer in these organs, a high factor of 0.12 is applied to the bone marrow, colon, lungs, stomach, and breasts. The entire body's skin is given a factor of 0.01. The result of multiplying the equivalent doses for all organs and tissues by the appropriate tissue weighting factors and adding the results is a millisieverts effective dose.

2.2 Empirical Review

2.2.1 Comparison of the Occupational Radiation dose with the standard value of ICRP

At the Sultan Qaboos University Hospital, Bouchareb et al., (2021) conducted a study to evaluate the occupational radiation doses received by 116 medical radiation employees between 2015 and 2018. A calibrated thermoluninescene dosimeter (TLD-100 (LiF: Mg, Ti)) was used to measure the doses. Five occupational groups of nuclear medicine, medical physicists, interventional radiology, diagnostic radiology, and nurses were taken into

consideration. The mean, maximum, and median cumulative doses were assessed and contrasted with the local investigative level (DIL) of 6mSv/y and the ICRP reference limit of 20mSv. Diagnostic radiology had a mean dose equivalent of 0.50 mSv, a maximum dose equivalent of 0.90 mSv, and a median dose equivalent of 0.00 mSv. Interventional radiology had a dosage equivalent of 0.50 mSv; nuclear medicine had a dose equivalent of 1.20 mSv, 7.40 mSv, and 0.00 mSv. The results of this study demonstrate that the radiation exposure of medical personnel is within the standard recommended limits with the exception of the nuclear medicine workers.

Using the Radiation Alert Monitor and questionnaires, Langa, et al., (2020) assessed the occupational radiation exposure in a teaching hospital in Nigeria. Measurements were made of the radiation dose within and outside the radiology unit. The outcome showed that 0.0225 mSv/y was the average radiation dosage in the vicinity of the radiology unit. When compared to the 50 mSv/y effective dosage equivalent for the whole body dose suggested by the ICRP, this dose is insignificant. These findings demonstrate that the Radiology unit's radiation workers were not at risk for radiation-related illnesses. The weakness of the study is that the absorbed dose by the radiation workers were not analyzed. This present study compensated for this weakness by using TLD to measure the absorbed dose of the radiation workers.

Another study carried out by Sani et al., (2020), employing Thermoluminiscent dosimeters to measure the occupational radiation dose of radiation employees in a Federal Medical Center. The 20 TLD quarterly reading was assessed and examined. The findings demonstrated the deep skin dose (10 mm) and superficial skin dose (0.07 mm) tissue depths respectively. The mean yearly dose equivalent per radiation worker ranges from 1.28 to 2.21 mSv (deep skin dose) and 0.74 to 1.20 mSv (superficial skin dose). The occupational dose is below the 5 mSv and 20 mSv recommended national and international limits. The study's sample size of 20 people is its main drawback; however it was made up for by employing a larger sample of 101 radiation workers in this current study.

In order to track the radiation exposure of staff in the nuclear medicine and diagnostic radiology departments of Makkah hospitals, Hani et al (2019), conducted an assessment. Between 2017 and 2018, the surface and deep skin dosages for the two personnel groups were measured. For each group, the yearly average Hp (10) and Hp (0.07) were determined. The T-test results showed a significant relationship between HP (10) in the sums of 2017 and 2018, which

increased from 2017 to 2018, with a T-test value of 9.500 and a P-value of 0.001 respectively. The Hp (10) yearly dosage was below the ICRP limit.

The occupational radiation doses for medical radiation workers in diagnostic radiology, nuclear medicine, and radiotherapy were quantified and studied by Nassef and Kinsara (2017). Thermoluminiscent dosimeter (TLD-100) was used to recruit 100 medical radiation workers for the study (LiF: Mg, Ti). Except for those in the catheterization lab, where the TLD was positioned at the thyroid protective collar, the TLD was placed above the lead apron at chest level. For diagnostic radiography, nuclear medicine, and radiation, the yearly average dosages were 0.66, 1.56, and 0.28 mSv, respectively. The obtained findings were much below the 20 mSv worldwide recommended dosage limit.

2.2.2 Compare the Hematological parameters of Radiation Workers with Reference Limits and those of Non-radiation workers:

Numerous studies have shown that exposure to high amounts of radiation, whether unintentionally or therapeutically, can harm human health by destroying hematopoietic cells and causing cancer (Behjati et al., 2018; Richardson et al., 2018; Hong et al., 2019). Only a small number of studies have been carried out in Nigeria, despite the fact that numerous other studies have likewise demonstrated the negative effects of low-dose ionizing radiation on the hematological parameters of occupational radiation workers.

The effects of occupational exposure to low dose ionizing radiation on the red blood cells and their constituent parts of 106 medical professionals between the ages of 18 and 60 were examined by Tian et al (2022). The findings showed that factors such as gender, age, type of employment, length of service (for females only), and the annual effective dose had an impact on RBC counts (males only). It was determined that long-term low-dose radiation exposure may have some effect on the RBC and hemoglobin status of occupational radiation professionals, although it is still unclear what kind of health effects may result.

In a different study carried out in southern Nigeria (Wejie-Okachi, Agi, & Douglas, 2019). In the cross-section retrospective comparison study, 30 radiation-exposed workers and 30 control subjects were compared. The average annual background radiation in x-ray rooms was measured (0.7724mSv). Although the WBCs, Neutrophils, and Lymphocytes were significantly lower in the radiation workers and control group, the mean values of hematocrit, platelets, and mean cell volume were higher. Except for the codocytes, normal blood cell

morphologies predominated in the control group as compared to the exposed group. WBCs values are inversely related to the amount of time exposed to x-rays. The study shown that even with the use of personal protective equipment, prolonged low-dose x-ray exposure can alter entire leucocyte characteristics. The small sample size and the measurement of background radiation rather than the absorbed dose of the occupational radiation workers are the study's limitations.

In order to assess the effect of ionizing radiation on the hematological parameters of catheterizations, Izadi-moud, Izanloo, Vogdanparast, Shirvan, and Eshraghi, (2019) conducted a cross-section study. Laboratory technicians with a two-year work history were exposed to ionizing radiation continuously. According to the Iranian Atomic Energy Organization, the effective absorbed dosage was determined using film badge Dosimetry and hematological parameters that were measured every three months. Because the hematological parameters were continuous, regression modeling and the multi-layer perception model were used in the study. The RBC parameter and the regression model's multi-layer perception show a non-linear relationship between the exposure doses of the participants. The study comes to the conclusion that due to the short sample size, hematological measures are unreliable for assessing biological risk.

Heydarheydari, Haghparast, and Eivazi, (2016), claim to have carried out a biodosimetry study between 2013 and 2014 in the Kermanshah hospital in Iran. The gender, age, and employment records (during the past three years) of 40 exposed and 40 unexposed radiation employees were compared. A personal dosimeter was used to measure the occupational radiation dose (film badge). By using film badge Dosimetry, the exposed subjects had a median exposure of 0.68 ± 1.58 mSv/year. When compared to the control group, occupational radiation workers with at least 10 years of experience had lower mean hemoglobin (Hb) and MCV values. Compared to the other radiation employees, the mean RBCs in professional radiology staff decreased. The study came to the conclusion that, despite the absorbed doses being below the ICRP's permitted dose, chronic low-dose exposure had a negative influence on the Hb and MCV levels in the blood of radiation workers with at least ten years of experience. The sample size and the personal dosimeter are the study's limitations (film badge). The small sample size and the use of TLD, which has many advantages over film badge, have been made up for in this work.

The clinical value of Complete Blood Count (CBC) testing for radiation workers was researched in South Korea by Jang et al (2016).They looked at the TLD doses, all of the

successive CBC findings, and the radiation absorbed doses determined by cytogenetic biodosimetry. 241 radiographers and 120 control healthy people (age over 20) who had never been exposed to IR for occupational purposes were recruited. After reviewing all the consecutive results of CBC and TLD doses from radiation workers registered nationwide, we selected two groups of high-risk radiation workers, CBC-high risk (CBC-HR) and TLD-high risk (TLD-HR) groups. A control group of unexposed healthy adults was also included. We compared the absorbed doses calculated by cytogenetic biodosimetry among those three groups, and examined possible confounding factors for each group. Both the CBC-HR and TLD-HR groups of high-risk radiation workers had more chromosomal abnormalities than the control group. The prevalence of chromosomal abnormalities was higher in the control group who had previously undergone a CT scan. In contrast, the frequency of chromosome aberrations in the high-risk radiation workers was affected not by the previous CT history but only by the duration of their work. CBC tests and cytogenetic analyses are helpful supplemental tools to TLD dosages for health protection regulation. For the interpretation of biodosimetry data, a number of confounding variables, including job length and prior medical history, must be taken into account.

Sahgh & Chapararian (2019) conducted a study to assess the hematological parameters of radiation professionals in Isfahan, Iran. The results of this study demonstrated the usefulness of the Complete Blood Count (CBC) test in predicting the health effects of radiation exposure on medical radiation workers. Using the CBC test, the study involved 160 radiation employees and 103 healthy non-radiation workers. The blood parameters of the two groups were compared. According to the findings, the hematocrit of the male radiation workers was considerably higher than that of the control group (45.98 ±3.00 vs. 44.33± 2.41%, P 0.05) than 45.98 ± 3.00. However, compared to the control, the mean corpuscular hemoglobin concentration and platelet count were lower in radiation workers. Female radiation workers had a substantially lower percentage of lymphocytes (33.78± 7.467) than the controls (937.84 ±8.77%).

This case-control study was conducted in Khuzestan Province, Iran, in 2015. Blood samples were collected from 95 radiology technologists and 85 matched, non-radiated controls; participants were selected using the cluster sampling method. The SPSS version 16 using the t-test and Pearson correlation coefficient were used to analyze the data. The results demonstrated that the mean values of blood factors were not significantly different between the two groups (P>0.05), and there was no significant difference between the two groups

(radiographer and non-radiographer) by gender. In this study, occupational exposure had no harmful impacts on the blood factor levels of radiographers; however, as radiographer's age and job experience increases, their white blood cell count decreases. (Davoudian, Farzanegan & Mahmoudi, 2018).

Heydarheydari, Sadeghi, Almasi and Sohrabi (2012) conducted a comparative analytical study to investigate the effectiveness of ionizing radiation on blood parameters in radiation and other ward workers in Kermanshah hospital. 49 radiation workers and 49 non-radiation workers were recruited for this study. The data was analyzed using SPSS 20 and the statistical student's t-test was used. The findings of the study shows there are no statistically significant difference in the blood parameter of radiation workers and the control group ($p > 0.05$).

In 2012, another research investigation in Iran (Caciari et al., 2012) aimed to evaluate the hematological outcomes among employees without health issues working in the radiology department of a hospital in Mashhad.. The study involved 55 participants, including 25 people who used x-ray machines and 30 healthy volunteers who served as controls. Blood samples were examined for basic routine cell counts such as hemoglobin, hematocrit (Hct%), red blood cell (RBC) count, white blood cell (WBC) count, and platelet and other parameters such as the MCH, MCHC, MCV, RBC Distribution Width (RDW), Platelet Distribution Width (PDW), and Platelet large cell ratio (P-LCR). Of all of these, the hematological parameters PDW and P-LCR compared to the control groups, technicians. The mean values and the distribution of the mean values of total white blood cells were significantly decreased in health workers of both sexes compare to controls. The average values of granulocytes neutrophils were significantly low in female health workers compare to female controls.

In a correlated investigation conducted by Davoudi et al. (2012), a comparison was made between 60 male workers exposed to radiation at their workplace and an equal number of unaffected, healthy workers.. Age, gender, and ethnic background were balanced between the two groups. When compared to the controls, the radiation workers' WBC and platelet counts were considerably lower.

30 radiation professionals and 7 controls were enrolled in a second, genetic cross-sectional investigation in Iran in 2015. Chromatid gaps and breaks have become more common in the blood cells of nuclear medicine and computed tomography professionals. There were significant increased incidence of chromatid gap (ctg) and chromatid break (ctb) with Mean±SD frequencies of 3±0.84 and 3.1±1.40 per 100 cells respectively in the nuclear

medicine workers versus controls with Mean±SD frequencies of 1.9±0.69 and 1.3±0.84 for ctg and ctb, respectively. Chromosome gaps (chrg) were higher significantly in the nuclear medicine population (2.47±0.91) than in controls (1.4±0.9) ($p< 0.05$). In CT scan group the ctg and ctb were increased with a Mean±SD frequency of 2.7±0.79 and 2.6±0.91 per 100 cells respectively compared with control group. The Mean±SD frequencies of the chrb were 2.0±0.75 and 0.86±0.690 per 100 cells for exposed workers and control group, respectively. (Changizi Alizadeh, & Mousavi, 2015)

A prospective cohort research that examined the health assessment and personal dose monitoring data of medical professionals exposed to low doses of ionizing radiation at work was conducted in Guangdong Province. For the study, 1265 medical professionals were employed. The results shows that changing platelet of 1265 medical workers followed up was statistically different among the cumulative dose groups ($P = 0.010$). Although the linear trend tested was not statistically significant ($P_{trend} = 0.258$), the non-linear trend tested was statistically significant ($P_{non\text{-}linear} = 0.007$). Overall, there was a correlation between changing platelets and cumulative radiation dose (a change of β^a 0.008×10^9/L during biennially after adjusting for gender, age at baseline, service at baseline, occupation, medical level, and smoking habits; 95% confidence interval [CI] = $0.003,0.014 \times 10^9$/L). Moreover, we also found positive first and then negative dose-response relationships between cumulative radiation dose and changing platelets by restricted cubic spline models, while there were negative patterns of the baseline service not less than 10 years (-0.015×10^9/L, 95% CI = $-0.024, -0.007 \times 10^9$/L) and radiation nurses(-0.033×10^9/L, 95% CI = $-0.049, -0.016 \times 10^9$/L). Despite the exposure dose being below the limit, the results showed that altering platelets and the cumulative radiation dose had a positive response initially and a negative dose response later and there was a dose-response relationship between the cumulative radiation dose and platelets changing. (Liu et al, 2021).

An investigation conducted in Indonesia to determine the impact of ionizing radiation on the hematological parameters of radiation workers in several public hospitals. It included 83 non-exposed control participants and 74 medical radiation employees who were occupationally exposed to low level ionizing radiation at the diagnostic and therapeutic units. The ABX Micro 60 Hematology Analyzer evaluated 14 hematological parameters, and linear regression was used to examine the relationship between years of employment and equivalent dose as well as the hematological parameters on exposed individuals. According to this study, workers who had been exposed to radiation had considerably higher red blood cell and monocyte counts than

the controls. Radiation workers had considerably lower levels for white blood cells, hematocrit, mean corpuscular volume, and lymphocytes, however. Red blood cell (RBC) characteristics showed a substantial association with the dose equivalent, with a reduction in RBC level of 0.54 X 106 /L per 1mSv increase in radiation dosage. The decrease in red blood cells can lead to leukemia and the level of decrease needs to be considered from the level of DNA damage especially double-stranded break. (Surniyantoro et al., 2019).

Seco et al., (2014) launched a prospective cohort study of all Korean radiation workers to assess the health effects associated with occupational radiation exposure. About 42,000 Korean radiation workers registered with Nuclear safety and security Commission from 2016-2017 were the initial target participants for the study. Radiation workers were enrolled for the study nation-wide using self-administered questionnaire survey. The enrolment was to continue for five years and the survey data was linked with the National dose registry and National health insurance through personal identification number. Age-specific and sex-specific standard incidence and mortality ratio were calculated for overall comparison of cancer risk. For dose-response evaluation excess relative risk per Gy and excess absolute risk per Gy will be estimated for age and potential confounders such as life-style factor and socio-economic status

A prospective cohort study of all Korean radiation workers was started by Seco et al., 2014 in order to evaluate the health effects of occupational radiation exposure. The study's initial target population consisted of about 42,000 Korean radiation employees who had registered with the Nuclear Safety and Security Commission between 2016 and 2017. Using a self-administered questionnaire survey, radiation employees were enlisted for the study across the country. The enrollment was set to last for five years, and through a personal identification number, the survey data was connected to the National Dose Registry and the National Health Insurance. For the purpose of comparing the overall risk of cancer, age- and sex-specific standard incidence and death ratios were determined. Age and potential confounders such lifestyle factor and socioeconomic status will be evaluated for the dose-response analysis of excess relative risk per Gy and excess absolute risk per Gy.

About 266 non-smokers, 133 radiation-exposed workers, and 133 controls were recruited for a 2012 study carried out in Italy. Both exposed male and female workers had considerably lower mean total white blood cell values than the control group. When compared to female controls, the mean neutrophil count in female radiation workers was considerably lower. The study came

to the conclusion that workers exposed to ionizing radiation may experience effects on some hematopoietic system (Caciari et al., 2012)

The effects of radiation on the hematological parameters of 47 apparently healthy x-ray technicians and 20 seemingly healthy controls were evaluated in a case-control study carried out in Iraq. The study found that while there was a highly significant number of atypical lymphocyte, there was no substantial alteration in the hematological parameters, as determined by laboratory testing of blood cell shape. The proportion of lymphocytes in the radiation-exposed workers was positively correlated with their years of radiation exposure (Mohammed et al., 2014).

In order to do a complete blood count and identify any alterations, a study conducted in the Kingdom of Saudi Arabia in the year 2002 enlisted 40 male x-ray technicians who appeared to be in good health and another 40 identical controls who appeared to be in good health. The study found that the exposed x-ray technicians' mean platelet counts significantly decreased. Red and white blood cell counts did not significantly alter, and there was no evidence of a significant relationship between exposure time and changes in these counts (Meo, 2004)

In 2014, Saman Shahid and his colleagues in Pakistan carried out a further study. Twenty radiotherapy (RT) workers, 41 radiology (RD) workers, 31 nuclear medicine workers, and 55 workers who had not been exposed to radiation were included in this study. When compared to non-exposed individuals, most radiation-exposed workers had lower levels of hemoglobin, white blood cells, hematocrit, MCH, MCHC, neutrophil, and platelets, while their levels of RBC and lymphocytes were higher (Shahid, Mahmood, Chaudhry, Sheikh, & Ahmad, 2014). In the same year, a cross-sectional study in the Indonesian province of West Nusa Tenggara's capital city of Mataram, Mataram town, which examined the impact of radiation on the lymphocytes of 28 radiographers produced findings that showed the characteristics of the radiographers affect the lymphocytes, includes age ($p=0.028$), radiation protection training ($p=0.046$), and use of avalanche-like techniques of Photodiode (APD) radiation protection equipment ($p = 0.026$) and radiation dose ($p = 0.046$). The result from this study Shows that the exposure of X-ray radiation in the ABCD hospital has influences on lymphocyte levels of the radiographer which is evaluated by the dose of radiation, radiation protection training, the use of PPE and age of the radiographer. (Alaydrus et al, 2015).

In Among Seoul, Republic of Korea, a survey on low-dose medical radiation exposure in occupational employees was carried out in 2013. This involved 335 controls and 370

occupational workers. When the occupation period was longer, male WBC levels declined and female WBC counts rose. In comparison to the control group, the RBC counts were lower in the male workers, while the eosinophil counts were lower in the female workers. Both male and female workers' lymphocyte counts fell when the cumulative exposure was high. Male and female workers had lower platelet counts and RBC counts than the control group, respectively. When compared to workers who had not been exposed to radiation, abnormal blood indices distributions were seen in occupational radiation workers (Ryu et al., 2013).

Meo (2004a) did a study in 2002 with 40 healthy male radiation technicians and 40 non-radiation workers between the ages of 25 and 50 in the department of physiology at the King Saud University, Saudi Arabia. Beckman Coulter's auto analyzer was used to do RBC, WBC, and platelet counts. The findings indicate that when x-ray technicians were compared to non-radiation professionals, their mean values of platelets were considerably lower (p 0.01). However, there was no discernible difference between the two participant groups in terms of RBC or WBC.

Another study was conducted in Saudi Arabia in 2003 by Meo, 2004b. He recruited 8 x-ray technicians and 8 control groups to measure the phagocytic activity of polymorph nuclear neutrophils. The luminometer chemiluminescence response was used to ascertain this. According to the study's findings, polymorpho-nuclear neutrophils' physiological functions are not impacted by greater protection or low dosage exposure to X-ray radiation via chemiluminescence. To confirm the effects of dental X-ray radiation on the phagocytic activity of polymorpho-nuclear neutrophils (PMNs) in dental X-ray technicians, they have, nevertheless, advocated the need for large-scale investigations (Meo, 2004)

In 2011, 95 male employees at the state hospital in Khartoum, Sudan, had their hematopoietic systems' response to x-ray radiation evaluated. Hematologic parameters were examined in samples from the participants, and the results showed that their leukocyte, neutrophil, and lymphocyte counts were significantly lower than those of the controls. Cell numbers are dramatically reduced by exposure time as well. However, except from the top three characteristics, there was no variation (Waggiallah, 2013),

A study was conducted at the six main governmental hospitals. A total of 54 healthy medical radiographers with at least 5 years of experience were compared with 59 healthy participants as control group. The study group matched with controls in age, gender, years of experience, and smoking status. Hematological parameters were observed by ABX Micros 60 analyzer.

The statistical analysis was done by using Student's t test and one way ANOVA test. The study reported that the basic hematological parameters including the mean value of red blood cells (P=0.611), white blood cells (P=0.942), and platelets level (P=0.28) did not show any statistical significant differences between the compared groups. Low and high disturbance in the mean values of hematocrit and corpuscular hemoglobin in some medical radiographers, but their means did not reach the statistical significant levels. No statistical significant difference was found between the duration of exposure and hematological parameters of medical radiographers (Alnahhal et al., 2017).

When all of the studies discussed above were combined, they showed that low dose radiation had an impact on the hematologic parameters of workers who had been exposed to it, but some of them did not clearly show a link. However, the effects of low-dose ionizing radiation have not been studied in Nigerian publications, nor has the absorbed dose of radiation workers been quantified.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

This study was conducted in some selected Tertiary hospitals and Radio diagnostic Centre in South-East and South-South Nigeria namely: University of Port Harcourt Teaching Hospital (UPTH) Rivers State, Niger-Delta University Teaching Hospital (NDUTH), Bayelsa State, Delta State University Teaching Hospital (DELSUTH), Delta State, National Orthopedic Hospital (NOH), Enugu State, Federal Medical Centre (FMC), Yenagoa, Bayelsa State, Federal Medical Centre, Owerri, Imo State, Federal Medical Centre, Asaba, Delta State, Federal Medical Centre, Umuahia, Abia State and Image Diagnostic Centre (IDC), Port Harcourt, Rivers State. All the selected eight Hospitals and radio-diagnostic Centre have high number of patient flow where high numbers of Medical Radiation Professionals are expected to work in.

3.2 Study Period

The study was conducted from December 2018 to December 2020 where data collection took eighteen months from June 2019 to December 2020.

3.3 Study Design

A comparative cross-sectional study was conducted to assess the effects of ionizing radiation in the hematological profile and blood cell morphology of Medical Radiation workers in selected government tertiary hospitals and a Radio-diagnostic Centre in South-South and South-Eastern Nigeria.

3.4 Population

3.4.1 Source Population

About 101 Professional radiation workers working in UPTH, NDUTH, DELSUTH, NOH,

FMC Yenagoa, FMC Owerri, FMC Asaba, FMC Umuahia and IDC Port Harcourt.

3.4.2 Study Population

About 15 Radiologist, 13 Resident Doctors in Radiology and 71 Medical Radiographer/Medical imaging Scientists and 2 Medical Physicists in the selected Hospital and Radio-diagnostic Centre.

3.4.3 Control

The study recruited 101 Healthy controls from other department and Units not involved in any radiation activities, with the same range of age, sex and area of residence with the exposed workers were taken.

3.5. Inclusion and exclusion criteria

3.5.1 Inclusion criteria

All healthy workers with one year (1 year) and above and the radiation workers who

Works with ionizing radiation were included for this study.

3.5.2 Exclusion criteria

Participants, both exposed and unexposed, who are pregnant, with known history of diabetes mellitus, cardiovascular diseases and malignancy, those who have taken chemotherapy or radiotherapy, those who are smoker and radiation workers working with Non-ionizing radiation were all excluded.

3.6. Variables

3.6.1 Dependent variable

Hematological parameters

3.6.2 Independent variables

Sex

Place of work/hospital

Use of protective equipment

Work experience

3.7. Measurement and Data collection

3.7.1 Sampling Method

Convenient sampling (also known as availability sampling) method was used to collect data from the study site. The participants were on job while collecting data. Convenience sampling is a non-probability sampling method where units are selected for inclusion in the sample because they are the easiest for the researcher to access. In medical research, convenience sampling often involves selecting clinical cases or participants that are available around a particular location (such as a hospital) or a medical records database.

3.7.2 Sample determination

Sample size was determined by taking all Radiologists, Resident doctors in Radiology and Medical Radiographers/medical imaging scientists in the eight hospitals and radio-diagnostic Centre available through the data collection period who are full filling the explained criteria and who are volunteers to participate by giving their informed consent. In this study 202 participants were recruited. A total of 101 apparently healthy occupational radiation exposed worker and 101 apparently healthy and unexposed controls were included.

3.7.3 Data collection procedure

Details of socio-demographic background, occupational and medical history regarding work-related exposure to mutagenic agents, safety measures taken, duration of exposure, use of therapeutic drugs, and smoking was obtained from a questionnaire that was completed by each participant. The information was used to include and exclude participants. Physical Dosimetry was used to collect data on the absorbed dose of ionizing radiation by the radiation workers and Biological Dosimetry is used to collect data on the hematological parameter by all the participants.

3.8 Physical Dosimetry

The occupational exposure to ionizing radiation was routinely monitored by personal exposure measurement devices (Thermoluminescent dosimeter, TLD). The absorbed radiation dose measured in millisieverts using the TLD was compared with the values of International Commission on Radiological Protection (ICRP) 20mSv/yr for radiation workers. The TLD badge contains the TLD chips (LiF). The calibration of the TLD reader and chips were done in the secondary standard Dosimetry laboratory which maintains radiation protection standards

for Nigeria and is housed at the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan. The NIRPR serves as the custodian of the national secondary traceable with traceability to the IAEA standard laboratory in Vienna. The dosimeter chips were read at the TLD Laboratory, Department of Physics and Engineering physics, Obafemi Awolowo University. Ile-Ife. Nigeria.

3.8.1 Preparation of the TLD for Personnel Monitoring at the TLD Laboratory Obafemi Awolowo University and NNRA Laboratory University of Ibadan

The preparation of the Thermoluminence Dosimeters was done at the TLD laboratory, Physics and Engineering Physics Department, Obafemi Awolowo University Ile-Ife Osun State and the Nigerian Nuclear Regulatory Authority Laboratory, Elizabeth Way University of Ibadan, Oyo State.

The Harshaw Model 3500 manual TLD Reader was used for the thermoluninescene Dosimetry measurement. The TLD Reader is a personal computer driven manually operated table top instrument. The Harshaw 3500 reader reads a dosimeter per loading and accommodates a variety of TL configuration including chips, disk, rods and powder.

Fig 3.1: Personal Computer, TLD Reader and Tweezer

The system consists of two major components:

1. TLD Reader
2. The windows radiation evaluation and management system (WinREMS) Software resident on a personal computer (PC) which is connected to the reader via serial communication port.

3.9 The Reader 3500 has the following Accessories:

Personal computer (to control the reader 3500)

External printer (to print the reading & results)

Annealing oven (carbolite)

Micro vacuum cleaner (to clean the sample drawer)

Tweezer – for placing the dosimeteric material chips rods and disk)

Dosimeter Holding Tray – for storing and staging the chips.

Nitrogen pressure regulator and hoses – to feed Nitrogen gas into the 3500 reader unit.

Ups – Uninterrupted Power supplies to ensure continuity of the power supply to the reader and the pc during power failure.

3.10 Application software for instrument and dosimeter calibration

Day 1: About 40 chips were annealed using the carbolite oven. The chips were placed on the dosimeter holding tray using the tweezers. The tray was securely closed using two screws on both sides. The tray was placed on the shelf inside the oven. The oven was closed and the power button pressed on the on position.

The oven can be automatically be programmed to the 100^0C or 400^0C depending on the temperature needed for the TLD annealing, 400^0C is used for 1hour. After 1 hour the temperature start dropping until it gets to the room temperature, the tray can then be removed from the oven. The chips were put inside a black rubber bag to prevent light ray, after the annealing process the chips were put in the black rubber bag using the red-safe room light because the chips are sensitive to white light.

Fig 3.2: Carbolite Oven (Closed and Open)

Day 2: The 40 chips were taken to the NNRA laboratory at the University of Ibadan for calibration. The 40 chips were calibrated by attaching the chips in the black rubber bag eight on a row using a paper masking tape to a water phantom (75% water just like the human body). The 40 chips were attached and two rows above and two rows below. The chips were calibrated using the exposure factors of 5mSv at 80kv, 15.0ma, 5.5Foc and 989.9secs. After the calibration process, at OAU, the pre-read heating is done on that same day using the carbolite oven programmed at 100^0C for 10mins and allowing the temperature to cool to ambient temperature.

Fig 3.3: X-ray machine use for calibration at NNRA Laboratory University of Ibadan

Fig 3.4: Efe Omita placing the chips on the water phantom for calibration at the NNRA Lab University of Ibadan

3.10.1 Time temperature Profile (TTP) – Defines the temperature to which the TL material were heated as a function of time. It is define in 3 segments:

I. Preheat
II. Acquisition
III. Anneal

Preheat – Establishes a common starting point for all dosimeters in a group and may be used to eliminate the fast-fading low temperature peaks.

Acquisition – Is the segment during which the dosimeter data is acquired and the glow curve is generated.

Anneal - The Anneal segment is used to hold the dosimeter at a high temperature to ensure that all the TL signals were removed.

Each TTP were calibrated by generating a reader calibration factor (RCF) to convert the raw data (in Nano coulombs) to a meaningful dosimeter unit (Servert, rad etc.).

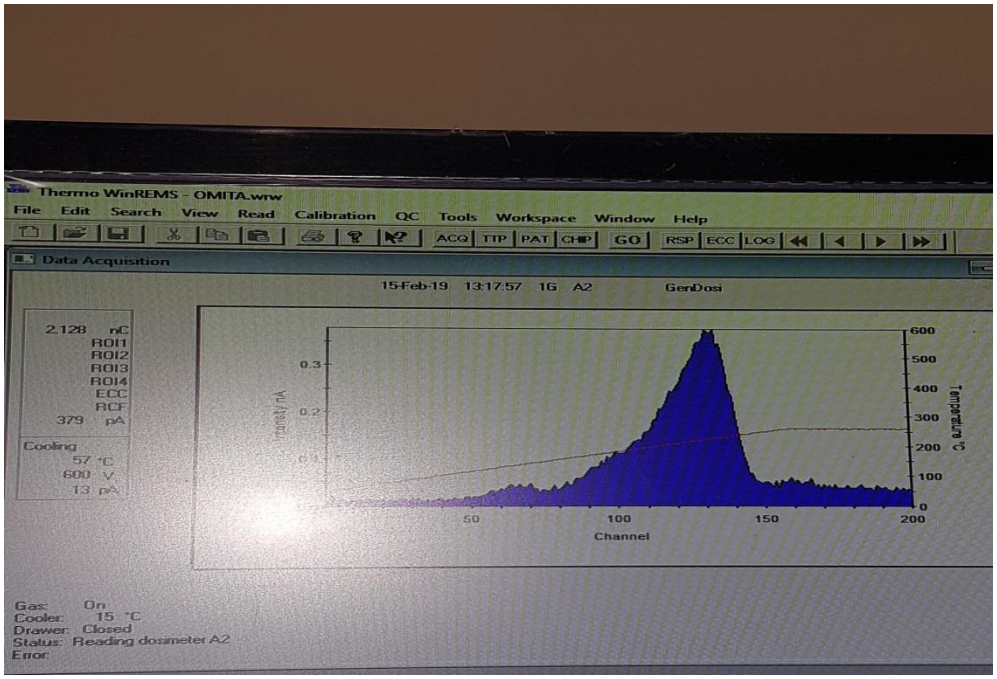


Fig 3.5: Glow Curve

2.10.2 Photomultiplier Tube Noise and Reference Light.

These two groups of fields were available for the purpose of checking the consistency and accuracy of the readings. Each type of reading has an interval and a range. The interval field sets the successive PNT noise and reference light reading. The ends of each group of dosimeter as define by the group ID.

The PMT noise is a reading taken with no chip or any other light source under the PMT Assembly. Its purpose is to measure the electronic noise in the system and determine if there were any light leaks in the system. The PMT reading is reported in picocoulmbs.

The references light readings were taken with the reference light directly in view of the PMT. The light provides a consistent light source to detect any drift in the system or accumulation of dirt on the PMT lens. The reference lights are located in the PMT Assembly. The readings were taken for 10secs. Reference light readings were taken at the beginning and at the end of each group of dosimeters. Reference light readings are reported in Nano coulombs. If the reading is significantly lower than normal, the most likely cause is a dirty neutral density filter or clean-out glass. Solution is to clean according to the instructions given.

How the PMT noise and reference light checks are done before and after every 10 dosimeter reading were done, a dialog box saving PMT noise check message box pop-up. The planchet

(where the chips were kept during reading) is empty inside the drawer. The drawer is pulled out with the sight on the monitor saying between, press on the read button on the TLD reader to carry out the PMT noise check and the reaching should be less than a for a good noise reading.

After the PMT noise reading is performed, the reference light reading is done by pulling the drawer to the open position and press the read button on the reader.

3.10.3 Calibration Procedure

The purpose of calibrating the TLD is to ensure that all dosimeter in a system will give essentially the same response to a given radiation exposure. The estimated calibration coefficient (ECC), is used as a multiplier with the reader output dosimeter of a designated group of dosimeter maintained as calibration dosimeter. The purpose of the reader calibration is to maintain a consistent output from the reader over a period of time based on convenient local source. The reader calibration factor (RCF). The factor converts the raw charge data from the PMT (nacocoulombs) to dosimeteric units (rems) or generic unit using the formula.

$$\text{Exposure} = \frac{\text{ECC x Charge}}{\text{RCF}} \qquad (3.1)$$

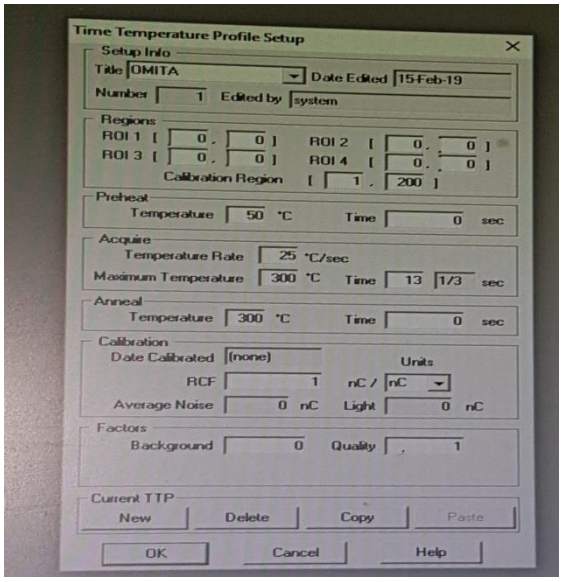


Fig 3.6: Time Temperature Profile Setup

3.10.4 Practical Calibration Process and preparation of TLD.

Day 3: After the 40 chips have anneal for 1hour at 400^0C is allowed to cool to ambient temperature and the TLD read with reader. The 40 chips were packed in black rubber bag, one per bag and taken to the NNRA laboratory at the University of Ibadan the 40 chips were exposed at the same time of 988.9 sec at 80kv, 5.5Foc and dose of 5mSv. After the irradiation at the NNRA laboratory, the 40 chips were taken back to the TLD laboratory at OAU. The pre-read heating was done at 100^0C for 10mins and allows to cool ambient temperature before the chips were read.

Fig 3.7: The Exposure console of X-ray machine at the NNRA Lab University of Ibadan

The reader switch on using the Ups and Pc also on. The reader on-switch is at the back of the reader. The TLD reader is allowed on for 30mins before using it to maintain the temperature of 260^0C between the ranges of 200^0C to 300^0c with the Nitrogen gas flowing to remove moisture due to condensation.

After reader has warm up for 30mins, the setup is programmed using the WinREMS. The interval of 10 dosimeters reading is done a PMT noise and reference light checks have been done, the chip ID is typed in using the keyboard on the screen and the enter key is pressed, then the drawer is drawn open and the chips is placed on the planchet using the tweezer. The chip

ID is based on the alphabet and number position where the chip is on the dosimeter holding tray.

Fig 3.8: Dosimeter Holding Tray (Empty and carrying chips)

The drawer is closed and the read button on the TLD reader is pressed to carry out the reading process. During the reading of the chip, the glow curve appears on the screen with the preheat process first, then the acquisition when the temperature get to 260^0C, the glow peak of the core is acquire and the temperature start dropping, the cooling process starts and when the cooling temperature drops to 50^0c the read of the chip is completed. Then you can pull open the drawer to remove the red chip using the tweezer and place the chip in the dosimeter holding tray and place on the planchet to be read again following the same above process.

After reading all the chips, a PMT noise and reference light checks were carried out and the done button is click to complete the reaching process. When the reading process is completed, the systems automatically select the golden chips which are with the range of the upper and lower units of the reader (1.027 and 0.94).

For this reading of 40 chips, the system automatically selects 6 chips with values:

$B_6 = 0.9823$

$B_8 = 0.9829$

$B_9 = 0.9971$

$C_2 = 1.024$

$D_5 = 1.024$

$D_6 = 0.9915$

The golden chips (Calibration Chips) were used to calibrate the other chips about 200 chips were anneal at 400^0C for 1 hour and taken to the NNRA laboratory together with six golden chip for irradiation at 5mSv, 80kv, 15mA and at 989.9secs after which pre-read heating is done at 100^0C for 10mins is done using the calibrate oven. All the chips were read using the same reading process.

At the end of the reading process the reader automatically selects the calibrated dosimeter and the bad dosimeter. The bad dosimeters were physically removed and the calibrated dosimeter packed in the TLD badges, 2 chips per badge. The packing of the chips into the badges were done after a port reading annealing is done to remove all the trapped phosphor. The post reading annealing was done at 400^0C for 1 hour.

3.11 Biological Dosimetry

About 3ml blood samples were collected from volunteer participants who have fulfilled the selection criteria, into the Ethylendiaminetetraacetic acid (EDTA) tube for complete blood count .In this collection process 20 ml needle was used to avoid clotting. Standard venous blood collection procedure was followed to ensure the quality of specimen. Complete Blood Count was performed within four hours of collection as to prevent the anticoagulant in the EDTA tube. The standard operating procedure for venous blood collection is appended (Cheesbrough, 2006).

3.11.1 Parameters to be tested

The hematological parameters of Complete Blood Count Tested were White blood cells (WBC), Red blood cells (RBC), hemoglobin (Hb), Hematocrit (Hct), Mean corpuscular volume (MCV), Mean corpuscular hemoglobin concentration (MCHC), Mean corpuscular hemoglobin (MCH), platelets (PLT) and Lymphocytes will be compared the Normal values of (Hb- 11.0-16.0g/dl male,11-16.5g/dl female), (Platelet Count – 100,000-300,000mm3) , (WBC – 4000-11,000mm3) ,(RBC -4.5-6.6 X 10,6- male, 3.5-5.5 x106 - female), (MCV 80.0-100.0 fL), (Lymphocytes – 20.0 – 40.0 %), (MCHC 32.0 – 36.0 g/L), and (MCH 27.0 – 34.0 pg).

3.11.2 Hematological Analysis

The collected blood samples were analyzed for all the hematological parameters aimed to be assessed in this study. Complete Blood Count (CBC) were performed by Mindray BC-5380 Automated analyzer.

Fig.3.9: Mindray BC-5380 Automatic Analyzer.

The hematological parameters generated by the automated analyzer were WBC, RBC, Hb, Hct,

MCV, MCH, MCHC, PLT, RDW (Red cell distribution Width), PDW (Platelet Distribution Width), MPV (Mean Platelet Volume), Lymphocytes, BASO (absolute Basophile count) NEUT (absolute Neutrophil count).

a. Data Quality Control

Specimens underwent analysis in a laboratory where the essential elements of a quality program, including internal quality control (IQC) and external quality assurance (EQA), were applied to each laboratory assay. This was done to ensure the accuracy and precision of test results. Proper procedures were followed for the collection, transportation, and storage of samples. The analysis adhered to the standard operating procedure (SOP) for Complete Blood Count (CBC).

3.13. Data analysis and Interpretation

The TLD results and that hematological test results were entered into the statistical Package for Social Sciences (SPSS) software version 21 for statistical analysis. The student t-test was used to compare the radiation dose of radiation workers with Standard value of 20mSv given by the ICRP, the t-test is also use to compare the hematological parameters of occupational radiation workers with the standard complete blood count Reference limits, and to compare the hematological parameters of healthy radiation professionals and healthy non-radiation workers. Simple regression was used to compare the effects of ionizing radiation on the hematological parameters of radiation workers. Tables, bar charts and Figures are used to display results.

3.14. Ethical Approval

The study was commenced after getting ethical approval from the Ethical and Research committee of each of the hospital and the Radio diagnostic Centre.

3.15 Statistical Analysis used for the study

The statistical tools used for this research work includes the cumulative mean, standard deviation and mean difference, t-test, simple Regression, and Anova.

I. **Mean Cumulative**: Cumulative mean is a statistical measure that calculates the mean of a set of numbers up to a certain point in time or after a certain number of observations.

$$\text{Mean Cumulative Radiation Dose (MCRD)} = \frac{\sum \text{Effective dose for 101 radiation work}}{n}$$

n = total number of radiation for the study

n = 101

E.D (Sv) = $\sum$ (W_R X H_T) (3.2)

= $\sum$ (Tissue weighting factor X Equivalent dose)

$H_T = D_T$ x W_R (3.3)

H_T = Equivalent dose

D_T = Absorbed dose (Dose Measurement from the TLD readings for the 101 radiation workers)

W_R = Radiation weighting factor

Weighting factor for x-ray = 1

II. **Standard Deviation:** The standard deviation is the average distance from the mean value of all values in a set of data.

Standard deviation is given as,

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{X})^2}{n-1}} \quad (3.4)$$

S= Standard Deviation = Square root of Variance

n = 101

$\overline{x}$ = cumulative mean

III. **Mean Difference**: The mean difference, or difference in means, measures the absolute difference between the mean values in two different groups. In clinical trials, it gives you an idea of how much difference there is between the averages of the experimental group and control groups.

Mean Difference = ($x_i - \overline{x}$) (3.5)

IV. T-test

The t test is a statistical test employed to compare the means of two groups. It is frequently employed in hypothesis testing to establish whether a procedure or treatment actually affects the population of interest or whether two groups differ from one another.

A t-test may be used to evaluate whether a single group differs from a known value (a one-sample t-test), whether two groups differ from each other (an independent two-sample t-test). In this study, it is used to compare the mean cumulative radiation dose with the international standard dose given by ICRP.

The t-test statistic can be found as in Nwaigwe (2020). For example, the One-sample t-test statistic is given by,

$$t = \frac{\overline{X} - \mu}{S/\sqrt{n}} \tag{3.6}$$

Where, $\overline{X}$ is the sample mean, μ is a specified mean value for the population,

S is the standard deviation and n is the sample size.

Standard deviation is given as,

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{X})^2}{n-1}}$$

The t-test statistic for testing the significance of difference between means of two groups is given as,

$$t = \frac{\overline{X}_A - X_B}{\sqrt{\frac{S_A^2}{n_A} + \frac{S_B^2}{n_B}}} \tag{3.7}$$

$$\vec{X}_A = \frac{\sum_{i=1}^{n} X_A}{n_A} \tag{3.8}$$

, that is the sample mean for group A

$$\vec{X}_B = \frac{\sum_{i=1}^{n} X_B}{n_B} \tag{3.9}$$

, that is the sample mean for group B

V. **Simple Regression:** Simple linear regression is used to estimate the relationship between two quantitative variables (Dependent and independent variable). In this study, simple Regression is used to compare the effects of ionizing radiation dose on the

hematological parameters of radiation workers using (with the absorbed dose of radiation as the independent variable and the hematological parameter as the dependent variable.

VI. **ANOVA:** which stands for Analysis of Variance, is a statistical test used to analyze the difference between the means of more than two groups. A one-way ANOVA uses one independent variable, while a two-way ANOVA uses two independent variables. The simple Anova is used in this current study to do an inter-hospital/diagnostic Centre and an inter-state comparison on the impacts of ionizing radiation on the Blood parameters of radiation workers.
For this present study the statistical package Statistical Package for the Social Sciences SPSS software was used

For this research work, the Cumulative radiation dose is the sum of the first and second absorbed doses by the radiation workers. It is obtained for each hospital/diagnostic center. The mean cumulative dose is the average of the cumulative doses from all the hospitals/diagnostic center that data were collected from. The Standard deviation is the average deviation of the individual values from their mean value. Mean difference is obtained by subtracting the mean of one group from the mean of the second group. T-test is used to compare means of two groups. In this study, the t-test was used to compare the mean radiation dose of the 101 radiation workers with the standard value given by ICRP, also to compare the hematological parameters of the radiation with the reference level and to compare the Hematogical parameters of radiation workers and non-radiation workers.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The demographic information of study participants serves as a fundamental aspect of research findings, providing valuable insights into the composition and characteristics of the study population. This section offers a comprehensive overview of the individuals involved in the research, encompassing factors such gender, types of radiation equipment, and other pertinent variables. Understanding the demographic profile of study participants is essential for contextualizing and interpreting the subsequent results, allowing for identification of potential patterns, correlations, or variations that may influence the outcomes of the study. The demographic information of the study participants are presented in Table 4.1.

Table 4.1: Demographic Information of the Study Participants

STUDY SUBJECTS	South-South number	South-East number	TYPES OF EQUIPMENT WORKED WITH			
			X-ray machine	Fluoroscopy	CT	Mammography
MALE RADIATION WORKERS (66 male radiation workers)	40	26	66	20	30	--
MALE NON-RADIATION WORKERS. (65 male non-radiation workers)	42	26	--	--	--	--
FEMALE RADIATION WORKERS (35 female radiation workers)	19	15	35	15	10	17
FEMALE NON-RADIATION WORKERS (36 non-radiation workers)	21	15	---	--	--	--

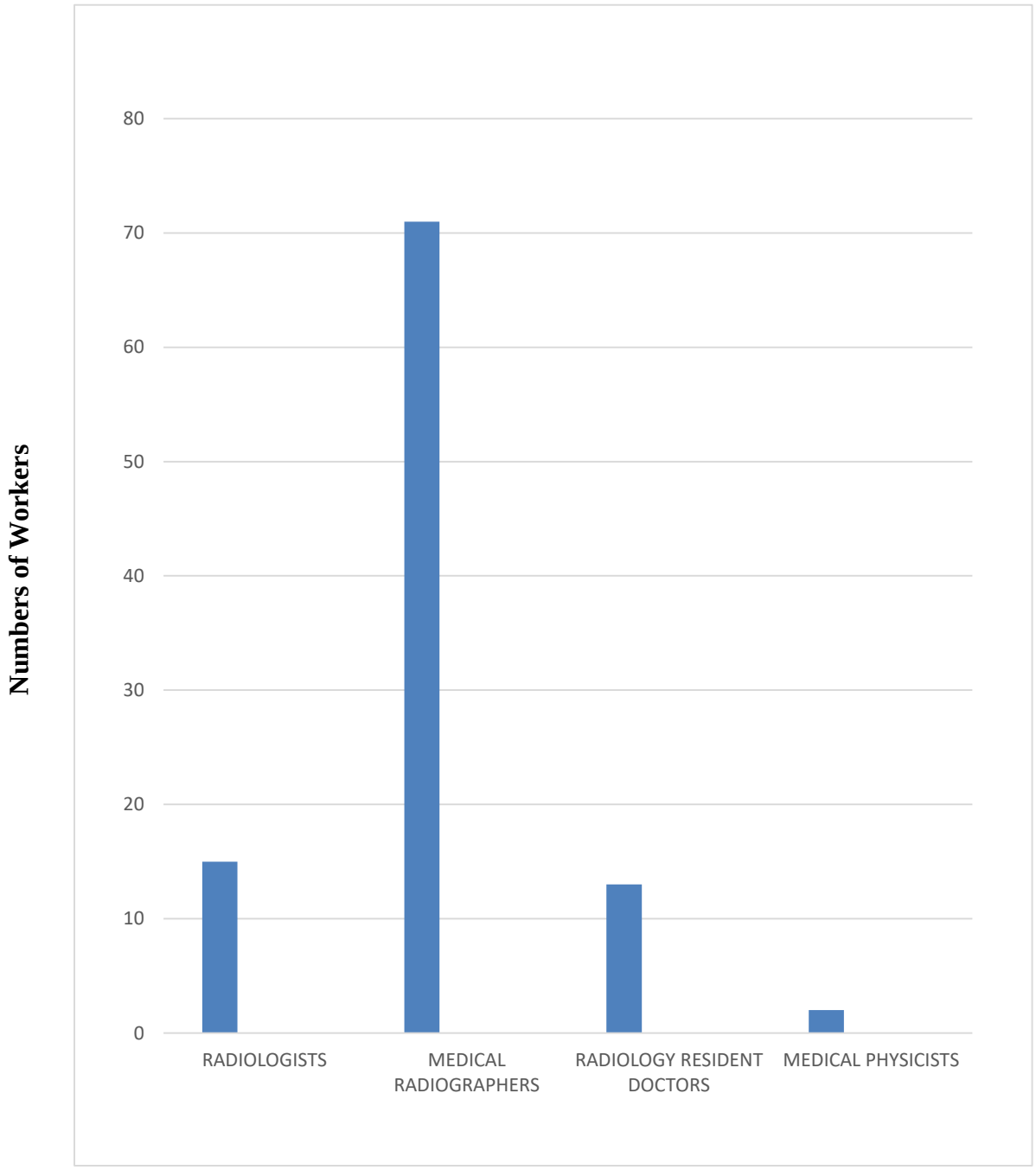


Fig. 4.1: The Number of Radiation worker in the study

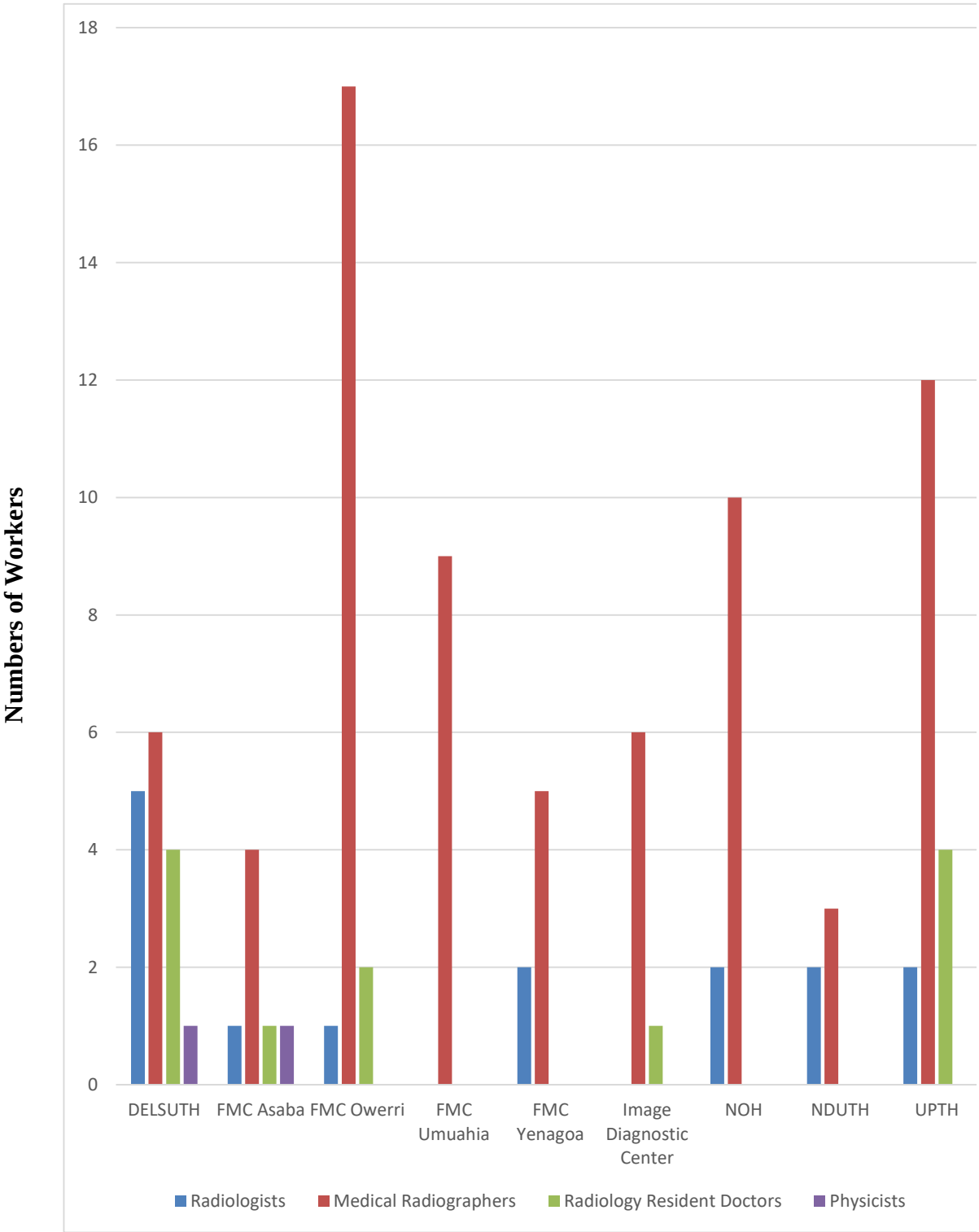


Fig.4.2: Distribution of Radiation workers recruited from the various hospitals/center in the study.

RESULT FOR HYPOTHESIS ONE

Table 4.2A: Comparison of the absorbed dose of the radiation workers

Mean Cumulative Radiation Dose	Std. Deviation	Mean Difference	Degree of Freedom	t- value	p-value	Remark
1.670	0.785	-18.330	100	-234.600	0.000	Significant

Number of radiation workers = 101

Level of significance = 0

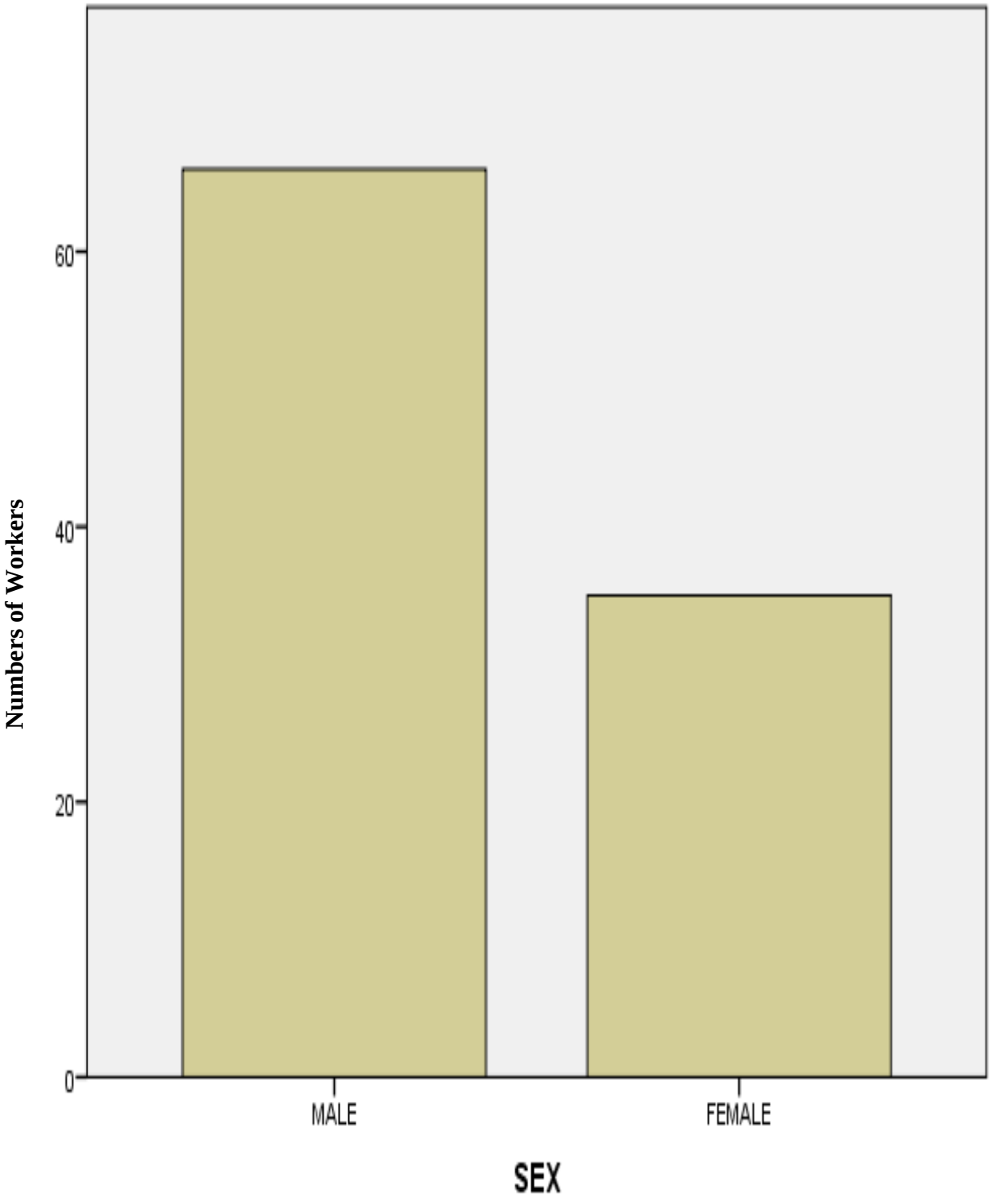


Fig 4.3: the number of Male and Female Radiation Worker recruited for the Study

RESULTS FOR HYPOTHESIS TWO

Table 4.3A: t-test Comparison of Blood Parameters of Radiation Workers with the Standard Full Blood Count Limits

Blood parameters	Mean value for radiation workers	Standard value	t-for lower limit	P	t-for upper limit	P	Mid-point	t-value for mid-point	P	Degree of freedom	Remark
WBC	5.19	4.00-10.00x10^9	8.09	0.00	-32.34	0	7.0x10^9	12.16	0	100	Significant
RBC	4.98	3.50-5.50x10^{12}	-12.7	0.00	-4.52	0	4.50x10^{12}	4.09	0	100	Significant
PLT	228.22	100-300x10^9	16.2	0.00	-9.07	0	200x10^9	3.57	0.001	100	Significant
Hb	12.32	15-17	1.44	0.16	-21.21	0	14.5	-9.89	0.000	100	Significant
HcT	37.05	35-55	3.67	0.00	-32.12	0	45.0	-14.22	0.000	100	Significant
McV	80.51	80-100	0.47	0.64	-17.99	0	90.0	-8.76	0.000	100	Significant
McH	28.42	26-34	7.5	0.00	-17.31	0	30.0	-4.91	0.000	100	Significant
MCHC	33.94	31-35	15.63	0.00	-5.67	0	33.0	4.99	0.000	100	Significant
Lymphocytes	33.94	25-50	47.58	0.00	-85.53	0	37.5	-18.98	0.000	100	Significant

Table 4.3B 1: One-Sample WBC Lower Descriptive Statistics

	N	Mean	Std. Deviation	Std.Error Mean
WBC	101	5.19	1.495	0.149

Table 4.3 B 2: One-Sample WBC Lower Limit t-Test

	Test Value = 4					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
WBC	8.009	100	0.000	1.191	0.90	1.49

Table 4.3B 3: One-Sample WBC Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Standard Error Mean
WBC	101	5.19	1.495	0.149

Table 4.3B 4: One-Sample WBC Upper Limit t-Test

	Test Value = 10					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
WBC	-32.337	100	0.000	-4.809	-5.10	-4.51

Table 4.3B 5: One-Sample WBC Mid-point descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
WBC	101	5.19	1.495	0.149

Table 4.3B 6: One-Sample WBC Mid-Point t-Test

	Test Value = 7					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
WBC	-12.164	100	.000	-1.809	-2.10	-1.51

Table 4.3B 7: One-Sample RBC Lower Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
RBC	101	4.9752	1.16768	.11619

Table 4.3B 8: One-Sample RBC Lower t-Test

	Test Value = 3.50					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
RBC	12.697	100	.000	1.47525	1.2447	1.7058

Table 4.3B 9: One-Sample RBC Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
RBC	101	4.9752	1.16768	0.11619

Table 4.3B 10: One-Sample RBC Upper Limit t-Test

	Test Value = 5.50					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
RBC	-4.516	100	.000	-.52475	-.7553	-.2942

Table 4.3B 11: One-Sample RBC Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
RBC	101	4.9752	1.16768	.11619

Table 4.3B 12-Sample RBC Mid-Point t-Test

	Test Value = 4.50					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
RBC	4.090	100	.000	.47525	.2447	.7058

Table 4.3B13: One-Sample PLT Lower Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
PLT	101	228.2228	79.56414	7.91693

Table 4.3B 14: One-Sample PLT Lower Limit t-Test

	Test Value = 100					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PLT	16.196	100	.000	128.22277	112.5158	143.9297

Table 4.3B 15: One-Sample PLT Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
PLT	101	228.2228	79.56414	7.91693

Table 4.3B 16: One-Sample PLT Upper Limit t-Test

	Test Value = 300					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PLT	-9.066	100	.000	-71.77723	-87.4842	-56.0703

Table 4.3B 17: One-Sample PLT Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
PLT	101	228.2228	79.56414	7.91693

Table 4.3B 18 One-Sample PLT Mid-Point t-Test

	Test Value = 200					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PLT	3.565	100	.001	28.22277	12.5158	43.9297

Table 4.3B 20: One-Sample Hb Lower Limit t-Test

	Test Value = 12					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Hb	1.435	100	.155	.31683	-.1213	.7550

Table 4.3B 21: One-Sample Hb Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hb	101	12.3168	2.21955	.22085

Table 4.3B 22: One-Sample Hb Upper Limit t-Test

	Test Value = 17					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Hb	-21.205	100	.000	-4.68317	-5.1213	-4.2450

Table 4.3B 23: One-Sample Hb Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hb	101	12.3168	2.21955	.22085

Table 4.3B 24: One-Sample Hb Mid-Point t-Test

	Test Value = 14.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Hb	-9.885	100	.000	-2.18317	-2.6213	-1.7450

Table 4.3B 25: One-Sample HcT Lower Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
HcT	101	37.05250	5.61647	.55886

Table 4.3B 26: One-Sample HcT Lower Limit t-Test

	Test Value = 35					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
HcT	3.673	100	.000	2.05248	.9437	3.1612

Table 4.3B 27: One-Sample HcT Upper Limit descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
HcT	101	37.0525	5.61647	.55886

Table 4.3B 28: One-Sample HcT Upper Limit t-Test

	Test Value = 55					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
HcT	-32.115	100	.000	-17.94752	-19.0563	-16.8388

Table 4.3B 29: One-Sample HcT Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
HcT	101	37.0525	5.61647	.55886

Table 4.3B 30: One-Sample HcT t-Test

	Test Value = 45					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
HcT	-14.221	100	.000	-7.94752	-9.0563	-6.8388

Table 4.3B 31: One-Sample McV Lower Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std.Error Mean
McV	101	80.5069	10.88687	1.08328

Table 4.3B 32: One-Sample McV Lower Limit t-Test

	Test Value = 80					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
McV	.468	100	.641	.50693	-1.6423	2.6561

Table 4.3B 33: One-Sample McV Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
McV	101	80.5069	10.88687	1.08328

Table 4.3B 34: One-Sample McV Upper Limit t-Test

	Test Value = 100					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
McV	-17.994	100	.000	-19.49307	-21.6423	-17.3439

Table B 35: One-Sample McV Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
McV	101	80.5069	10.88687	1.08328

Table 4.3B 36: One-Sample McV Upper Limit t-Test

	Test Value = 90					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
McV	-8.763	100	.000	-9.49307	-11.6423	-7.3439

Table 4.3B 37: One-Sample MCH Lower Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
MCH	101	28.4178	3.24168	.32256

Table 4.3B 38: One-Sample MCH Lower Limit t-Test

	Test Value = 26					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
MCH	7.496	100	.000	2.41782	1.7779	3.0578

Table 4.3B 39: One-Sample MCH Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
MCH	101	28.4178	3.24168	.32256

Table 4.3B 40: One-Sample MCH Upper Limit t-Test

	Test Value = 34					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
MCH	-17.306	100	.000	-5.58218	-6.2221	-4.9422

Table 4.3B 41: One-Sample MCH Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
MCH	101	28.4178	3.24168	.32256

Table 4.3B 42: One-Sample MCH Mid-Point t-Test

	Test Value = 30					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
MCH	-4.905	100	.000	-1.58218	-2.2221	-.9422

Table 4.3B 43: One-Sample MCHC Lowe Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
MCHC	101	33.9356	1.88752	.18781

Table4.3 B 44: One-Sample MCHC Lower Limit t-Test

	Test Value = 31					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
MCHC	15.631	100	.000	2.93564	2.5630	3.3083

Table 4.3B 45: One-Sample MCHC Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
MCHC	101	33.9356	1.88752	.18781

Table 4.3B 46: One-Sample MCHC Upper Limit t-Test

	Test Value = 35					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
MCHC	-5.667	100	.000	-1.06436	-1.4370	-.6917

Table 4.3B 47: One-Sample MCHC Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
MCHC	101	33.9356	1.88752	.18781

Table 4.3B 48: One-Sample MCHC Mid-Point t-Test

	Test Value = 37.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
MCHC	-18.978	100	.000	-3.56436	-3.9370	-3.1917

Table 4.3B 49: One-Sample Lymphocytes Lower Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lymphocytes	101	39.0277	11.24891	1.11931

Table 4.3 B 50: One-Sample Lymphocytes Lower Limit t-Test

	Test Value = 25					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Lymphocytes	12.532	100	.000	14.02772	11.8070	16.2484

Table 4.3B 51: One-Sample Lymphocytes Upper Limit Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lymphocytes	101	39.0277	11.24891	1.11931

Table 4.3B 52: One-Sample Lymphocytes Upper Limit t-Test

	Test Value = 50					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Lymphocytes	-9.803	100	.000	-10.97228	-13.1930	-8.7516

Table 4.3B 53: One-Sample Lymphocytes Mid-Point Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lymphocytes	101	39.0277	11.24891	1.11931

Table 4.3B 54: One-Sample Lymphocytes Mid-Point t-Test

	Test Value = 37.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Lymphocytes	1.365	100	.175	1.52772	-.6930	3.7484

RESULTS FOR HYPOTHESIS THREE

Table 4.4 presents a comparison of blood parameters between radiation workers and non-radiation workers within the same hospital. This result explored potential variations in blood parameters among these distinct groups, shedding light on the impact, if any, of occupational exposure to radiation on physiological measures. The table provides a detailed examination of relevant blood parameters, fostering a comprehensive understanding of the differences or similarities between the two groups of hospital employees.

Table 4.4: Comparison of Blood Parameters of Radiation Workers and Non-radiation Workers in the same Hospital.

Hospital		Blood Parameters								
		WBC ($10^{\wedge 9}$/l)	**RBC ($10^{\wedge 12}$/L)**	**PLT ($10^{\wedge 12}$/L)**	**Hb (g/dL)**	**HcT (%)**	**MCV (fL)**	**MCH (pg)**	**MCHC (g/dL)**	**Lymphocytes (%)**
DSUTH	$\overline{X_R}$	6.410	5.470	240.280	13.640	37.710	81.040	31.580	35.900	27.860
	S_R	2.331	1.205	90.691	1.720	4.500	11.016	4.541	0.922	11.393
	$\bar{X}_N$	6.410	5.470	250.750	13.632	37.790	82.600	31.650	35.940	27.460
	S_N	2.331	1.205	71.003	1.708	4.450	5.800	4.573	0.965	11.782
	t-value	0.000	0.000	-0.364	0.010	-0.051	-0.500	-0.043	-0.112	0.096
	df	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000
	P	1.000	1.000	0.719	0.992	0.959	0.620	0.966	0.911	0.924
	Remark	*Not sig.*	*Not sig.*	*Not sig.*	*Not sig.*	*Not sig.*	*Not sig.*	*Not sig.*	*Not sig.*	*Not sig.*
FMC ASABA	$\overline{X_R}$	4.670	5.910	295.290	12.700	33.730	68.040	27.810	33.970	42.110
	S_R	0.637	1.717	61.970	1.485	5.280	23.150	2.935	2.480	9.650
	$\bar{X}_N$	5.940	5.460	193.860	14.300	41.330	80.610	30.010	34.910	44.640
	S_N	1.029	0.980	45.250	1.474	4.630	8.220	7.336	1.650	7.770
	t-value	-2.779	0.612	3.497	-2.020	-2.865	-1.354	-0.737	-0.838	-0.540
	df	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
	P	0.020	0.560	0.010	0.060	0.010	0.220	0.480	0.420	0.600
	Remark	*Sig.*	*Not sig.*	*Sig*	*Not sig.*	*Sig*	*Not sig*	*Not sig*	*Not sign*	*Not sig*
Hospital		**Blood Parameters**								
		WBC ($10^{\wedge 9}$/l)	**RBC ($10^{\wedge 12}$/L)**	**PLT ($10^{\wedge 12}$/L)**	**Hb (g/dL)**	**HcT (%)**	**McV (fL)**	**McH (pg)**	**McHc (g/dL)**	**Lymphocytes (%)**
FUTH OWERRI	$\overline{X_R}$	5.020	4.340	194.900	11.840	35.765	83.450	28.260	33.670	41.580
	S_R	1.614	0.635	54.015	1.710	5.635	5.678	1.950	0.836	10.651
	$\bar{X}_N$	6.470	5.580	232.600	12.320	32.060	85.450	28.495	33.080	44.510
	S_N	1.825	1.444	36.863	0.992	8.880	5.216	2.202	1.327	7.462
	t-value	-2.662	-3.500	-2.578	-1.092	1.578	-1.160	-0.357	1.668	-1.006
	df	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000
	P	0.010	0.002	0.015	0.283	0.124	0.253	0.723	0.105	0.322
	Remark	***Sig.***	***Sig.***	***Sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***
FMC UMUAHIA	$\overline{X_R}$	5.811	3.960	189.220	10.720	32.240	83.610	29.040	33.460	44.320
	S_R	1.315	0.662	44.860	0.948	2.981	6.436	2.191	0.667	3.972
	$\bar{X}_N$	7.560	5.633	218.220	12.200	34.980	83.930	27.570	33.010	43.190
	S_N	1.876	1.557	36.949	0.461	2.899	5.370	2.507	0.462	7.858
	t-value	-2.280	-2.975	-1.497	-4.254	-1.972	-0.115	1.332	1.643	0.386
	df	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000
	P	0.038	0.013	0.155	0.001	0.066	0.910	0.202	0.122	0.706
	Remark	**Sig.**	**Sig.**	**Not sig.**	**Sig.**	**Not sig**	**Not sig**	**Not sig**	**Not sig**	**Not sig**

Hospital		Blood Parameters								
		WBC ($10^{\wedge 9}$/l)	**RBC ($10^{\wedge 12}$/L)**	**PLT ($10^{\wedge 12}$/L)**	**Hb (g/dL)**	**HcT (%)**	**McV (fL)**	**McH (pg)**	**McHc (g/dL)**	**Lymphocytes (%)**
FCM YENAGOA	$\overline{X_R}$	4.290	5.570	232.140	12.440	36.990	80.360	27.630	35.060	40.800
	S_R	0.897	1.570	52.570	1.367	5.240	5.229	2.679	1.988	13.660
	$\bar{X}_N$	5.900	6.200	223.140	12.890	38.060	80.390	30.890	34.460	37.190
	S_N	1.570	1.130	48.580	1.135	4.150	7.503	3.598	3.289	7.820
	t-value	-3.365	-0.859	0.333	-0.660	-0.424	-0.008	-1.869	0.413	0.607
	df	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
	P	0.060	0.409	0.745	0.522	0.679	0.994	0.088	0.688	0.558
	Remark	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***	***Not sig.***
IMAGE DIAGNOSTIC CENTER	$\overline{X_R}$	5.060	4.770	263.430	12.260	37.590	79.830	27.490	34.630	39.440
	S_R	1.407	0.610	61.354	1.014	2.871	5.872	14.356	3.004	6.889
	$\bar{X}_N$	5.710	4.960	231.710	14.070	39.210	85.360	31.060	37.570	40.000
	S_N	1.963	0.887	100.620	1.101	2.801	4.130	2.568	0.953	14.163
	t-value	-0.720	-0.456	0.712	-3.206	-1.074	-2.037	-1.869	-2.470	-0.094
	df	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
	P	0.487	0.657	0.493	0.008	0.304	0.067	0.092	0.042	0.928
	Remark	***Not Sig.***	***Not sig.***	***Not Sig***	***sig.***	***Not Sig***	***Not sig***	***Not sig***	***t sig***	***Not sig***

Hospital		WBC ($10^{\wedge 9}$/l)	RBC ($10^{\wedge 12}$/L	PLT ($10^{\wedge 12}$/L)	Hb (g/dL)	HCT (%)	MCV (fL)	MCH (pg)	MCHC (g/D)	Lymphocytes (%)
NATIONALOTHOPEPIC HOSPITAL	$\bar{X}_R$	4.983	4.790	167.500	11.967	41.075	79.590	29.610	33.220	42.190
	δ_R	1.242	0.686	51.093	3.938	4.383	17.325	1.686	0.144	8.296
	$\bar{X}_N$	8.140	4.780	216.330	11.940	36.110	80.800	27.120	32.790	42.980
	δ_N	3.260	0.652	29.040	0.799	2.300	7.434	2.301	0.774	5.260
	t-value	-3.136	0.061	-2.880	0.022	3.480	-0.222	3.026	1.872	-0.276
	df	22.000	22.000	22.000	22.000	22.000	22.000	22.000	22.000	22.000
	p	0.005	0.952	0.01	0.983	0.003	0.827	0.007	0.086	0.785
	Remark	**Sig.**	**Not sig.**	**Sig.**	**Not sig.**	**Sig.**	**Not sig.**	**Sig.**	**Not sig.**	**Not sig.**
NDUTH	$\bar{X}_R$	5.020	4.680	366.000	11.660	31.960	80.760	26.660	33.060	37.000
	δ_R	0.482	1.420	99.005	3.798	8.431	4.744	1.717	0.783	15.831
	$\bar{X}_N$	8.420	5.740	234.400	14.760	40.620	82.260	31.260	34.720	32.940
	δ_N	4.114	0.207	50.861	31.960	5.421	5.100	8.631	1.427	9.006
	t-value	-1.836	-1.651	2.644	-1.655	-1.932	-0.439	-1.169	-2.280	0.498
	df	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
	p	0.138	0.171	0.039	0.152	0.096	0.673	0.303	0.060	0.635
	Remark	**Not sig.**	**Not sig.**	**Sig.**	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**
UPHTH	$\bar{X}_R$	4.840	5.440	234.940	12.720	40.150	80.920	25.990	32.730	39.880
	δ_R	0.972	1.096	72.570	1.923	5.290	6.599	1.960	2.370	11.057
	$\bar{X}_N$	5.320	4.940	214.830	13.060	37.910	77.660	27.440	35.690	43.340
	δ_N	1.204	0.856	55.815	1.618	4.777	9.855	3.266	1.765	12.887
	t-value	-1.310	1.525	0.932	-0.572	1.333	1.165	-1.615	-4.250	-0.870
	df	34.000	34.000	34.000	34.000	34.000	34.000	34.000	34.000	34.000
	p	0.190	0.137	0.358	0.571	0.192	0.253	0.118	0.000	0.393
	Remark	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**	Not Sig	Sig.	**Not sig.**

$\bar{X}_R$ Mean blood parameter for radiation workers

$\bar{X}_N$ Mean blood parameter for non-radiation workers

δ_R Standard deviation from the mean blood parameter for radiation worker

δ_N Standard deviation from the mean blood parameter for non-radiation workers.

df = degree of freedom

p = p-value

RESULTS FOR HYPOTHESIS FOUR

Table 4.5 provides a summary of the comparison of blood parameters between radiation workers and non-radiation workers within the same hospital. This summary aims to offer a comprehensive overview of the key findings related to blood parameters, emphasizing the distinctions or similarities observed between the two groups of hospital employees. The table serves as a quick reference for understanding the essential outcomes derived from the detailed analysis presented earlier in the study.

Table 4.5: Summary of the Comparison of Blood Parameters of Radiation Workers and Non-radiation Workers in the same Hospital.

Health Institutions	Blood parameters					
	WBC	RBC	PLT	HCT	Hb	MCHC
DSUTH	Not Sig	Not Sig	Not Sig	Not Sig	Not Sig	Not Sig
FMC Asaba	Sig	Sig	Sig			
FMC/FUTH Owerri	Sig	Sig				
FMC Umuahia	Sig	Sig				
FMC Yenagoa	Not Sig	Not Sig	Not Sig	Not Sig	Not Sig	Not Sig
IDC					Sig	
NOH	Sig		Sig			
NDUTH			Sig			
UPTH						Sig

RESULTS FOR HYPOTHESIS FIVE

Table 4.6: Summary of Effects of Radiation on the Blood Parameters across the Hospitals.

Blood Parameters	F-value	P-value	Remark
WBC	2.326	0.025	Significant
RBC	3.969	0.000	Significant
PLT	6.06	0.000	Significant
Hb	1.69	0.111	Not Significant
HCT	4.066	0.000	Significant
MCV	1.502	0.167	Not Significant
MCH	4.898	0.000	Significant
MCHC	5.377	0.000	Significant
Lymphocytes	3.007	0.000	Significant

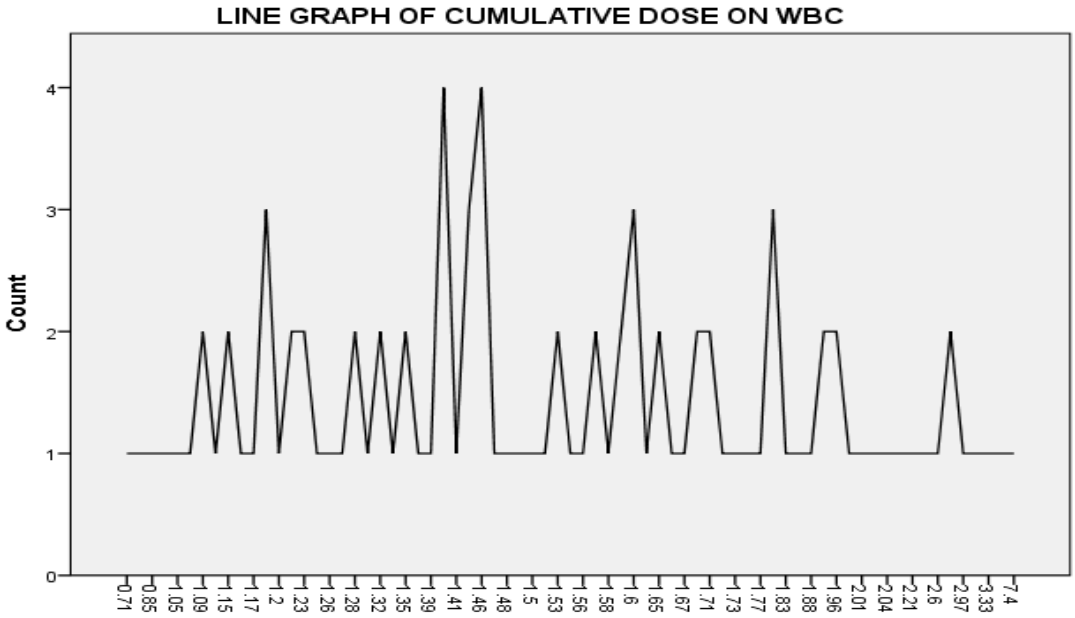


Fig. 4.4: The relationship between cumulative absorbed dose by the radiation workers and their WBC.

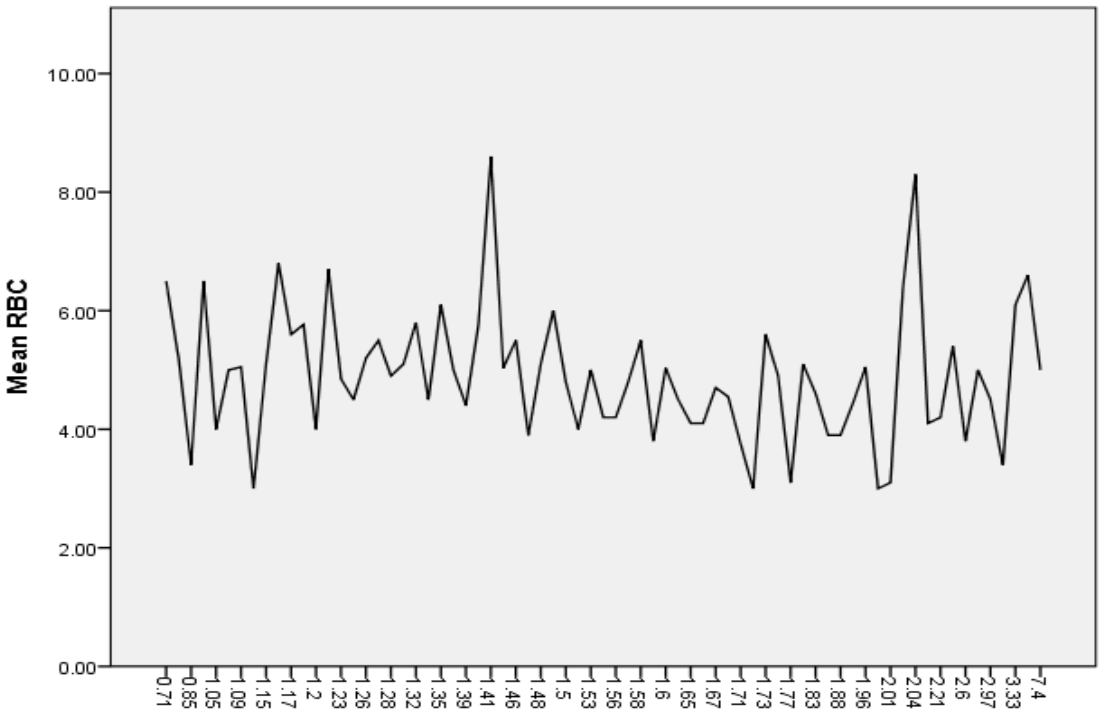


Fig. 4.5: The relationship between cumulative absorbed dose by the radiation workers and their RBC.

Fig. 4.5 above shows that there is no linear relationship between cumulative absorbed doses of radiation workers and the effect on the red blood cells.

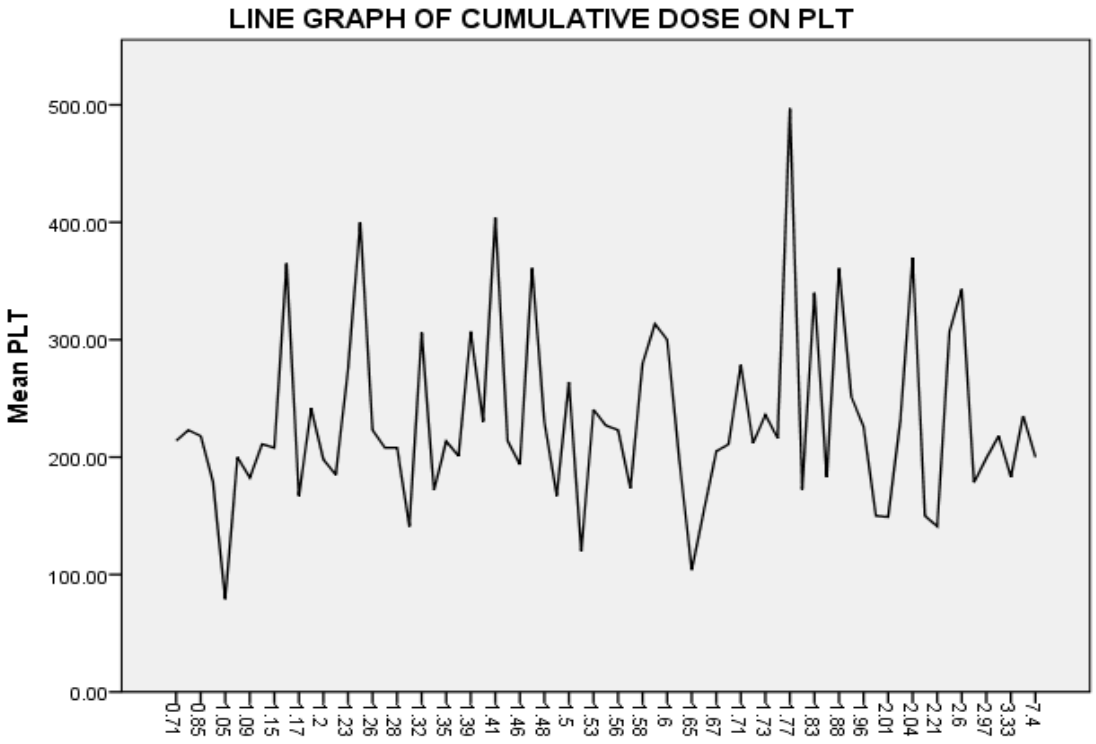


Fig. 4.6: The relationship between cumulative absorbed dose by the radiation workers and their PLT.

Fig. 4.6 shows that there is no linear relationship between cumulative dose taken by the radiation workers and their PLT.

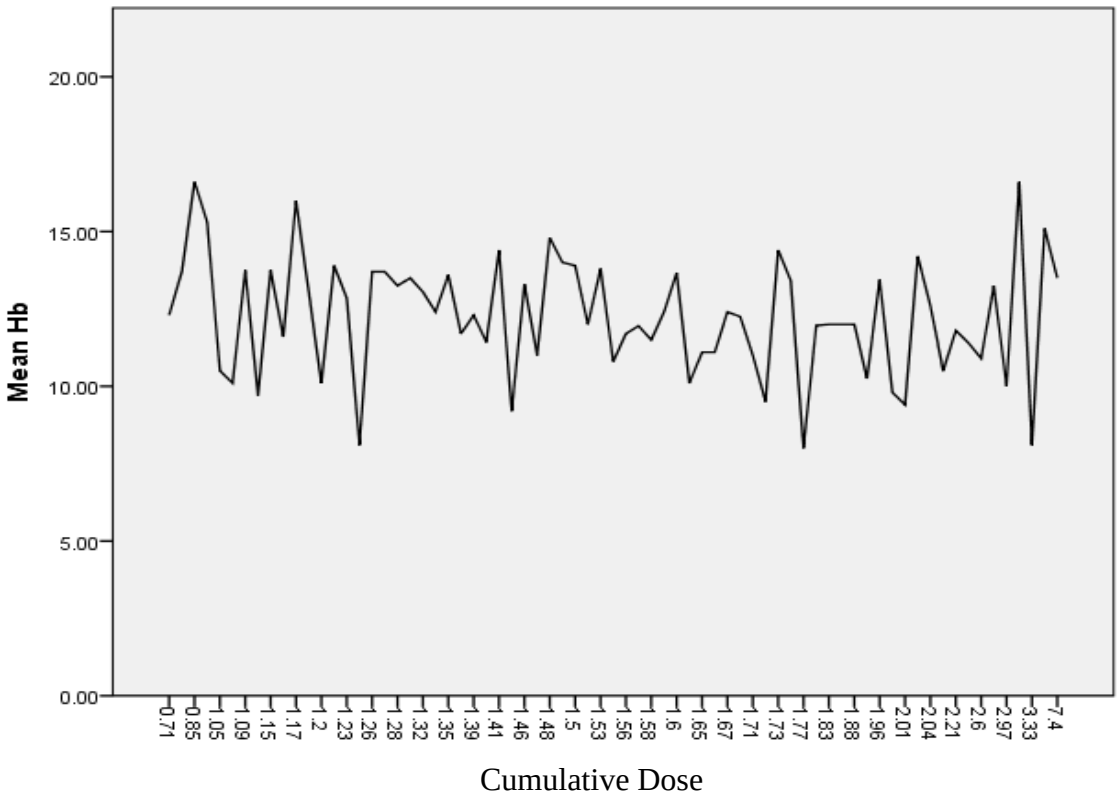


Fig. 4.7: The relationship between cumulative absorbed dose by the radiation workers and their Hb.

Fig. 4.7 shows that there is no linear relationship between cumulative dose taken by the radiation workers and their Hb

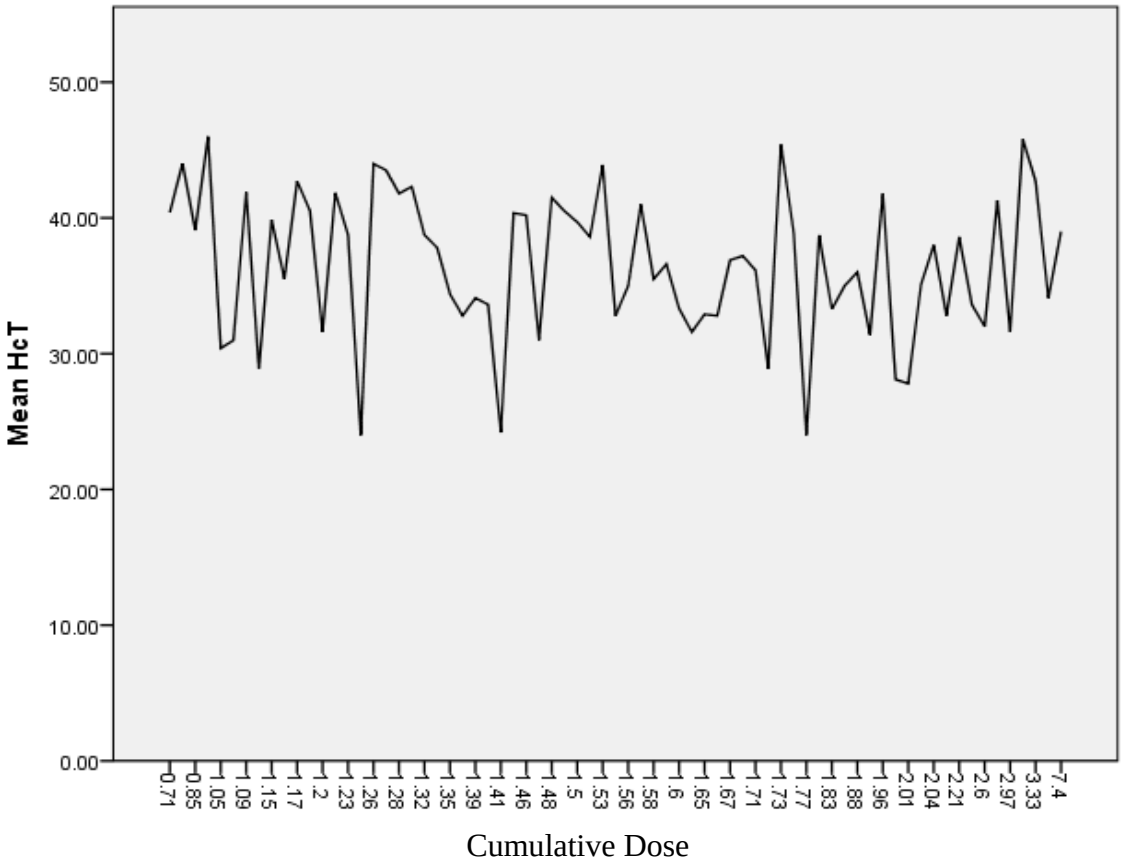


Fig. 4.8: The relationship between cumulative absorbed dose by the radiation workers and their HcT.

Fig. 4.8 shows that there is no linear relationship between cumulative dose taken by the radiation workers and their HcT.

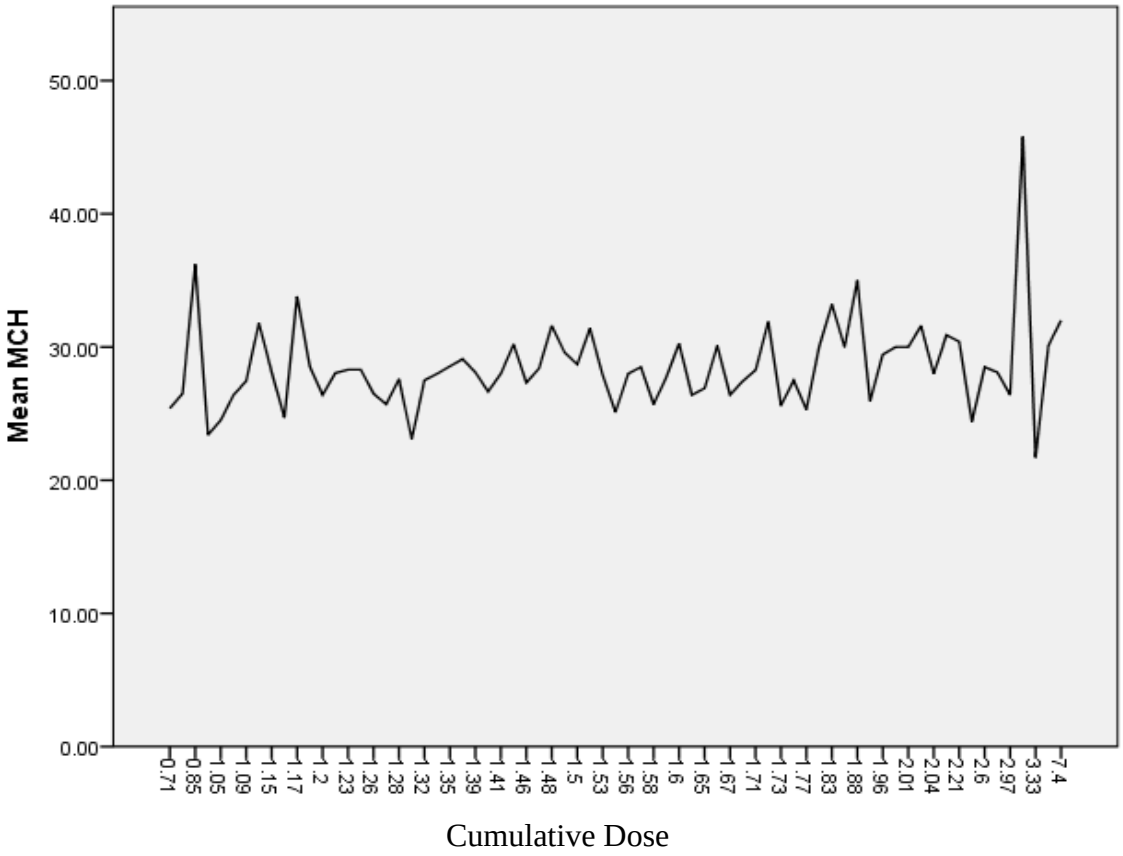


Fig. 4.9: The relationship between cumulative absorbed dose by the radiation workers and their MCH.

Fig. 4.9 shows that the relationship between cumulative dose absorbed by the radiation workers and their MCH may be approximated with a linear relationship

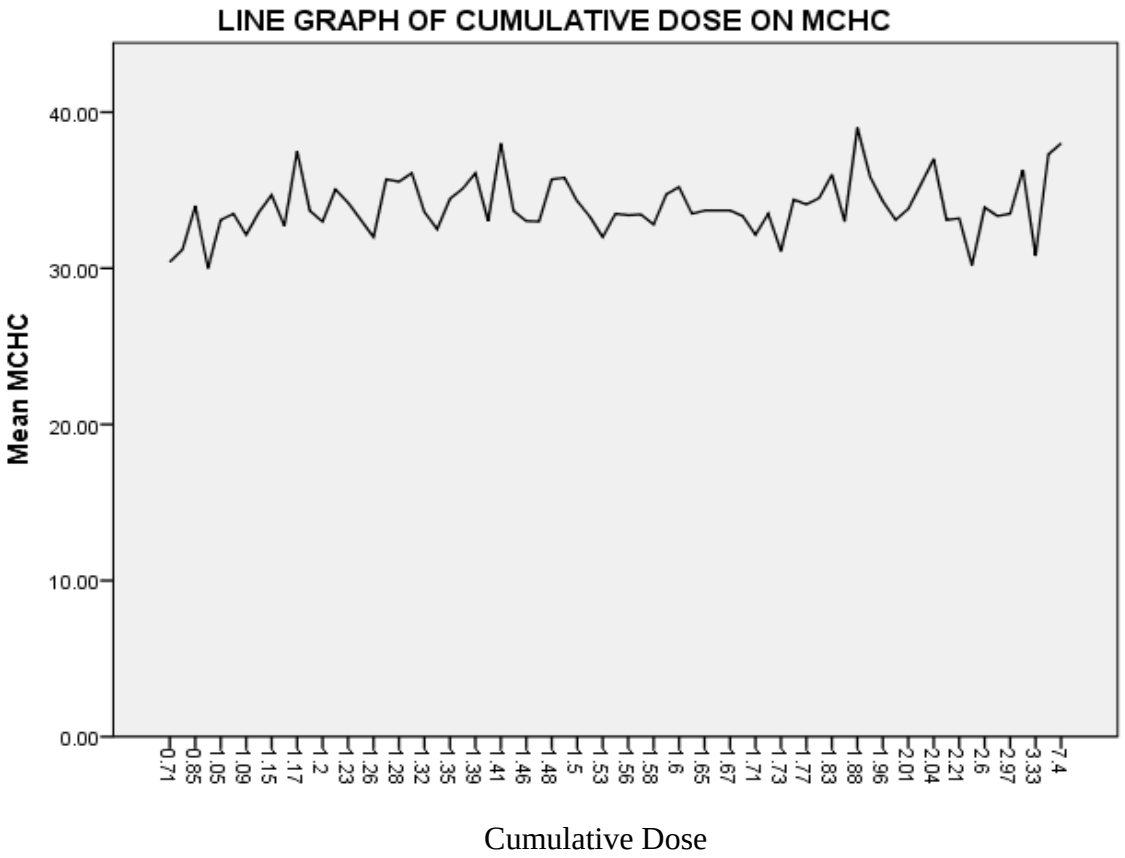


Fig. 4.10: The relationship between cumulative absorbed dose by the radiation workers and their MCHC.

Fig. 4.10 shows that the relationship between cumulative effective dose by the radiation workers and their MCHC may be approximated with a linear relationship.

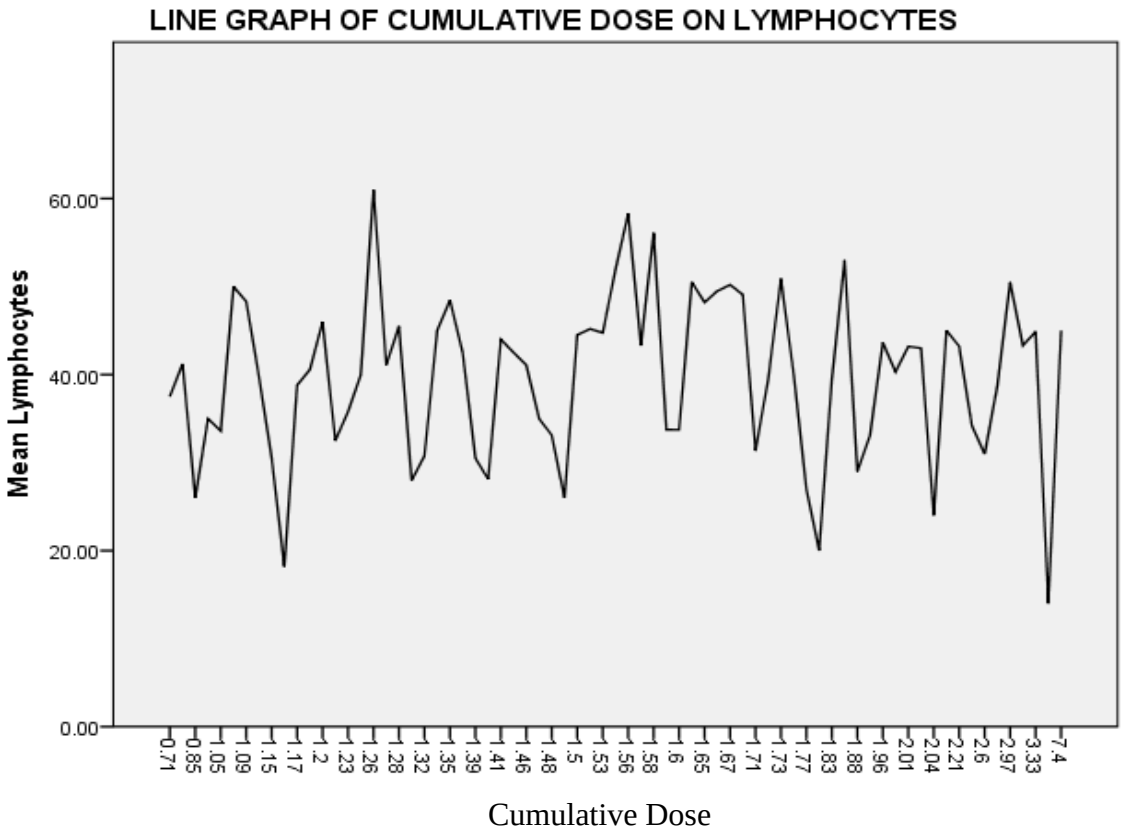


Fig. 4.11: The relationship between cumulative absorbed dose by the radiation workers and their Lymphocytes

Fig. 4.11 shows that the relationship between cumulative dose taken by the radiation workers and their Lymphocytes is not a linear relationship.

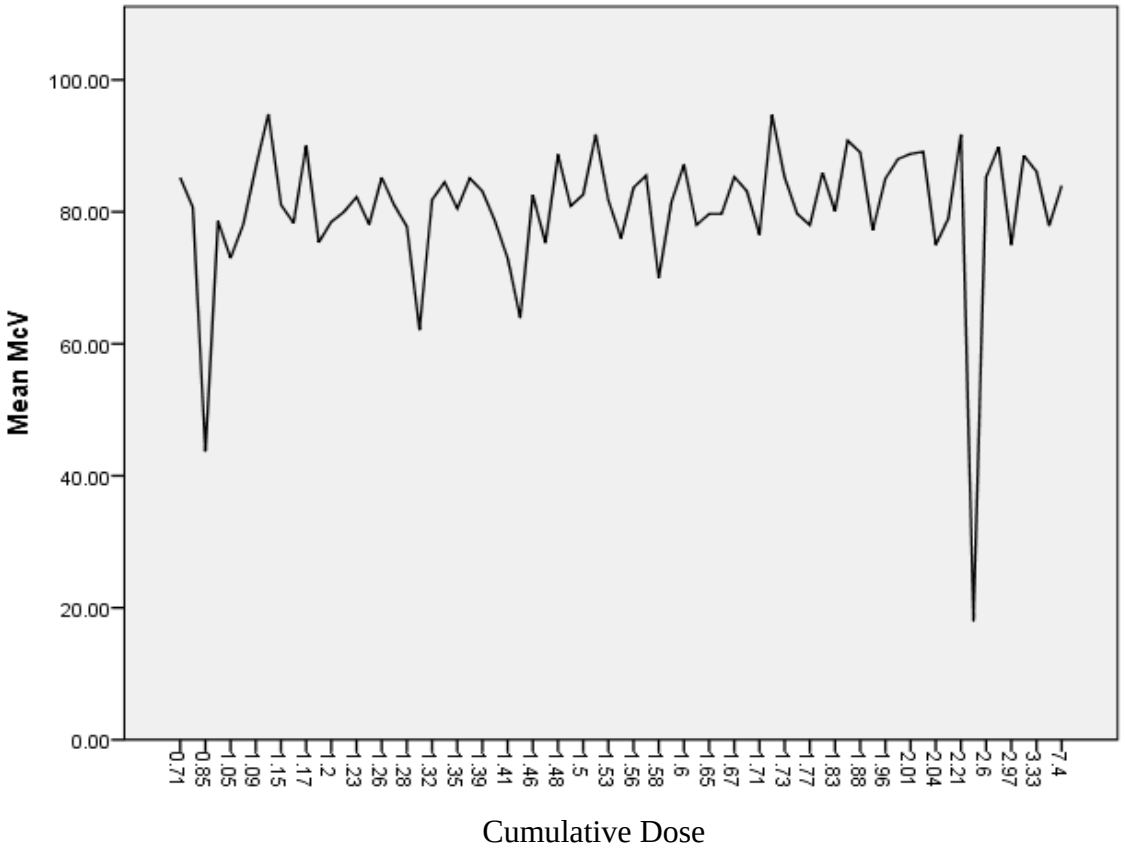


Fig. 4.12: The relationship between cumulative dose absorbed by the radiation workers and their McV.

Fig. 4.12 shows that the relationship between cumulative dose equivalent by the radiation workers and their McV is not a linear relationship

RESULT FOR HYPOTHESIS SIX

Table 4.7: Summary of the Results of Test of Hypothesis for Comparison of the Hematological Parameters of Male and Female Radiation Workers.

Statistic	WBC	RBC	PLT	Hb	HCT	MCV	MCH	MCHC	Lymphocytes
$\bar{X}_F$	5.3	4.97	230.09	12.45	38.01	79.71	28.17	33.72	40.31
s_M	1.225	1.12	71.069	2.448	5.867	12.645	3.532	2.017	10.507
df	4.98	4.99	224.7	12.06	35.25	82.02	28.89	34.35	36.6
s_f	1.906	1.27	94.57	1.71	4.675	6.269	2.588	1.56	12.322
$\bar{X}_M$	99	99	99	99	99	99	99	99	99
t-value	0.896	-0.063	0.296	0.952	2.575	-1.227	-1.162	-1.745	1.514
P-value	0.376	0.95	0.768	0.344	0.012	0.223	0.24	0.085	0.135
Remark	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**	**Sig.**	**Not sig.**	**Not sig.**	**Not sig.**	**Not sig.**

$\overline{X}_M$= Mean for male radiation workers,

$\mathcal{s}_M$= Standard deviation for male radiation workers,

$\overline{X}_F$= Mean for female radiation workers

$\mathcal{s}_f$ = Standard deviation for female radiation workers

df= Degree of freedom.

4.2 Discussion

Long term exposure to low-dose ionizing radiations may affect cells and tissues, which can lead to severe health effects (Amundson et al., 2003). Keeping in view with the impacts of exposure to ionizing radiation, the aim of this current study was to ascertain the impacts of low doses of ionizing radiation on the hematological parameters of Medical Professional radiation workers in South-East and South-South Nigeria. Assessment of the dose equivalent of each radiation professional and the results were compared to the recommended dose equivalent given by the International Commission on Radiological Protection (ICRP) of 20mSv. Evaluation of the Complete Blood count in medical practice is a necessary screening test in routine medical-check, a normal blood cell count is reassuring. However, high or low hematological parameters values even in a healthy participant may lead to suspicious of disease and it should trigger further investigation.

Table 4.1 shows that out of 101 radiation workers, the majority 70.3% (n=71) were medical radiographers, followed by radiologists 14.85 %(n= 15) and the least 1.98% (n=2) were medical physicists. Fig. 4.1 shows the numbers of the radiation professionals recruited for this research work. There are 15 radiologists, 71 Medical Radiographers, 13 Radiology Resident doctors and 2 Physicists.

The reason for the high number of Medical radiographers is due to the fact that in most of the hospitals and diagnostic centers, the medical radiographers are more involved in the production of the X-ray images which uses ionizing radiation while the doctors are more involved in the interpretation of the X-ray images. Table 4.1 shows the percentage distribution of the radiation workers.

Fig 4.2 above reveals the distribution of the different radiation workers from the various hospitals and diagnostic center involved in this study. It shows that all the hospitals and diagnostic center have medical radiographers, follow by the Radiologists that volunteer to participate are from 7 hospitals out of the 9 hospitals. Only two hospitals have Physicists (DELSUTH and FMC Asaba).

4.2.1: Hypothesis one: There is a significant mean difference between the standard Dose Equivalent And the dose Equivalent received by radiation workers

The results presented in Table 4.2 highlight a significant finding regarding the mean cumulative absorbed dose among radiation workers, specifically in relation to the standard values recommended by the International Commission on Radiological Protection (ICRP). The mean cumulative radiation dose equivalent for x-ray exposure, with a value of 1.67 mSv/year, was compared to the ICRP's standard value of 20 mSv/year. The obtained p-value of 0.00, which is less than the conventional significance level of 0.05, indicates a statistically significant mean difference between the radiation dose equivalent received by the radiation workers and the ICRP standard ($t = -234.6$, $p = 0.00$) (Table 4.2).

This notable difference suggests that the mean cumulative radiation dose equivalent experienced by the radiation workers is significantly below the established standard set by the ICRP. Such a substantial variance prompts a closer examination of the occupational exposure levels and the protective measures in place. It is crucial to consider factors such as the nature of the work environment, safety protocols, and individual compliance with radiation protection guidelines.

4.2.2: Hypothesis two: There were statistical significant mean difference between the blood parameters of radiation workers (BPRW) and standard full blood count limits (SFBCL).

Table 4.3 shows a comparison of hematological parameters (blood cell counts) between radiation workers (BPRW) and standard reference limits (SFRCL) represented by the mid-point values of lower and upper limits. The mean values for White Blood Cells (WBC), Red Blood Cells (RBC), and Mean Corpuscular Volume (MCV) were all statistically lower in radiation workers compared to the SFBCL mid-point ($p < 0.001$). This finding aligns with some studies suggesting a potential decrease in these cell types due to low-dose radiation exposure (Güngördü et al., 2023; Dimitar, & Gordana, 2018). Platelet count in radiation workers (BPRW = 228.22) was higher than the SFBCL mid-point (200×10^9) but not statistically significant ($p = 0.001$). This indicates platelet levels remained within the reference range, although some studies report conflicting results on platelet counts following radiation exposure (Vaziri et al., 2022; Omita et al., 2021).

4.2.3 Hypothesis Three: There were statistical significant the blood parameters of radiation workers and non-radiation workers

The mean values for some of the blood parameters for radiation workers (RW) and non-radiation workers (NRW) at Delta State University Teaching Hospital (DSUTH) are WBC (RW= 6.41 and NRW = 6.41), RBC (RW= 5.47 and NRW = 5.47), Platelets (RW= 240.28 and NRW = 250.75) and MCV (RW= 81.04 and NRW = 82.28). There were no statistically significant mean differences in the blood parameters of RW and NRW in DSUTH of the following parameters; WBC (t= 0.00, df= 30, p=1.00), RBC (t=0.00, df = 30, p =1.00), Platelet (t = 0.01, df = 30, p= 0.992) and MCV (t= -0.5, df =30 and p =0.62) (Table 4.4). The results from DSUTH shows that there is proper radiation protection practices among the radiation workers and the hospital have a medical Physicist who is the Radiation safety Officer. The ionizing radiation room have their x-ray sources more than 2 m from the control room where the radiation workers take the x-ray exposures from.

At Federal Medical Centre (FMC) Asaba, the mean values of the blood parameters for RW and NRW are WBC (RW= 4.67 and NRW = 5.94), the p-value is 0.02 which mean there is significant difference between the mid-point value of WBC 7.00 and the value of RW and NRW, RBC (RW= 5.91 and NRW = 5.46), Platelets (RW = 295.29 and NRW = 193.86), Hb (RW= 12.7 and NRW = 14.3) and MCV (RW= 68.04 and NRW = 80.61). There are no statistically significant mean differences between blood parameters of RW and NRW at RBC (t=0.612, df =10, p= 0.56), Hb (t= -2.02, df= 10, p=0.06) and MCV (t=-1.354, df = 10, p= 0.22). There were statistically significant mean differences in the blood parameters of RW and NRW at WBC (t= -2.779, df = 10, p= 0.02), the low WBC of 4.67 of the RW implies leukopenia and this leads to weak immune system among some of the RW as a result of exposure to radiation platelets (t= 3.497, df =10, p= 0.01) and HCT (t= -2.865, df=10, p = 0.01) , low HCT for RW in FMC Asaba implies anemia (Table 4.4). This effects on the WBC and HCT could be as a result of radiation workers work with a lot x-rays equipment like fluoroscopy, conventional x-ray, and computed tomography machine and the number of RW is low compare to the number of patients seen daily from the information filled in the questionnaire, average of 90-100 patients daily.

The results at FMC/FUTH Owerri revealed mean values of WBC (RW= 5.02 and NRW = 6.47), RBC (RW= 4.34 and NRW = 5.58), Platelets (RW = 194.9 and NRW = 232.6) and MCV (RW= 83.45 and NRW= 85.45). At FMC/FUTH Owerri, some parameters such as WBC(t= -2.662, df= 38, p= 0.01), RBC(t= -3.5, df=38, p=0.002) and Platelets (t= -2.578, df=38, p

=0.015) of RW and NRW, shows statistically significant mean differences while the other parameters shows non-statistically significant mean differences; Hb(t=-1.092, df=38, p= 0.283), MCV (t= -1.16, df= 38, p= 02.53) and lymphocytes (t= -1.006, df= 38, p= 0.322). Low values of WBC, RBC and Platelet in RW could mean leukopenia, anemia and thrombocytopenia and these have linear relationship with radiation and cancer. The lower values for RW than those of the NRW could be as a result of the effects of ionizing radiation on the blood parameter of RW.

In FMC Umuahia, the result shows that two parameters which are lower for the RW than for the NRW are WBC (RW=5.80 and NRW=7.56) and RBC (RW=3.9 and NRW=5.63). The implications of these are leukopenia and Anemia.

For Image Diagnostic Centre, only the Hb is lower for RW and the implication is lower oxygen carrying capacity in the blood of the RW.

National Orthopedic Hospital, the RW have the WBC and Platelet lower than that of the NRW. WBC (RW=4.98 and NRW= 8.14) and PL (RW=167.50 and NRW=216.33), implications are leucopenia and thrombocytopenia for the RW.

In NDUTH, the blood parameter affected is the platelets with higher value for RW more than that of the NRW. PL (RW=366.00 and NRW= 234.40) . The mean value of Platelet for RW is higher that the upper limit and a high plantlet value implies Thrombocythemia which can lead to blood clot and blockage in the blood vessels

At University of Port Harcourt Teaching Hospital(UPTH), the mean values of the blood parameters for RW and NRW are; WBC(RW= 4.84 and NRW = 5.30), RBC (RW= 5.44 and NRW = 4.94) and MCV (RW = 80.92 and NRW = 77.66)(Table 4.4). Some blood parameters of the participants showed non-statistically significant mean differences in RW and NRW at WBC (t=-1.31, df= 34, p= 0.19), RBC (t= 1.525, df= 34, p = 0.137) and MCV (t= 1.165, df= 34, p = 0.253) (Table 4.4). The only parameter that is lower than the mid-point value is MCHC and the implication is iron deficiency which could lead to anemia.

4.2.4 Hypothesis Four: There were statistical different in the radiation effects on the blood parameters of radiation workers across the hospitals

The analysis of variance (ANOVA) results revealed that there were statistically significant different in the radiation effects on the blood parameters such as WBC (F= 2.326, p = 0.025), RBC (F = 3.969, p= 0.000), Platelets (F=6.060, p = 0.000), MCH (F=4.898, p = 0.000), HCT

(F=4.060, p = 0.000) and MCHC (F=5.377, p =0.000). There were no statistically significant different in the effect of radiations on Hb (F=1.690, p=0.111) and MCV (F=1.502, p = 0.167) (Table 4.5).

4.2.5 Hypothesis Five: There is significant relationship between the cumulative radiation dose absorbed by the radiation workers and their blood parameters.

The results revealed that the blood parameters MCH (a:r= 26.10, p = 0.000, b:r=0.852, p = 0.038) and MCHC(a:r= 32.94, p = 0.000, b:r=0.597, p = 0.012) showed statistically significant relationships between the cumulative radiation dose taken by the radiation workers and the blood parameters while other parameters such as WBC(a:r= 5.548, p= 0.000, b:r=-0.214, p= 0.263), RBC(a:r= 5.109, p= 0.000, b:r= -0.080, p= 0.59) and Hb(a:r=12.385, p=0.000, b:r=-0.041,p=0.886) showed no statistically significant relationships the regression coefficient b (Table 4.6). Implication of low MCH and MCHC can result in iron deficiency and anemia. This could also be as a result of the longer hours spent by the radiation workers in the radiation environment.

4.2.6 Hypothesis Six: There is significant difference in the hematological parameters of male and female radiation workers.

In Table 4.7, the mean and standard deviation values for selected hematological parameters among male and female radiation workers are presented as follows: for males (WBC = 5.30 ± 1.225, RBC = 4.97 ± 1.12, Platelets = 230.09 ± 71.069, Hb = 12.45 ± 2.448, and MCV = 79.71 ± 12.645) and females (WBC = 4.98 ± 1.906, RBC = 4.99 ± 1.270, Platelets = 224.70 ± 94.570, and MCV = 82.02 ± 6.269). Statistical analyses indicated no significant mean differences in blood parameters between male and female radiation workers (WBC: t = 0.896, df = 99, p = 0.376; RBC: t = 0.063, df = 99, p = 0.950; Platelets: t = 0.296, df = 99, p = 0.768; MCV: t = 1.227, df = 99, p = 0.223) (Table 4.7).

This study further identified that the mean annual cumulative radiation dose for the radiation workers is 1.67 mSv, significantly below the 20 mSv recommended by the International Commission on Radiological Protection. Additionally, a majority of the radiation workers reported work experience exceeding five years. These findings align with similar studies conducted by Heydarheydari et al. (2016), Nassef & Kinsara (2017), Langa et al. (2020), Sani

et al. (2020), and Bouchareb et al. (2021), all of which reported lower annual cumulative radiation doses among radiation workers compared to the recommended values set by the International Commission on Radiological Protection.

This study compared the blood cell counts (parameters) of radiation workers with standard reference limits (lower, upper limits, and mid-point). The results showed statistically significant differences ($p < 0.05$) in at least two out of the three limits for each parameter. This suggests that radiation exposure may lower blood cell counts in radiation workers. These findings align with previous research by Davoudi et al. (2012), Heydarheydari et al. (2016), Surniyantoro et al. (2019). All these studies reported a decrease in blood cell counts due to ionizing radiation exposure. However, some studies like Caciari et al. (2014) and Bosswell et al. (2014), found either an increase in blood cell counts or no significant changes compared to reference limits in radiation workers. These discrepancies might be due to differences in sample size across the various studies.

This study found that in DELSUTH and FMC Yenagoa, there were no significant difference between the blood parameters of radiation workers and non-radiation workers. This finding is in consonant with the findings of the studies conducted by Meoos (2004); Waggiallah, (2013); Alnahhal et al (2017). In FMC Asaba and National Orthopedic Hospital, Enugu, there was no significant difference in the blood parameters of radiation workers and non-radiation workers with the exception of the WBC counts which is lower in radiation workers when compared to the non-radiation workers. These findings are in agreement with finding of the studies conducted by Caciari et al (2012) and Mohammed et al (2014). In FMC/FUTH Owerri and FMC Umuahia there is significant difference in the WBC, RBC and PLT between radiation professional and non-radiation worker. This result agrees with results of the studies carried out by Caciari et al (2012); Seco et al (2014) and Sabagh and Chapararian (2019). The results at NDUTH and UPTH show that almost all the blood parameters, there were no significant difference with the exception of the Platelets of radiation workers and non-radiation workers, This finding is with keeping with the findings of the studies carried out by Meos (2004); Ryu et al., (2013) and Shahid et al., (2014).

Chapter five

Conclusion and Recommendation

5.1 Conclusion

The findings of this study suggest that while the average annual effective radiation dose remained below the limits recommended by the International Commission on Radiological Protection, there is evidence indicating that low ionizing radiation exposures may still influence certain hematological parameters among radiation workers. Despite this observation, there exists no definitive threshold for the onset of biological alterations resulting from exposure to low doses of radiation. Consequently, despite advancements in diagnostic technology and the implementation of safety measures, professionals remain susceptible to radiation exposure from sources emitting low doses.

It is evident that low-dose ionizing radiation can impact the hematological and immunological systems of medical radiation professionals. As such, continued vigilance and adherence to radiation safety protocols are imperative to minimize occupational exposure risks and safeguard the health and well-being of healthcare workers. Further research is warranted to better understand the long-term effects of low-dose radiation exposure and to inform more effective protective measures for those working in radiation-intensive environments.

5.2 Recommendations

Recommendations for maintaining the health of radiation professionals while working with ionizing radiation include:

I. Ensure continuous health and safety protection for radiation employees before, during, and after work.

II. Prioritize the use of personal protective equipment in radiation-exposed workplaces.

III. Regularly audit personal protective equipment for medical radiation workers to ensure effectiveness in reducing occupational risks related to ionizing radiation.

IV. Implement yearly periodic medical surveillance for radiation employees to assess their health conditions regularly, mitigating the effects of occupational hazards and identifying diseases in their early stages.

V. Adhere to the International Commission on Radiological Protection (ICRP) guidelines, monitoring individuals with yearly exposure surpassing 6 mSv and ensuring exposure does not exceed 50 mSv in any one year, with a maximum of 20 mSv per year over five years.

VI. Provide Thermoluminescent Dosimeter (TLD) badges and maintain regular records of TLD readings for occupational radiation workers to monitor annual effective average exposure.

VII. Conduct cohort studies for a better understanding of the consequences of ionizing radiation.

VIII. Encourage genetic studies, particularly in regions with limited research, such as Nigeria, to enhance our understanding of the effects of ionizing radiation.

IX. Utilize cytogenetic tests, such as the dicentric assay, as a gold-standard method for radiation workers with abnormal hematological parameters identified through complete blood counts.

X. Emphasize the importance of radiation safety awareness in the workplace, encouraging accurate assessments of potential exposure not solely based on perceived radiation danger.

XI. Recommend future studies with larger sample sizes and the inclusion of various independent variables (genetic polymorphism, chromosome aberration, micronuclei frequency) to investigate the long-term effects of low-dose radiation exposure in workers.

5.3 Contribution to Knowledge

This novel research work has made the following contributions to Knowledge

1. The effects of low-dose ionizing radiation have not been studied in Nigerian publications, nor has the absorbed dose of radiation workers been quantified, therefore it will give a data base for the radiation professionals from the study area.

2. The results of the Thermoluminence dosimeter from this study will help the individual radiation worker to know their absorbed dose of radiation as some of the radiation workers have never been monitored.
3. Radiation workers now know their health status in relation to the effects of ionizing radiation on their hematological parameters.
4. This research work has added value to knowledge of some the management of these health institutions as some of the recommendations to them have been implemented.
5. The radiation workers in these health institution have acquired knowledge in areas related to radiation protection as some of them were carefree of the effects ionizing radiation by not using the radiation protective equipment but now their compliance levels have improved from the feedbacks received from their Heads of Department.
6. The result of this study will assist the management of these health institutions where the radiation workers works to plan for proper radiation protection monitoring procedures as they now know the importance radiation monitoring.
7. This study will help the management of the health institution and the regulatory bodies see the importance of biological Dosimetry to be introduce into the monitoring surveillance of the radiation professionals from the feedback received so far.
8. This research will give other researchers areas for further study like the Cytogenic test for Radiation worker with higher or lower blood parameter values.

REFERENCE

Aborisade**,** C.A. (2021). Radiological Implications of Radiation Dose Distribution in Pediatric Patients Undergoing Diagnostic X-Ray Examination in Some Nigerian Teaching Hospitals. *International Journal of Engineering Research & Technology* 10 (2), 444-450

Aborisade**,** C.A., Famurewa, O.C., Ibitoye, F.I & Balogun, F.A. (2019). Organ Dose Distribution and Estimated Cancer Risk to Pediatric Patients Undergoing Computed Tomography in a Nigerian Tertiary Hospital. *Journal of Advances in Medicine and Medical Research*, 29, (7), 1-9.

Abdolmaleki, A., Sanginabadi, F., Rajabi, A., & Saberi, R. (2012). The Effect of Electromagnetic Waves Exposure on Blood Parameters. *International Journal of Hematology-Oncology and Stem Cell Research*, *6*, (2), 13–16.

Adhikari, S. R. (2013). Effect and Application of Ionization Radiation (X-Ray) In Living Organism. *Himalayan Physics*, 3, (3), 89–92. https://doi.org/10.3126/hj.v3i0.7315

Akpochafor, M.O., Omojola, A.D., Adeneye, S.O., Aweda, M.A & Ajayi, H.B. (2016). Determination of reference dose levels among selected X-ray centers in Lagos State, South-West Nigeria. J Clin Sci, 13(4), 167-72.

Al-Abdulsalam, A., & Brindhabam, A. (2014). Occupational Radiation Exposure among the Staff of Department of Nuclear Medicine and Diagnostic Radiology in Kuwait. *Med. Princ Pract*, 23, (2), 129-133. Doi: 10.1159/000357123

Alnahhal, M., Alajeramy, Y., Mostafa, S. A., Shab, K. A., Jaber, S., & Najim, A. (2017). Assessment of Hematological parameters among medical radiographers at governmental Hospitals, Gaza strip. *Am J Med Sci*, *7*(6), 238-241

Alaydrus, M.A., Julianto, G.E., Yusbud, M., Hanafi, H.L., Harjanto, M., & Sumaningrum, N.D. (2015).Exposure Toward Lymphocytes of Radiographers in ABCD Hospital of Mataram. Town 2014. *IRJES*. 2015; 4(1): 35-41

Amundson, S.A., Lee, R.A., Koch-Paiz, C.A., Bittner, M.L., Meltzer, P., Trent, J.M., & Fornance, A.J. (2003). Differential Responses of Stress Genes to Low Dose-Rate γ Irradiation. *Mol Cancer Res,* 1 (6): 445–452.

Aya, M. H. A. (2018). New Trend in Radiation Dosimeters. *American Journal of Modern Physics*. 7(1), 21-30. Doi: 10.11648/j.ajmp.20180701.13

Banik, S., Bandyopadhyay, S., & Ganguly, S. (2003). Bio effects of microwave- A brief review [PubMed] [Google Scholar]. *Bioresource Technology*, *87*(2), 155–159. https://doi.org/10.1016/S0960-8524(02)00169-4 PMID: 12765354

Bappah, S.Y., Umar, I., Samson, D.Y., Abduhali, A.M., Mustapha, M.I., Habib, S., Anas, M. Reuben, J.S. (2019). Performance Evaluation of Thermoluminence Dosimeters in Personnel in-vivo Dosimetry. *Journal of Pure & Appl. Sci.,* 5(2a) 195-203.

Bashore T. (2001) Fundamentals of X-ray imaging and radiation safety. *Catheter Cardiovasc Interv*, 54:126–35. doi.org/10.1002/ccd.1250. PubMed PMID: 11553961. [PubMed] [Google Scholar]

Behjati, S., Gundem, G., Wedge, D. C., Roberts, N. D., Tarpey, P. S., Cooke, S. L., Van Loo, P., Alexandrov, L. B., Ramakrishna, M., Davies, H., Nik-Zainal, S., Hardy, C., Latimer, C., Raine, K. M., Stebbings, L., Menzies, A., Jones, D., Shepherd, R., Butler, A. P., Teague, J. W., Campbell, P. J. (2016). Mutational signatures of ionizing radiation in Second Malignancies. *Nature Communications*, (7), 1-8 https://doi.org/10.1038/ncomms12605

Bichsel, H., Schindler, H. (2020). The Interaction of Radiation with Matter. In: Fabjan, C., C., Schopper, H. (2nd Ed) Particle Physics Reference Library. Springer, Cham. https://doi.org/10.1007/978-3-030-35318-6_2

Boswell, S. G., Schnabel, L. V., Mohammed, H. O., Sundman, E. A., Minas, T., & Fortier, L. A. (2014). Increasing platelet concentrations in leukocyte-reduced platelet-rich plasma

decrease collagen gene synthesis in tendons. *The American journal of sports medicine*, *42*(1), 42-49.

Briggs-Kamara, M.A., Okoye, P.C & Omubo-Ppple, V.B. (2013). Radiation Safety Awareness among Patients and Radiographers in three Hospitals in Port Harcourt. *American Journal Scientific & Industrial Research,* 4, (1), 83-88

Berkeley, L. (2000). Radiation at low doses: Guide to the nuclear wall chart. National Laboratory, US Department of Energy. 17 (1): 105. http://www.lbl.gov/abc/wallchart/chapters/appendix/appendixf.html

Bouchareb, Y., Maimani, N., Maskery, I., Zeheimi, H., Rasbi, A., Dhuhli, H., Makhmari, N & Haji, A. (2021). Assessment of Occupational Radiation Doses in Different Diagnostic, Interventional and Therapeutic Radiology and Molecular Imaging Services in Oman. *Rad.Protection. Dosimetry*, 197, 1:36-45

Caciari, T., Capozella, A., Tomei, F., Nieto, H.A., Gioffre, P.A., & Valentini, V. (2012). Professional Exposure to Ionizing Radiation in Health Workers and White Blood Cells. *Ann Lg,* 24 (6), 465-474

Caciari, T., Casale, T., Loreti, B., Schifano, M. P., Capozzella, A., Scala, B., & Tomei, F. (2014). Peripheral blood counts in workers exposed to synthetic fibres. *Journal of Environmental Science and Health, Part A, 49*(2), 146-152.

Calabrese E.J., Dhawan, G., & Kapoor, R. (2014). Use of X-rays to treat shoulder/bursitis: a historical assessment. *Arch Toxicol*, 88, (8), 1503–1517. doi.org/10.1007/s00204-014-1295-6. PubMed PMID: 24954447. [PubMed] [Google Scholar]

Cengiz, M., Gurkaynak, M., Vural, H., Aksoy, N., Cengiz, B., Yildiz, F., & Atahan, I.L. (2003) (2003).Tissue trace element change after total body irradiation. *Nephron. Experimental nephrology*, *94*(1), 12–16. https://doi.org/10.1159/000070814

Changizi, V., Alizadeh, M. H., & Mousavi, A. (2015). A study of professional radiation Hazards in CT scan and nuclear medicine workers using GTG-banding and solid stain. *Medical journal of the Islamic Republic of Iran*, (29), 200. 1-7

Christensen, D.M., Iddins, C.J., Sugarman, S.L. (February 2014). "Ionizing radiation injuries And illnesses". *Emergency Medicine Clinics of North America.* 32 (1): 245–65. doi:10.1016/j.emc.2013.10.002. PMID 24275177

Clarke, C. (2011). Production of X-rays. FRCR Physics Notes/ X-ray imaging. *Radiology café* 2011-2023. https://www.radiologycafe.com

Covens, P., Berus, D., Buls N., Clerinx, P. & Vanhavere, F. (2007). Personal dose monitoring In Hospitals: Global Assessment, Critical Application and Future needs. *Journal of Radiat Protection and Dosimetry,* 124(3), 250 – 259. https://www.researchgate.net/publication/339943708_Performance_Evaluation_of_Thermolumniscence_Dosimeters_in_Personnel_in-Vivo_Dosimetry#fullTextFileContent

Davioudi, M., Keikhaei, B & Mortezatahmasebi, R.F. (2012). Hematological Profile Change In Radiation Field Workers. *Apadama Journal of Clinical Research.* (1).38-44

Davoudian T. A., farzanegan, Z., & Mahmoudi, F. (2018). Effects of Occupational Exposure on Blood Cells of Radiographers Working in Diagnostic Radiology Department of Khuzestan Province. *Iranian Journal of Medical Physics, 15*(2), 66-70. doi: 10.22038/ijmp.2018.26692.1273

Dimitar, D., & Gordana, S. (2018). Haematological profile of healthy workers exposed to low dose radiation. *Age*, *21*(30), 31-40.

Erdal, N., Gürgül, S., & Celik, A. (2007). Cytogenetic effects of extremely low frequency magnetic field on Wistar rat bone marrow. [PubMed] [Google Scholar]. *Mutation Research, 630* (1-2), 69–77. https://doi.org/10.1016/j.mrgentox.2007.03.001 PMID: 17452120

Eze, C. U., Abonyi, L. C., Njoku, J, Irurhe, N. K, & Olowu, O. (2013). Assessment of Radiation Protection practices among radiographers in Lagos, Nigeria. *Nigerian medical journal of the Nigerian Medical Association, 54*(6), 386-391. https://doi.org/10.4103/0300-1652.126290

Feinendegen, L.E., Brooks, A.L., & Morgan, W.F., (2011). Biological consequences and Health risks of low-level exposure to ionizing radiation: commentary on the workshop. *Health Phys*, (100)247–59. doi.org/10.1097/HP.0b013e31820a83ae. PubMed PMID: 21285724.

Furetta, C., & Weng, P. S. (1997).Operational Thermoluninescene Dosimetry, *World Scientific Singapore*, 3(1-2), 22-28

Garzón, W.J., Khoury, H., Ovalle, S.A.M., & Medeiros, R.B. (2019).Performance of the Instadose^{tm} Dosemeter for Interventional Radiology and Cardiology Application. *Radiation Protection Dosimetry*, 183(4): 522-528. https://doi.org/10.1093/rpd/ncy172

Ginjaume, M. (2011).Performance and approval procedures for active personal Dosimeter. *Radiation Protection Dosimetry*, 144 (1-4) 144-149. https://doi.org/10.1093/rpd/ncq457

Guan, J., Stewart, J., Ware J.H, Zhou, Z., Donahue, J.J., & Kennedy, A.R. (2006). Effects of Dietary supplements on the space radiation-induced reduction in total antioxidant status in CBA mice. *Radiat Res*, 165,(4),373-378. Doi. org/10.1667/RR3523.1. PubMed PMID: 16579649.

Güngördü, N., Kurtul, S., Özdil, A., & Erdoğan, M. S. (2023). Does occupational ionizing radiation exposure in healthcare workers affect their hematological parameters? *Archives of Environmental & Occupational Health*, 78(2), 80-87. https://doi.org/10.1080/19338244.2022.2089088

Hani, A. A., Del, S. A., Meteb, N. A., Faisal A. A., Mohammed, A. T & Esam A. J,(2019). ''Occupational Radiation Dose for Medical Workers in Diagnostic Radiology and Nuclear Medicine in Makkah Hospital". *Pharmacophore*, 10(6): 62-73.

Hong, J. Y., Han, K., Jung, J. H., & Kim, J. S. (2019). Association of Exposure to Diagnostic Low-Dose Ionizing Radiation with Risk of Cancer among Youths in South Korea. *JAMA Network open*, *2*(9), e1910584. https://doi.org/10.1001/jamanetworkopen.2019.10584

Heydarheydari, S., Sadeghi, S., Almasi, A., Sohrabi, N. (2012). Evaluation of the Effects of Ionizing Radiation Worker's Blood Parameters of Kermanshah Hospitals. *J Clin Res Paramed Sci*., 1(3):e82194

Heydarheydari, S., Haghparast, A., & Eivazi, M. T. (2016). A Novel Biological Dosimetry Method for Monitoring Occupational Radiation Exposure in Diagnostic and Therapeutic Wards: From Radiation to Biological Effects. *Journal of biological Physics & engineering*, 6(1), 21-26

International Commission on Radiological Protection (ICRP) (2007). Draft: Recommendation of the International Commission on Radiological Protection, Sweden.

Izewska, J. & Rajan, G. (2012). Radiation dosimeters. Chapter 3. Dosimetry and Medical Radiation Physics. http://www.naweb.iaea.org/nahu/dmrp/pdf_files/Chapter3.

Izadi-moud, A., Izanloo, A., Vogdanparast, M., Shirvan, G.N., & Eshraghi, A. (2019).

Investigating the Effect of Ionizing Radiation on Hematological Parameters of Catheterization Laboratory Technicians: Multilayer Perceptron Modeling. *Ann Med Health Sci Res*, (9), 684-687

Jang, S., Lee, J.K., Cho, M., Yang, S.S., Kim, S.K., & Kim, W.T. (2016). Consecutive results of blood cell count and retrospective biodosimetry: useful tools of health protection regulation for radiation workers. *Occup Environ Med*, 73,(10) 694–700. Doi: 10.1136/oemed-2016-103775

Kopjar, N., & Garaj-Vrhovac V. (2005). Assessment of DNA damage in nuclear medicine personnel--comparative study with the alkaline comet assay and the chromosome aberration test. *Int J Hyg Environ Health*, 208, (3), 179–191. doi.org/10.1016/j.ijheh.2005.01.027. PubMed PMID: 15971857.

Koguchi, Y., Yamamoto, T. & Maria R. (2010). Intercomparison of various Dosimetry System For routine individual monitoring, Dosimetry Oral presentations, 4(19), 835

Lamarsh, J.R., (1983). Introduction to Nuclear Reactor Theory, 2nd ed., Addison-Wesley, Reading MA

Land, C. (2007). Ionizing Radiation Encyclopedia Britannica. https://www.britannica.com/science/ionizing-radiation

Langa, E., Adamu, A., and Meludu, O. (2020). Occupational Radiation Dose Evaluation in University of Maiduguri Teaching Hospital, Maiduguri, Nigeria. *J.Rad. Nucl. Appl.*5 (3), 181-186

Linet, M. S., Kim, K. P., Miller, D. L., Kleinerman, R. A., Simon, S. L., & De Gonzalez, A. B. (2010). Historical review of occupational exposures and cancer risks in medical radiation workers. *Radiation research*, *174*(6b), 793-808.

Liu, N., Peng, Y., Zhong, X., Ma, Z., He, S., Li, Y., Zhang, W., Gong, Z., & Yao, Z. (2021). Effects of exposure to low-dose ionizing radiation on changing platelets: a prospective cohort study. *Environmental health and preventive medicine*, *26*(1), 14-19 https://doi.org/10.1186/s12199-021-00939-z

Leyton, F., Canevaro, L., Dourado. A., Castello, H., Bacelar, A., Navarro, M. T., & Lykawka, R. (2014). Radiation risks and the importance of radiological protection in interventional cardiology: a systematic review. Revista Brasileira de Cardiologia Invasiva (English edition), 87-98.

Lumniczky, K., Impens, N., Armengol, G., Candéias, S., Georgakilas, A.G., Hornhardt, S., Martin, O.A., Rödel, F., & Schaue, D. (2021). Low dose ionizing radiation effects on t the immune system. *Environment international*, *149*, 1-22 https://doi.org/10.1016/j.envint.2020.106212

Lummis, S. (2013). Personal Radiation Monitoring System Inefficiencies: A Comparison in Service Provision. In Proceedings of the 2013 Conference of the ACPSEM, Pan Pacific Hotel Perth, 2013, 226

Maqsudur, R., Latha, R., Arwa, J., Naima, M & Hanna, M. (2018). Low Dose Radiation, Inflammation, Cancer and Chemoprevention. *International Journal of Radiation Biology*, 95.(6) 1-35. 10.1080/09553002.2018.1484194

Meo, S.A. (2004a). Hematological Findings in Male X-ray Technicians. *Saudi Medical Journal*, 2 25 (7): 852 – 858

Meo, S.A. (2004b). Phagocytic Functions of Polymorph nuclear Neutrophils in Dental X-Ray Technicians. *Pakistan Oral & Dent. Jr.* 24 (1):105-109

Miron (2018).Instadose Dosimeter, Instant, Precise, Portable. Accessed on 8th October, 2018 from http://www.miron.com

Mirion Technologies (2014). Instadose Dosimeter, Instant. Precise, Portable. Copyright (c)

2014 Mirion Technologies, Inc. or its affiliates. Avenue, Irvine, CA 92614, USA, dsdsupport@mirion.com. LIT4386_5v1.

Mohammed, M.R., Abdulateef, S.M., Dawood, N.A., Taher, M.G., Jabur, S.A., & Alwairi, A A.H. (2014). Effects of radiation on the hematological parameters in X-ray technicians: a case control study. *J Pioneer Med Sci.*; 4(2), 85-88

Nabil, M. H., Mansour, N.A., Talaat, S., & Saher, G. (2020). Comparison of Thermoluninescene Dosimeter's Response to Neutron and Gamma in a Mixed Radiation Field. *Arab J. Nucl. Sci. Appl*, 53, (1), 149-155
DOI: 10.21608/ajnsa.2019.11356.1198

Nassef, M.H., & Kinsara, A.A. (2017). Occupational Radiation Dose for Medical Workers at a University Hospital. *Journal of Taibah University for Sci.* 10,(6), 62-73 doi.org/10.1016/j.jtusci.2017.01.003

Niels, B., & Erwin, S. (2022). The Concept of Energy Level and Aufbau Order. Wondrium Daily Lecture series.

Nwaigwe C.C. (2020). "Test of Hypothesis" in Introduction to Statistics and Probability STA 211 Manual, Hephzibah Press, Owerri, Imo State

Nwodo, V., Chiaghanam, N., Ogolodom, M.P., Ohagwu, C., Nwodo, C., Agbadaola. , O., Mbaba, A., Ezenma, I., & Abubakar, U. (2020). Assessment of Knowledge and Awareness of Radiation Hazards and Protection among Patient's Relative in Southeast, Nigeria. *Journal of Clinical and Diagnostic Research.*14,(8),10-13 10.7860/JCDR/2020/44841.13914

Okoye, I. (2021, February 06). How to Reduce Cancer Cases, Deaths in Nigeria. *The Guardian Newspaper*

Onojo, R.A., Idoko, E.E., Onojo, R.O., & Ageda, V.I., (2017). Evaluation of Radiation

Exposure Level from the use of Diagnostic Facilities at the Ahmadu Bello University Teaching Hospital, Zaria- Nigeria. International Journal on Medical Sciences. 5(1), 001-007

Parkin, D.M., Boyd, L., Walker, L.C. (2011). The Fraction of Cancer Attributable to Lifestyle And Environmental Factors in the UK in 2010. *British Journal of Cancer*.105 (2), S77–81. Doi:10.1038/bjc.2011.489. PMC 3252065. PMID 22158327

Persson, L. (2000). Effects of low--dose ionizing radiation. Swedish Radiation Protection Institute: Stockholm. [Google Scholar].

Puthra, S.S., Sudha, K., Gayathri, M.R & Shetty, B.V. (2009). Oxidative Stress and Low Dose Ionizing Radiation. *Indian .J. Physio Pharmacol*, 53 (2),181-184

Raditya, F., Hafizah, C.H., and Regidor, III .D. (2019). Hematologic Parameters among Radiation Exposed Workers: An Observational Study. Open Access Journal of Nursing 2(2),29-41.

Rai, H. C. (2019). A brief history of the periodic table. Prowess Publishing.

Richardson, D. B., Cardis, E., Daniels, R. D., Gillies, M., Haylock, R., Leuraud, K., Laurier, D., Moissonnier, M., Schubauer-Berigan, M. K., Thierry-Chef, I., & Kesminiene, A. (2018). Site-specific Solid Cancer Mortality after Exposure to Ionizing Radiation: A Cohort Study of Workers (INWORKS). *Epidemiology Cambridge, Mass*, 29(1), 31-40. https://doi.org/10.1097/EDE.0000000000000761

Rivera, T. (2012, April 30). Applied Radiation and Isotopes.

Ropolo, M., Balia, C., Roggieri, P., Lodi V., Nucci, M.C., & Violante, F.S. (2012). The Micronucleus assay as a biological dosimeter in hospital workers exposed to low doses of ionizing radiation. *Mutat Res*.; 747:7–13. doi.org/10.1016/j.mrgentox.2012.02.014. PubMed PMID: 22525360. [PubMed]

Roobottom, C.A., Mitchell, G., & Morgan-Hughes, G. (2010). Radiation-Reduction Strategies in Cardiac Computed Tomographic Angiography. *Clinical Radiology*, 65 (11) 859-867

Ryu, J. K., Cho, S. M., Cho., J. H., Dong, K. R., Chung, W .K., & Lee, J. W.(2013). Survey on Low-dose Medical Radiation exposure in occupational workers: the effect on hematological Changes. Radiation Effects and Defects in Solids Incorporating Plasma Science and Plasma Technology. 168, (3), 228-246

Sacks, B., Meyerson, G., & Siegel, J. A. (2016). Epidemiology without Biology: False Paradigm Unfounded Assumptions, and Specious Statistics in Radiation Science (with Commentaries by Inge Schmitz-Feuerhake and Christopher Busby and a Reply by the Authors). *Biological theory*, *11*, 69–101. https://doi.org/10.1007/s13752-016-0244-4

Sabagh, M., & Chaparian, A. (2019). Evaluation of Blood Parameters of the Medical Radiation Workers. Iran J Med Phys, 16, (6) 439-443. 10.22038/ijmp.2019.37427.1477

Sani, U Muhammad, B.G., Skam, J.D & Zira, D. (2020). Evaluation of Occupational Radiation Exposure in a Radio-Diagnostic Facility in Katsina- Nigeria. *FUDMA Journal of Science*, 4 (2): 722-729. DOI: 10.33003/fjs-2020-0402-406

Seco, J., Clasie, B. & Partridge, M. (2014). Review on the characteristics of radiation Detectors for Dosimetry and imaging. Phys. Med. Biol. 59(20), 303-347. doi:10.1088/0031-9155/59/20/R303.

Seo, S., Lee, D., Seong, K. M., Park, S., Kim, S. G., Won, J. U., & Jin, Y. W. (2018). Radiation-related occupational cancer and its recognition criteria in South Korea. *Annals of occupational and environmental medicine*, *30*,(2) 9-15 https://doi.org/10.1186/s40557-018-0219-y

Shahid, S., Mahmood, N., Chaudhry, M.N., Sheikh, S., Ahmad, N. (2014). Assessment of

Impacts of Hematological Parameters of Chronic Ionizing Radiation Exposed Workers in Hospitals. FUUAST J. BIOL. 2014; 4(2), 135-146

Shore, R., Walsh, L., Azizova, T. and Rühm, W. (2017). "Risk of solid cancer in low Dos-rate radiation. Epidemiologic studies and the dose-rate effectiveness factor," Int. J. Radiat.Biol. 93(10), 1064-1078. doi:10.1080/09553002.2017.1319090

Shore, R. E., Beck, H. L., Boice Jr, J. D., Caffrey, E. A., Davis, S., Grogan, H. A., & Dauer, L. T. (2019). Recent epidemiologic studies and the linear no-threshold model for radiation protection—considerations regarding NCRP commentary 27. *Health physics*, *116*(2), 235-246.

Shrader-Frechette, K. (2007). Trimming Exposure Data, Putting Radiation Workers at Risk: Improving Disclosure and Consent through a National Radiation Dose-Registry. *Am J Public Health*, 97(10) 1782-1786

Singh, V.P., Managanvi, S.S., Bihari, R.R. & Bhat, H.R. (2013). Operational experience of Electronic active Personal Dosimeter and Comparison with CaSo4: Dy TL dosimeter in Indian PHWR. *Radiation Protection Dosimetry*, 156(1), 93–102.

Smith-Bindman, R., Lipson, J., Marcus, R., Kim, K. P., Mahesh, M., Gould, R., Berrington De González, A., & Miglioretti, D. L. (2009). Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of Cancer *Archives of internal medicine*, 169(22), 2078–2086.

Sowunmi, A., Alabi, A., Fatiregun, O., Olatunji, T., Okoro, U. S., & Etti, A. F. D. (2018). Trend of cancer incidence in an oncology center in Nigeria. *West African Journal of Radiology*, *25*(1), 52-56.

Sprawls, P. (1995). Interaction of Radiation with Matter. The Principles of Medical Imaging. (2nd Ed.) Aspen Publishers. Atlanta Georgia, The United State of America.

Spycher, B.D., Lupatsch, J.E., Zwahlen, M., Röösli, M., Niggli, F., Grotzer, M.A., Rischewski,

J., Egger M., & Kuehni, C.E .(2015). "Background ionizing radiation and the risk of childhood cancer: a census-based nationwide cohort study". *Environ. Health Perspect*. 123 (6):622-628

Doi: 10.1289/ehp.1408548. PMC 4455589. PMID 25707026

Sunta, C. M., Munish, K., & Kher, R. K. (2006) Proceedings of National Symposium on Luminescence and its Applications, 271.

Sultan A. Meoos. (2004) Hematological findings in male X- ray technicians. *Saudi Medical Journal* (7), 852- 856

Surniyantoro, H.N.E., Rahardjo, T., Lusiyanti, Y., Rahajeng, N., Sadewa, A.H., Hastuti, P., &. Date, H (2019). Assessment of Ionizing Radiation Effects on the Hematological Parameters of Radiation-Exposed Workers. *Atom Indonesia*, 45 (2) 123 – 129

Taqi, A. H., Faraj, K. A., & Zaynal, S. A. (2019). The Effect of Long-Term X-Ray Exposure on Human Lymphocyte. *Journal of biomedical physics & engineering*, *9*(1), 127–132.

Tavakoli, J., Miar, S., Majid Zadehzare, M., & Akbari, H. (2012). Evaluation of Effectiveness Of Herbal medication in cancer care: a review study. *Iranian journal of cancer prevention, 5*(3), 144–156.

Tawfeeq, G., Tawfeeq, R., Ommar, A., & Ali, S. (2021). Hematological changes after Röntgenray exposure in radiologic technologists. *Zanco Journal of Medical Sciences .Zanco J Med Sci*, *25*(2), 526-531. https://doi.org/10.15218/zjms.2021.016

Tian, X. L., Lu, X., Lyu, Y. M., Zhao, H., Liu, Q. J., & Tian, M. (2022). Analysis of Red Blood Cells and their Components in Medical Workers with Occupational Exposure to Low-Dose Ionizing Radiation. *Dose-response: a publication of International Hormesis Society*, *20*(1), 15593258221081373. https://doi.org/10.1177/15593258221081373

United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

Sources and Effects of Ionizing Radiation. Report to General Assembly, with Scientific Annexes; United Nations: New York, NY, USA, 2000

Vaiseman, A., Kaliad, A., Zabuga, O., & Socol, Y. (2018). Health Impacts of Low-Dose Ionizing Radiation: Current Scientific Debates and Regulatory Issues. *Dose Response*, 16(3), 35-40. Doi 1559325818796331

Vaziri, S., Mirzaei, M., Saba, F., Salehi Zahabi, K., Salehi Zahabi, S., & Arab-Zozani, M. (2022). Hematological parameters and X-ray exposure among medical radiation workers: a systematic review and meta-analysis. *Expert Review of Hematology*, *15*(7), 645-656.

Waggiallah, H.A. (2013). The effect of X-ray radiation on hematopoietic system of radiology Technologists. NJIRM, 4(2): 16-20

Walter, J., Miller, H., & Bomford, C.K. (1999), Biological Effects of Radiation. In: Short text Book of Radiotherapy. 4th edition. New York: Churchill Livingstone.

Weisstein, E.W. (2014). Radiation: Eric E\Weinstein's World of Physics. Wolfram Research. Retrieved 11 January 2014. https://en.m.wikipedia.org

Wejie-Okachi, C., Agi, C., & Douglas, K. (2019). Profile of Hematological Parameters a Radiographers Exposed to Low-Dose X-Rays in Selected Port Harcourt Healthcare Facilities. *Asian Journal of Biotechnology and Bioresource Technology*.

Wilson-Stawart, K., Shanahan, M., Fontanarosa, D., & Davidson, R. (2018). Occupational Radiation Exposure to Nursing Staff during Cardiovascular Fluoroscopic Procedures. A review of the Literature. *Journal of applied clinical medical physics*, 19(6), 282-297. AAPM

World Health Organization (WHO). (2020). what is ionizing radiation.

Radiation Protection Dosimetry, 197, (1), 36-45

https://doi.org/10.1093/rpd/ncab152

Yahaya, B. S., Ibrahim, U., A. Mundi, A., M. Idris, M., A. Bilya, M., Mohammed, A., &

Ali G., M. (2019). Comparative performance assessment of the most commonly used personnel radiation dosimeters in Nigeria. *EDUCATUM Journal of Science, Mathematics and Technology, 6(2), 35-44*
https://doi.org/10.37134/ejsmt.vol6.2.4.2019

Zakeri, F., Hirobe, T., & Noghabi, K.A. (2010). Biological effects of low-dose ionizing Radiation exposure on interventional cardiologists, *Occupational Medicine*, 60, (6):464–, 469.
https://doi.org/10.1093/occmed/kqq062

Zare, A., & Mortazavi, S. M. J. (2020). The Efficacy of Periodic Complete Blood Count Tests in Evaluation of the Health Status of Radiation Workers in Iran: A Systematic Review. *Iranian journal of public health*, 49(4), 628–636.

APPENDIX

APPENDIX A

The Number of Radiation Workers in the Different Health Institutions

Health Institutions	RADIOLOGISTS	RADIOGRAPHERS	RESIDENT DOCTORS	MEDICAL PHYSCISTS	TOTAL
DSUTH	5	5	5	1	16
FMC ASABA	1	4	1	1	7
FMC/FUTH OWERRI	1	17	2		20
FMC UMUAHIA		9			9
FMC YENAGOA	2	5			7
IMAGE DIAGNOSTIC CENTER		6	1		7
NOH	2	12			12
UPTH	2	12	4		18
NDUTH	2	3			5
TOTAL	15	71	13	2	101

APPENDIX B

RESULTS FOR HYPOTHESIS ONE

B1: Dose Equivalent for Radiation Workers from Federal Medical Center, Asaba. Delta State

CODE/RAD.WORKERS	SEX	1st&2nd Reading(mSv) Mean-for 6months	3rd&4th Reading(mSv) Mean-for 6months	Mean Dose(mSv)
001(Radiographer)	Female	1.3308	1.2698	1.2698
002(Med.Physicist)	Male	0.5627	0.6172	0.6172
003 Radiographer)	Male	0.4776	0.8373	0.8373
004 Radiographer)	Male	0.8018	0.7820	0.7820
005 (Resident Doc)	Male	0.8001	0.6135	0.6135
006 Radiographer)	Male	1.0750	0.6901	0.6901
007(Radiologist)	Male	0.7135	0.5120	0.5120

Mean Cumulative dose = 0.7603 mSv/y

B2: Dose Equivalent for Radiation Workers from Delta state University Teaching Hospital (DELSUTH) Oghara. Delta State

CODE	SEX	1st&2nd Reading(mSv) Mean-for 6months	3rd&4th Reading (mean-for 6months	Mean Dose(mSv)
001(Med. Physicist)	male	0.5328	0.7335	0.6332
002(Resident doc)	Female	0.7935	0.8232	0.8084
003(Radiographer	Female	0.8674	1.0039	0.9357
004(Radiographer)	Female	0.7713	1.3483	1.0598
005(Radiographer)	Female	0.6176	1.0638	0.8409
006(Resident Doc	Female	0.4780	0.9905	0.6991
007(Radiographer)	Male	01.0143	1.0039	1.0024
008(Radiologist)	Male	0.7273	0.6901	0.8656
009(Radiographer)	Male	1.0750	0.7832	0.8826
010(Radiologist)	Female	0.3059	0.9086	0.5446
011(Radiologist)	Male	0.6880	0.9086	0.7983
012(Resident Doc)	Male	0.5730	0.8802	0.7266
013(Resident Doc)	Male	0.4750	0.8702	0.6776
014(Radiologist)	Male	0.6440	0.8507	0.7474
015(Radiologist)	Male	0.6732	0.8548	0.7640
016(Resident Doc)	Male	1.8370	0.9503	1.3937

Mean Cumulative dose = $\frac{\sum \text{mean dose}}{n}$

Mean Cumulative dose = $\frac{13.3799}{}$ = 0 .8362 mSv/year

B3: Dose Equivalent for Radiation Workers from University of Port Harcourt Teaching Hospital, Port Harcourt, Rivers State

CODE	SEX	1st&2nd Reading(mSv) Mean-for 6months	3rd&4th Reading(mSv) Mean-for 6months	Mean dose(mSv)
001(Radiographer)	Female	1.0080	0.9020	0.9550
002(Radiographer)	Female	1.1028	0.8794	0.9911
003(Radiographer)	Female	0.4352	0.7242	0.5797
004 (Radiographer	Female	0.7087	0.1242	0.4165
005(Radiographer)	Female	1.1322	0.9568	1.0445
006(Resident Doc)	Female	0.6328	0.7791	0.7050
007(Radiographer)	Female	0.3059	0.8368	0.5714
008(Radiographer)	Male	1.8361	0.7839	1.3100
009(Resident Doc)	Male	0.6732	0.9071	0.7902
010(Radiologist)	Male	0.1372	0.8548	0.4960
011(Resident Doc)	Male	0.6880	0.5704	0.6292
012(Radiographer)	Male	0.7174	1.1086	0.9130
013(Radiologist)	Male	0.5729	1.0077	0.7903
014(Radiographer)	Male	2.4744	0.8702	1.6723
015(Radiologist)	Male	0.6044	0.8500	0.7272
016(Radiologist)	Male	0.0143	0.9905	0.5024
017(Radiologist	Male	0.5113	0.7839	0.6476
018(Resident Doc)	Male	0.7307	0.6184	0.6746

Mean Cumulative dose = 0.8184mSv/y

B4: Dose Equivalent for Radiation Workers from Niger Delta University Teaching Hospital, Okolobiri. Bayelsa State

CODE	SEX	1st&2nd Reading(mSv) Mean-for 6months	3rd&4th Reading(mSv) Mean-for 6months	Mean Dose(mSv)
001(Radiographer)	Female	0.7390	0.8978	0.8184
002(Radiographer)	Female	0.5944	0.7290	0.6617
003(Radiologist)	Male	0.5670	0.6925	0.6298
004(Radiographer)	Male	0.7426	1.0229	0.8828
005(Radiologist)	Male	0.5300	0.7090	0.6195

Mean Cumulative dose = 0.7224mSv/y

B5: Dose Equivalent for Radiation Workers from Image Diagnostic Center, Port Harcourt. Rivers State

CODE	SEX	1^{st}&2^{nd} Reading(mSv) Mean-for 6months	3^{rd}&4^{th} Reading (mean-for 6months	Mean Dose(mSv)
001(Radiographer)	Female	0.4782	0.9206	0.6994
002(Radiographer)	Female	0.6176	01.082	0.8498
003(Radiographer)	Male	0.7175	1.1638	0.9407
004(Radiographer)	Male	0.6044	0.8512	0.7278
005(Radiographer)	Male	0.5383	0.7335	0.6359
006(Resident Doc)	Male	0.5338	0.7005	0.6172
007(Radiographer)	Male	0.7034	1.0072	0.8553

Mean Cumulative dose = 0.7609mSv/year

B6: Dose Equivalent for Radiation Workers from Federal University Teaching Hospital/ FMC Owerri

CODE	SEX	1st&2nd Reading(mSv) Mean-for 6months	3rd&4th Reading (mean-for 6months	Mean Dose(mSv)
Radiologist	female	0.8743	0.6901	0.7822
Resident Doc	female	0.4607	0.6447	0.5527
Resident Doc	female	0.9194	0.7316	0.8255
Radiographer	female	0.5531	1.4572	1.0052
Radiographer	female	0.7310	0.9047	0.8179
Radiographer	female	0.4917	0.9925	0.7421
Radiographer	female	0.9195	0.7315	0.8255
Radiographer	female	0.8195	0.7315	0.7755
Radiographer	male	0.7747	0.9822	0.8785
Resident Doc	male	0.5523	0.9748	0.7636
Radiographer	male	0.4248	0.6336	0.5292
Radiographer	male	0.3325	0.7143	0.5234
Resident Doc	male	0.9143	0.7836	0.8490
Radiographer	male	0.4850	1.0137	0.7494
Radiographer	male	0.8933	0.9498	0.9216
Radiographer	male	0.4303	0.8942	0.6623
Radiologist	male	0.6065	0.7323	0.6694
Radiographer	male	0.6119	0.7897	0.7008
Radiographer	male	0.6025	1.3561	0.9793
Radiographer	male	0.6880	1.1086	0.8983

Mean Cumulative dose = 0.7726 mSv/y

B7: Dose Equivalent for Radiation Workers from Federal Medical Center (FMC) Umuahia, Abia State

CODE	SEX	1st&2nd Reading(mSv) Mean-for 6months	3rd&4th Reading (mean-for 6months	Mean Dose(mSv)
Radiographer	female	1.0143	0.9805	0.9974
Radiographer	female	0.7813	1.3485	1.0649
Radiographer	female	0.8905	0.8223	0.8564
Radiographer	male	1.8361	0.9051	1.3706
Radiographer	male	1.0711	0.9005	0.9858
Radiographer	male	0.6845	1.0010	0.8428
Radiographer	male	0.5870	0.7920	0.6895
Radiographer	male	0.4066	0.8031	0.6049
Radiographer	male	0.7080	0.9560	0.8320

Mean Cumulative dose =0.9160 mSv/y

B8: Dose Equivalent for Radiation Workers from Federal Medical Center Yenagoa, Bayelsa State

CODE	SEX	1st&2nd Reading (mean-for 6months)	3rd&4th Reading (mean-for 6months	Mean Dose
Radiographer	female	0.7870	0.8123	0.79965
Radiographer	female	0.5023	0.8970	0.69965
Radiologist	male	0.5322	0.7501	0.64115
Radiographer	male	0.6390	0.9033	0.77115
Radiologist	male	0.5944	0.6290	0.6117
Radiographer	female	0.8024	0.5975	0.69995
Radiographer	male	0.7026	0.6523	0.67745

Mean Cumulative dose = 0.7001 mSv/y

B9: Dose Equivalent for Radiation Workers from National Orthopedic Hospital, Enugu, Enugu State

CODE	SEX	1st&2nd Reading (mean-for 6months)	3rd&4th Reading (mean-for 6months)	Mean Dose
Radiographer	female	1.2506	0.9641	1.1074
Radiographer	female	0.5485	0.7335	0.6410
Radiographer	female	0.4785	0.9006	0.6896
Radiologist	female	0.7175	0.5020	0.6098
Radiographer	Male	0.5730	0.8507	0.7119
Radiographer	Male	0.8507	0.6050	0.7279
Radiographer	Male	0.7840	0.3059	0.5450
Radiographer	Male	1.0050	0.7035	0.8543
Radiographer	Male	0.8210	0.7993	0.8102
Radiologist	Male	0.6125	0.5405	0.5765
Radiographer	Male	0.5319	0.6451	0.5885
Radiographer	male	0.8350	0.7310	0.7830

Mean Cumulative dose = 0.7204 mSv/y

Table B10: One-Sample Statistics

	N	Mean	Std. Deviation	Std.Error Mean
CUMULATIVED DOSE	101	1.6675	.78549	.07816

Table B11: One-Sample Test

	Test Value = 20					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
CUMULATIVED DOSE	-234.554	100	.000	-18.33249	-18.4876	-18.1774

APPENDIX C: RESULTS FROM HYPOTHESIS THREE

C1: Results from DELSUTH

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	radiation workers	16	6.4125	2.33063	.58266
	non-radiation workers	16	6.4125	2.33063	.58266
RBC	radiation workers	16	5.4688	1.20539	.30135
	non-radiation workers	16	5.4688	1.20539	.30135
PLT	radiation workers	16	240.2813	90.69104	22.67276
	non-radiation workers	16	250.7500	71.00282	17.75070
Hb	radiation workers	16	13.6375	1.71964	.42991
	non-radiation workers	16	13.6313	1.70830	.42708
HcT	radiation workers	16	37.7063	4.49733	1.12433
	non-radiation workers	16	37.7875	4.44520	1.11130
McV	radiation workers	16	81.0437	11.01611	2.75403
	non-radiation workers	16	82.6000	5.79943	1.44986
McH	radiation workers	16	31.5813	4.54140	1.13535
	non-radiation workers	16	31.6500	4.57253	1.14313
MCHC	radiation workers	16	35.9000	.92232	.23058
	non-radiation workers	16	35.9375	.96532	.24133
Lymphocyte	radiation workers	16	27.8563	11.39298	2.84824
	non-radiation workers	16	27.4625	11.78190	2.94547

Table 2: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
WBC	Equal variances assumed	0	1	0	30	1	0	0.824	-1.6828	1.68284
	Equal variances not assumed			0	30	1	0	0.824	-1.6828	1.68284
RBC	Equal variances assumed	0	1	0	30	1	0	0.42617	-0.8704	0.87035
	Equal variances not assumed			0	30	1	0	0.42617	-0.8704	0.87035
PLT	Equal variances assumed	0.276	0.603	-0.364	30	0.719	-10.469	28.7948	-69.276	48.3381
	Equal variances not assumed			-0.364	28.367	0.719	-10.469	28.7948	-69.418	48.4805
Hb	Equal variances assumed	0.001	0.982	0.01	30	0.992	0.00625	0.60598	-1.2313	1.24383
	Equal variances not assumed			0.01	29.999	0.992	0.00625	0.60598	-1.2313	1.24384
HcT	Equal variances assumed	0.008	0.929	-0.051	30	0.959	-0.0813	1.58086	-3.3098	3.14729
	Equal variances not assumed			-0.051	29.996	0.959	-0.0813	1.58086	-3.3098	3.14731
McV	Equal variances assumed	0.624	0.436	-0.5	30	0.621	-1.5563	3.11235	-7.9125	4.80002
	Equal variances not assumed			-0.5	22.721	0.622	-1.5563	3.11235	-7.999	4.88652
McH	Equal variances assumed	0.001	0.978	-0.043	30	0.966	-0.0688	1.61114	-3.3591	3.22163
	Equal variances not assumed			-0.043	29.999	0.966	-0.0688	1.61114	-3.3591	3.22164
MCHC	Equal variances assumed	0.024	0.879	-0.112	30	0.911	-0.0375	0.33378	-0.7192	0.64416
	Equal variances not assumed			-0.112	29.938	0.911	-0.0375	0.33378	-0.7192	0.64422
Lymphocytes	Equal variances assumed	0.046	0.831	0.096	30	0.924	0.39375	4.09736	-7.9742	8.76167
	Equal variances not assumed			0.096	29.966	0.924	0.39375	4.09736	-7.9746	8.76206

C2: Results from FMC ASABA

Table 3: Group Statistics

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	7	4.6714	0.63696	0.24075
	Non-Radiation Workers	7	5.9429	1.02933	0.38905
RBC	Radiation Workers	7	5.9143	1.717	0.64897
	Non-Radiation Workers	7	5.4571	0.97955	0.37024
PLT	Radiation Workers	7	295.286	61.97234	23.42334
	Non-Radiation Workers	7	193.857	45.24905	17.10253
Hb	Radiation Workers	7	12.7	1.48549	0.56146
	Non-Radiation Workers	7	14.3	1.47422	0.5572
HcT	Radiation Workers	7	33.7286	5.27532	1.99389
	Non-Radiation Workers	7	41.3286	4.62951	1.74979
McV	Radiation Workers	7	68.0429	23.15267	8.75089
	Non-Radiation Workers	7	80.6143	8.22018	3.10694
MCH	Radiation Workers	7	27.8143	2.93452	1.10915
	Non-Radiation Workers	7	30.0143	7.33563	2.77261
MCHC	Radiation Workers	7	33.9714	2.47973	0.93725
	Non-Radiation Workers	7	34.9143	1.64968	0.62352
Lymphocytes	Radiation Workers	7	42.1143	9.65426	3.64897
	Non-Radiation Workers	7	44.6429	7.77279	2.93784

C 3: RESULTS FROM FMC OWERRI

Table 5: Group Statistics

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	20	5.0150	1.61352	.36079
	Non-Radiation Workers	20	6.4650	1.82534	.40816
RBC	Radiation Workers	20	4.3400	.63528	.14205
	Non-Radiation Workers	20	5.5750	1.44436	.32297
PLT	Radiation Workers	20	194.9000	54.01452	12.07801
	Non-Radiation Workers	20	232.6000	36.86305	8.24283
Hb	Radiation Workers	20	11.8350	1.72055	.38473
	Non-Radiation Workers	20	12.3200	.99239	.22191
HcT	Radiation Workers	20	35.7650	5.63535	1.26010
	Non-Radiation Workers	20	32.0550	8.88040	1.98572
McV	Radiation Workers	20	83.4500	5.67826	1.26970
	Non-Radiation Workers	20	85.4500	5.21632	1.16640
MCH	Radiation Workers	20	28.2600	1.95055	.43616
	Non-Radiation Workers	20	28.4950	2.20155	.49228
MCHC	Radiation Workers	20	33.6650	.83620	.18698
	Non-Radiation Workers	20	33.0800	1.32689	.29670
Lymphocytes	Radiation Workers	20	41.5800	10.65095	2.38162
	Non-Radiation Workers	20	44.5050	7.46151	1.66845

Table 6: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
WBC	Equal variances assumed	0.995	0.325	-2.66	38	0.011	-1.45	0.54476	-2.55281	-0.34719
	Equal variances not assumed			-2.66	37.44	0.011	-1.45	0.54476	-2.55336	-0.34664
RBC	Equal variances assumed	8.31	0.006	-3.5	38	0.001	-1.235	0.35283	-1.94926	-0.52074
	Equal variances not assumed			-3.5	26.09	0.002	-1.235	0.35283	-1.96013	-0.50987
PLT	Equal variances assumed	1.84	0.183	-2.58	38	0.014	-37.7	14.62268	-67.3021	-8.09794
	Equal variances not assumed			-2.58	33.54	0.015	-37.7	14.62268	-67.4317	-7.96826
Hb	Equal variances assumed	8.442	0.006	-1.09	38	0.282	-0.485	0.44414	-1.38411	0.41411
	Equal variances not assumed			-1.09	30.38	0.283	-0.485	0.44414	-1.39157	0.42157
HcT	Equal variances assumed	0.426	0.518	1.578	38	0.123	3.71	2.35179	-1.05096	8.47096
	Equal variances not assumed			1.578	32.17	0.124	3.71	2.35179	-1.07947	8.49947
McV	Equal variances assumed	0.433	0.514	-1.16	38	0.253	-2	1.72413	-5.49032	1.49032
	Equal variances not assumed			-1.16	37.73	0.253	-2	1.72413	-5.49114	1.49114
MCH	Equal variances assumed	0.657	0.423	-0.36	38	0.723	-0.235	0.6577	-1.56645	1.09645
	Equal variances not assumed			-0.36	37.46	0.723	-0.235	0.6577	-1.56708	1.09708
MCHC	Equal variances assumed	0.22	0.642	1.668	38	0.104	0.585	0.3507	-0.12496	1.29496
	Equal variances not assumed			1.668	32.04	0.105	0.585	0.3507	-0.12933	1.29933
Lymphocytes	Equal variances assumed	1.677	0.203	-1.01	38	0.321	-2.925	2.90789	-8.81172	2.96172
	Equal variances not assumed			-1.01	34.03	0.322	-2.925	2.90789	-8.83436	2.98436

C 4: RESULTS FROM FMC UMUAHIA

Table 7: Group Statistics

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	9	5.8111	1.31477	.43826
	Non-Radiation Workers	9	7.5556	1.87624	.62541
RBC	Radiation Workers	9	3.9556	.66165	.22055
	Non-Radiation Workers	9	5.6333	1.55724	.51908
PLT	Radiation Workers	9	189.2222	44.86028	14.95343
	Non-Radiation Workers	9	218.2222	36.94854	12.31618
Hb	Radiation Workers	9	10.7222	.94839	.31613
	Non-Radiation Workers	9	12.2000	.46098	.15366
HcT	Radiation Workers	9	32.2444	2.98082	.99361
	Non-Radiation Workers	9	34.9778	2.89904	.96635
McV	Radiation Workers	9	83.6111	6.43554	2.14518
	Non-Radiation Workers	9	83.9333	5.36982	1.78994
MCH	Radiation Workers	9	29.0444	2.19095	.73032
	Non-Radiation Workers	9	27.5667	2.50699	.83566
MCHC	Radiation Workers	9	33.4556	.66729	.22243
	Non-Radiation Workers	9	33.0111	.46218	.15406
Lymphocytes	Radiation Workers	9	44.3222	3.97202	1.32401
	Non-Radiation Workers	9	43.1889	7.85787	2.61929

C 5: RESULTS FROM FMC YENOGOA

Table 9: Group Statistics

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	7	4.2857	.89709	.33907
	Non-Radiation workers	7	5.9000	.89815	.33947
RBC	Radiation Workers	7	5.5714	1.57132	.59390
	Non-Radiation workers	7	6.2000	1.12990	.42706
PLT	Radiation Workers	7	232.1429	52.57512	19.87153
	Non-Radiation workers	7	223.1429	48.58130	18.36201
Hb	Radiation Workers	7	12.4429	1.36609	.51633
	Non-Radiation workers	7	12.8857	1.13494	.42897
HcT	Radiation Workers	7	36.9857	5.24132	1.98103
	Non-Radiation workers	7	38.0571	4.14964	1.56842
McV	Radiation Workers	7	80.3571	5.22936	1.97651
	Non-Radiation workers	7	80.3857	7.50276	2.83578
MCH	Radiation Workers	7	27.8286	2.67937	1.01271
	Non-Radiation workers	7	30.8857	3.39776	1.28423
MCHC	Radiation Workers	7	35.0571	1.98818	.75146
	Non-Radiation workers	7	34.4571	3.28880	1.24305
Lymphocytes	Radiation Workers	7	40.8000	13.66028	5.16310
	Non-Radiation workers	7	37.1857	7.82463	2.95743

Table 10: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
WBC	Equal variances assumed	0.026	0.873	-3.37	12	0.006	-1.61429	0.4798	-2.65967	-0.5689
	Equal variances not assumed			-3.37	12	0.006	-1.61429	0.4798	-2.65967	-0.5689
RBC	Equal variances assumed	1.622	0.227	-0.86	12	0.407	-0.62857	0.73151	-2.22239	0.96524
	Equal variances not assumed			-0.86	10.9	0.409	-0.62857	0.73151	-2.24049	0.98334
PLT	Equal variances assumed	0.034	0.857	0.333	12	0.745	9	27.05625	-49.95051	67.95051
	Equal variances not assumed			0.333	11.93	0.745	9	27.05625	-49.99118	67.99118
Hb	Equal variances assumed	0.043	0.84	-0.66	12	0.522	-0.44286	0.67128	-1.90544	1.01973
	Equal variances not assumed			-0.66	11.61	0.522	-0.44286	0.67128	-1.91091	1.0252
HcT	Equal variances assumed	0.037	0.851	-0.42	12	0.679	-1.07143	2.52674	-6.57673	4.43387
	Equal variances not assumed			-0.42	11.4	0.679	-1.07143	2.52674	-6.60903	4.46617
McV	Equal variances assumed	0.322	0.581	-0.01	12	0.994	-0.02857	3.45662	-7.5599	7.50276
	Equal variances not assumed			-0.01	10.72	0.994	-0.02857	3.45662	-7.66117	7.60403
MCH	Equal variances assumed	0.383	0.548	-1.87	12	0.086	-3.05714	1.63549	-6.62057	0.50629
	Equal variances not assumed			-1.87	11.38	0.088	-3.05714	1.63549	-6.64218	0.52789
MCHC	Equal variances assumed	1.73	0.213	0.413	12	0.687	0.6	1.45254	-2.56481	3.76481
	Equal variances not assumed			0.413	9.869	0.688	0.6	1.45254	-2.6423	3.8423
Lymphocytes	Equal variances assumed	3.281	0.095	0.607	12	0.555	3.61429	5.95013	-9.34993	16.5785
	Equal variances not assumed			0.607	9.555	0.558	3.61429	5.95013	-9.72768	16.95625

C 6: RESULTS FROM IMAGE DIAGNOSTIC CENTER

Table 11: Group Statistics

Blood Parameters	Workers	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	7	5.0571	1.40696	.53178
	Non-Radiation workers	7	5.7143	1.96335	.74208
RBC	Radiation Workers	7	4.7714	.61023	.23065
	Non-Radiation workers	7	4.9571	.88667	.33513
PLT	Radiation Workers	7	263.4286	61.35378	23.18955
	Non-Radiation workers	7	231.7143	100.62424	38.03239
Hb	Radiation Workers	7	12.2571	1.01465	.38350
	Non-Radiation workers	7	14.0714	1.10108	.41617
HcT	Radiation Workers	7	37.5857	2.87079	1.08506
	Non-Radiation workers	7	39.2143	2.80085	1.05862
McV	Radiation Workers	7	79.8286	5.87274	2.21969
	Non-Radiation workers	7	85.3571	4.13072	1.56127
MCH	Radiation Workers	7	27.4857	4.35600	1.64641
	Non-Radiation workers	7	31.0571	2.56766	.97048
MCHC	Radiation Workers	7	34.6286	3.00484	1.13572
	Non-Radiation workers	7	37.5714	.95344	.36037
Lymphocytes	Radiation Workers	7	39.4429	6.88933	2.60392
	Non-Radiation workers	7	40.0000	14.16251	5.35293

Table 12: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
WBC	Equal variances assumed	1.046	0.327	-0.72	12	0.485	-0.65714	0.91295	-2.64628	1.33199
	Equal variances not assumed			-0.72	10.876	0.487	-0.65714	0.91295	-2.66931	1.35503
RBC	Equal variances assumed	0.49	0.497	-0.456	12	0.656	-0.18571	0.40683	-1.07212	0.70069
	Equal variances not assumed			-0.456	10.642	0.657	-0.18571	0.40683	-1.08483	0.7134
PLT	Equal variances assumed	2.528	0.138	0.712	12	0.49	31.71429	44.54456	-65.33997	128.76854
	Equal variances not assumed			0.712	9.92	0.493	31.71429	44.54456	-67.64642	131.07499
Hb	Equal variances assumed	0.015	0.906	-3.206	12	0.008	-1.81429	0.56593	-3.04733	-0.58124
	Equal variances not assumed			-3.206	11.921	0.008	-1.81429	0.56593	-3.04824	-0.58033
HcT	Equal variances assumed	0.005	0.943	-1.074	12	0.304	-1.62857	1.51592	-4.93149	1.67434
	Equal variances not assumed			-1.074	11.993	0.304	-1.62857	1.51592	-4.93171	1.67457
McV	Equal variances assumed	0.271	0.612	-2.037	12	0.064	-5.52857	2.71377	-11.44137	0.38423
	Equal variances not assumed			-2.037	10.769	0.067	-5.52857	2.71377	-11.51718	0.46004
MCH	Equal variances assumed	1.892	0.194	-1.869	12	0.086	-3.57143	1.91116	-7.73548	0.59262
	Equal variances not assumed			-1.869	9.72	0.092	-3.57143	1.91116	-7.84642	0.70356
MCHC	Equal variances assumed	11.71	0.005	-2.47	12	0.03	-2.94286	1.19152	-5.53896	-0.34675
	Equal variances not assumed			-2.47	7.196	0.042	-2.94286	1.19152	-5.74488	-0.14084
Lymphocytes	Equal variances assumed	2.472	0.142	-0.094	12	0.927	-0.55714	5.95266	-13.52689	12.4126
	Equal variances not assumed			-0.094	8.689	0.928	-0.55714	5.95266	-14.09683	12.98255

C 7: RESULTS FROM NATIONAL OTHOPEDIC HOSPITAL ENUGU

Table 13: Group Statistics

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	12	4.9833	1.24231	0.35862
	Non-Radiation Workers	12	8.1417	3.26008	0.9411
RBC	Radiation Workers	12	4.7917	0.68551	0.19789
	Non-Radiation Workers	12	4.775	0.65244	0.18834
PLT	Radiation Workers	12	167.5	51.09261	14.74917
	Non-Radiation Workers	12	216.3333	29.04646	8.38499
Hb	Radiation Workers	12	11.9667	3.93777	1.13674
	Non-Radiation Workers	12	11.9417	0.79938	0.23076
HcT	Radiation Workers	12	41.075	4.38284	1.26522
	Non-Radiation Workers	12	36.1083	2.29919	0.66372
McV	Radiation Workers	12	79.5917	17.32484	5.00125
	Non-Radiation Workers	12	80.8	7.43371	2.14593
MCH	Radiation Workers	12	29.6083	1.68602	0.48671
	Non-Radiation Workers	12	27.1167	2.30053	0.6641
MCHC	Radiation Workers	12	33.2167	0.14035	0.04051
	Non-Radiation Workers	12	32.7917	0.77396	0.22342
Lymphocytes	Radiation Workers	12	42.1917	8.29605	2.39486
	Non-Radiation Workers	12	42.975	5.26103	1.51873

Table 14: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the	
									Lower	Upper
WBC	Equal variances assumed	6.983	0.015	-3.14	22	0.005	-3.15833	1.00712	-5.24697	-1.0697
	Equal variances not assumed			-3.14	14.13	0.007	-3.15833	1.00712	-5.31654	-1.00012
RBC	Equal variances assumed	0.165	0.688	0.061	22	0.952	0.01667	0.27319	-0.5499	0.58323
	Equal variances not assumed			0.061	21.95	0.952	0.01667	0.27319	-0.54998	0.58331
PLT	Equal variances assumed	7.196	0.014	-2.88	22	0.009	-48.83333	16.96602	-84.0187	-13.648
	Equal variances not assumed			-2.88	17.44	0.01	-48.83333	16.96602	-84.5602	-13.1065
Hb	Equal variances assumed	3.651	0.069	0.022	22	0.983	0.025	1.15992	-2.38053	2.43053
	Equal variances not assumed			0.022	11.91	0.983	0.025	1.15992	-2.50449	2.55449
HcT	Equal variances assumed	8.76	0.007	3.476	22	0.002	4.96667	1.42874	2.00364	7.92969
	Equal variances not assumed			3.476	16.63	0.003	4.96667	1.42874	1.94714	7.98619
McV	Equal variances assumed	1.357	0.256	-0.22	22	0.826	-1.20833	5.4422	-12.4948	10.07809
	Equal variances not assumed			-0.22	14.92	0.827	-1.20833	5.4422	-12.8137	10.39702
MCH	Equal variances assumed	2.577	0.123	3.026	22	0.006	2.49167	0.82336	0.78412	4.19921
	Equal variances not assumed			3.026	20.17	0.007	2.49167	0.82336	0.7751	4.20824
MCHC	Equal variances assumed	14.711	0.001	1.872	22	0.075	0.425	0.22707	-0.04591	0.89591
	Equal variances not assumed			1.872	11.72	0.086	0.425	0.22707	-0.07104	0.92104
Lymphocytes	Equal variances assumed	3.289	0.083	-0.28	22	0.785	-0.78333	2.83583	-6.66448	5.09781
	Equal variances not assumed			-0.28	18.62	0.785	-0.78333	2.83583	-6.72709	5.16042

C 8: RESULTS FROM NIGER DELTA UNIVERSITY TEACHING HOSPITAL

Table 15: Group Statistics

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	5	5.02	0.48166	0.21541
	Non-Radiation Workers	5	8.42	4.11364	1.83967
RBC	Radiation Workers	5	4.68	1.42021	0.63514
	Non-Radiation Workers	5	5.74	0.20736	0.09274
PLT	Radiation Workers	5	366	99.00505	44.2764
	Non-Radiation Workers	5	234.4	50.86059	22.74555
Hb	Radiation Workers	5	11.66	3.79776	1.69841
	Non-Radiation Workers	5	14.76	1.76579	0.78968
HcT	Radiation Workers	5	31.96	8.43107	3.77049
	Non-Radiation Workers	5	40.62	5.42144	2.42454
McV	Radiation Workers	5	80.76	4.74373	2.12146
	Non-Radiation Workers	5	82.26	5.99692	2.6819
MCH	Radiation Workers	5	26.66	1.71697	0.76785
	Non-Radiation Workers	5	31.26	8.63151	3.86013
MCHC	Radiation Workers	5	33.06	0.78294	0.35014
	Non-Radiation Workers	5	34.72	1.42724	0.63828
Lymphocytes	Radiation Workers	5	37	15.83098	7.07983
	Non-Radiation Workers	5	32.94	9.00628	4.02773

Table 16: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
WBC	Equal variances assumed	16.947	0.003	-1.836	8	0.104	-3.4	1.85224	-7.67128	0.87128
	Equal variances not assumed			-1.836	4.11	0.138	-3.4	1.85224	-8.48898	1.68898
RBC	Equal variances assumed	6.413	0.035	-1.651	8	0.137	-1.06	0.64187	-2.54016	0.42016
	Equal variances not assumed			-1.651	4.17	0.171	-1.06	0.64187	-2.81376	0.69376
PLT	Equal variances assumed	0.671	0.436	2.644	8	0.03	131.6	49.7771	16.81379	246.38621
	Equal variances not assumed			2.644	5.974	0.039	131.6	49.7771	9.67009	253.52991
Hb	Equal variances assumed	2.772	0.134	-1.655	8	0.137	-3.1	1.87302	-7.41919	1.21919
	Equal variances not assumed			-1.655	5.652	0.152	-3.1	1.87302	-7.75234	1.55234
HcT	Equal variances assumed	0.836	0.387	-1.932	8	0.089	-8.66	4.48274	-18.99723	1.67723
	Equal variances not assumed			-1.932	6.825	0.096	-8.66	4.48274	-19.31538	1.99538
McV	Equal variances assumed	0.809	0.395	-0.439	8	0.673	-1.5	3.41953	-9.38546	6.38546
	Equal variances not assumed			-0.439	7.597	0.673	-1.5	3.41953	-9.4588	6.4588
MCH	Equal variances assumed	3.784	0.088	-1.169	8	0.276	-4.6	3.93576	-13.67588	4.47588
	Equal variances not assumed			-1.169	4.316	0.303	-4.6	3.93576	-15.21896	6.01896
MCHC	Equal variances assumed	2.716	0.138	-2.28	8	0.052	-1.66	0.72801	-3.3388	0.0188
	Equal variances not assumed			-2.28	6.208	0.061	-1.66	0.72801	-3.42704	0.10704
Lymphocytes	Equal variances assumed	0.644	0.445	0.498	8	0.632	4.06	8.14534	-14.72319	22.84319
	Equal variances not assumed			0.498	6.344	0.635	4.06	8.14534	-15.61208	23.73208

C 9: RESULTS FROM UNIVERSITY OF PORT HARCOURT TEACHING HOSPITAL

	Blood Parameters	N	Mean	Std. Deviation	Std. Error Mean
WBC	Radiation Workers	18	4.8389	0.97204	0.22911
	Non-Radiation workers	18	5.3167	1.20404	0.28379
RBC	Radiation Workers	18	5.4389	1.09606	0.25834
	Non-Radiation workers	18	4.9389	0.85622	0.20181
PLT	Radiation Workers	18	234.9444	72.57408	17.10587
	Non-Radiation workers	18	214.8333	55.81508	13.15574
Hb	Radiation Workers	18	12.7167	1.923	0.45326
	Non-Radiation workers	18	13.0556	1.61763	0.38128
HcT	Radiation Workers	18	40.15	5.29031	1.24694
	Non-Radiation workers	18	37.9111	4.77677	1.1259
McV	Radiation Workers	18	80.9167	6.59931	1.55547
	Non-Radiation workers	18	77.6611	9.85466	2.32277
MCH	Radiation Workers	18	25.9889	1.95956	0.46187
	Non-Radiation workers	18	27.4389	3.26607	0.76982
MCHC	Radiation Workers	18	32.7333	2.37264	0.55924
	Non-Radiation workers	18	35.6944	1.76484	0.41598
Lymphocytes	Radiation Workers	18	39.8778	11.05875	2.60657
	Non-Radiation workers	18	43.3389	12.88703	3.0375

Table 18: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
WBC	Equal variances assumed	0	1	-1.31	34	0.199	-0.47778	0.36474	-1.21901	0.26345
	Equal variances not assumed			-1.31	32.553	0.199	-0.47778	0.36474	-1.22022	0.26467
RBC	Equal variances assumed	1.02	0.32	1.525	34	0.136	0.5	0.32782	-0.16622	1.16622
	Equal variances not assumed			1.525	32.118	0.137	0.5	0.32782	-0.16766	1.16766
PLT	Equal variances assumed	0.381	0.541	0.932	34	0.358	20.11111	21.57972	-23.74416	63.96639
	Equal variances not assumed			0.932	31.898	0.358	20.11111	21.57972	-23.85085	64.07307
Hb	Equal variances assumed	0.381	0.541	-0.572	34	0.571	-0.33889	0.5923	-1.54258	0.8648
	Equal variances not assumed			-0.572	33.032	0.571	-0.33889	0.5923	-1.54388	0.8661
HcT	Equal variances assumed	0.204	0.655	1.333	34	0.192	2.23889	1.68003	-1.17534	5.65312
	Equal variances not assumed			1.333	33.652	0.192	2.23889	1.68003	-1.17664	5.65442
McV	Equal variances assumed	7.04	0.012	1.165	34	0.252	3.25556	2.79548	-2.42555	8.93666
	Equal variances not assumed			1.165	29.694	0.253	3.25556	2.79548	-2.45605	8.96716
MCH	Equal variances assumed	5.424	0.026	-1.615	34	0.116	-1.45	0.89775	-3.27444	0.37444
	Equal variances not assumed			-1.615	27.835	0.118	-1.45	0.89775	-3.28944	0.38944
MCHC	Equal variances assumed	1.394	0.246	-4.248	34	0	-2.96111	0.69698	-4.37755	-1.54468
	Equal variances not assumed			-4.248	31.403	0	-2.96111	0.69698	-4.38187	-1.54035
Lymphocytes	Equal variances assumed	0.916	0.345	-0.865	34	0.393	-3.46111	4.00258	-11.59533	4.67311
	Equal variances not assumed			-0.865	33.234	0.393	-3.46111	4.00258	-11.60224	4.68002

APPENDIX-D

Table 1: ANOVA TABLE ON THE EFFECTS OF RADIATION ON BLOOD PARAMETERS OF RADIATION WORKERS BY HOSPITAL

		Sum of Squares	df	Mean Square	F	Sig.
WBC	Between Groups	37.583	8	4.698	2.326	0.025
	Within Groups	185.779	92	2.019		
	Total	223.362	100			
RBC	Between Groups	34.986	8	4.373	3.969	0
	Within Groups	101.362	92	1.102		
	Total	136.348	100			
PLT	Between Groups	218462.95	8	27307.9	6.06	0
	Within Groups	414582.28	92	4506.33		
	Total	633045.24	100			
Hb	Between Groups	63.105	8	7.888	1.69	0.111
	Within Groups	429.537	92	4.669		
	Total	492.641	100			
HcT	Between Groups	823.944	8	102.993	4.066	0
	Within Groups	2330.528	92	25.332		
	Total	3154.472	100			
McV	Between Groups	1368.812	8	171.102	1.502	0.167
	Within Groups	10483.573	92	113.952		
	Total	11852.385	100			
MCH	Between Groups	313.863	8	39.233	4.898	0
	Within Groups	736.985	92	8.011		
	Total	1050.848	100			
MCHC	Between Groups	113.51	8	14.189	5.377	0
	Within Groups	242.762	92	2.639		
	Total	356.272	100			
Lymphocytes	Between Groups	2622.969	8	327.871	3.007	0.005
	Within Groups	10030.833	92	109.031		
	Total	12653.802	100			

APPENDIX E

RESULTS FROM HYPOTHESIS FIVE

Table 1: Regression Coefficients of Radiation Dose on WBC

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.548	.350		15.854	.000
	CUMULATIVE DOSE	-.214	.190	-.112	-1.126	.263

a. Dependent Variable: WBC

Table 2: Regression Coefficients of Radiation Dose on RBC

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.109	.275		18.595	.000
	CUMULATIVE DOSE	-.080	.149	-.054	-.537	.592

a. Dependent Variable: RBC

Table 3: Regression Coefficients of Radiation Dose on PLT

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	231.665	18.744		12.359	.000
	CUMULATIVE DOSE	-2.064	10.178	-.020	-.203	.840

a. Dependent Variable: PLT

Table 4: Regression Coefficients of Radiation Dose on Hb

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.385	.523		23.683	.000
	CUMULATIVE DOSE	-.041	.284	-.014	-.143	.886

a. Dependent Variable: Hb

Table 5: Regression Coefficients of Radiation Dose on HcT

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	37.430	1.323		28.297	.000
	CUMULATIVE DOSE	-.227	.718	-.032	-.316	.753

a. Dependent Variable: HcT

Table 6: Regression Coefficients of Radiation Dose on McV

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	78.841	2.559		30.814	.000
	CUMULATIVE DOSE	.999	1.389	.072	.719	.474

a. Dependent Variable: McV

Table 7: Regression Coefficients of Radiation Dose on MCH

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	26.997	.747		36.122	.000
	CUMULATIVE DOSE	.852	.406	.206	2.099	.038

a. Dependent Variable: MCH

Table 8: Regression Coefficients of Radiation Dose on MCHC

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	32.940	.431		76.459	.000
	CUMULATIVE DOSE	.597	.234	.248	2.551	.012

a. Dependent Variable: MCHC

Table 9: Regression Coefficients of Radiation Dose on Lymphocytes

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	39.177	2.651		14.780	.000
	CUMULATIVE DOSE	-.089	1.439	-.006	-.062	.951

a. Dependent Variable: Lymphocytes

APPENDIX F

Table 1: Mean and Standard Deviation of Blood Parameters of Male and Female Radiation Workers

	SEX	N	Mean	Std. Deviation	Std. Error Mean
WBC	MALE	66	5.30	1.225	.151
	FEMALE	35	4.98	1.906	.322
RBC	MALE	66	4.9697	1.11975	.13783
	FEMALE	35	4.9857	1.27005	.21468
PLT	MALE	66	230.0909	71.06892	8.74798
	FEMALE	35	224.7000	94.57010	15.98526
Hb	MALE	66	12.4545	2.44837	.30137
	FEMALE	35	12.0571	1.70971	.28899
HcT	MALE	66	38.0076	5.86747	.72224
	FEMALE	35	35.2514	4.67461	.79015
McV	MALE	66	79.7061	12.64542	1.55654
	FEMALE	35	82.0171	6.26918	1.05969
MCH	MALE	66	28.1652	3.53212	.43477
	FEMALE	35	28.8943	2.58820	.43749
MCHC	MALE	66	33.7167	2.01674	.24824
	FEMALE	35	34.3486	1.56024	.26373
Lymphocytes	MALE	66	40.3136	10.50729	1.29336
	FEMALE	35	36.6029	12.32247	2.08288

Table 2: t-Test Statistics on Comparison of Blood Parameters of Male and Female Radiation Workers

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
WBC	Equal variances assumed	1.812	0.181	1.02	99	0.31	0.319	0.312	-0.301	0.939
	Equal variances not assumed			0.896	49.272	0.375	0.319	0.356	-0.396	1.033
RBC	Equal variances assumed	1.163	0.283	-0.07	99	0.948	-0.01602	0.24539	-0.50292	0.47088
	Equal variances not assumed			-0.06	62.273	0.95	-0.01602	0.25512	-0.52594	0.49391
PLT	Equal variances assumed	5.643	0.019	0.323	99	0.748	5.39091	16.71192	-27.7692	38.55098
	Equal variances not assumed			0.296	54.842	0.768	5.39091	18.2224	-31.13	41.91178
Hb	Equal variances assumed	2.445	0.121	0.855	99	0.395	0.3974	0.46473	-0.52473	1.31954
	Equal variances not assumed			0.952	91.535	0.344	0.3974	0.41754	-0.43193	1.22674
HcT	Equal variances assumed	4.447	0.037	2.402	99	0.018	2.75615	1.14736	0.47954	5.03275
	Equal variances not assumed			2.575	83.909	0.012	2.75615	1.0705	0.62731	4.88498
McV	Equal variances assumed	1.211	0.274	-1.02	99	0.312	-2.31108	2.27609	-6.82735	2.20518
	Equal variances not assumed			-1.23	98.687	0.223	-2.31108	1.88302	-6.04755	1.42538
MCH	Equal variances assumed	0.257	0.614	-1.08	99	0.284	-0.72913	0.6773	-2.07304	0.61477
	Equal variances not assumed			-1.18	88.943	0.24	-0.72913	0.61678	-1.95468	0.49641
MCHC	Equal variances assumed	1.129	0.291	-1.61	99	0.11	-0.6319	0.39155	-1.40883	0.14502
	Equal variances not assumed			-1.75	85.735	0.085	-0.6319	0.36218	-1.35194	0.08813
Lymphocytes	Equal variances assumed	1.648	0.202	1.59	99	0.115	3.71078	2.3344	-0.92117	8.34273
	Equal variances not assumed			1.514	60.564	0.135	3.71078	2.45176	-1.19254	8.6141

INFORMATION DOCUMENT FOR RESEARCH PARTICIPANTS

TITLE OF RESEARCH – **"The Health Effects of Ionizing Radiation on Professional Diagnostic Radiation Workers in Some Selected Health Institutions in southern-Nigeria".**

PURPOSE OF RESEARCH – The purpose of this study is to monitor the effect of the absorbed dose of radiation measured by the Thermoluminence dosimeter (TLD) on the hematological parameters of Professional Radiation workers. Biological Dosimetry can be performed in addition to physical Dosimetry with the aim of individual dose Assessment and Biological effects

WHAT IS EXPECTED FROM RESPONDENTS – Potential candidates will be required to fill a questionnaire containing demographic questions and nature of job in relation to radiation protection practices. Carry out Full Blood Count Test and wear a TLD Badge for the study period. **CONFIDENTIALITY** – To ensure absolute confidentiality, please do not write your name in any of the questionnaires. Do not give us any clue that will aid to identify you. Please copy the research code number on your questionnaire as your Identification number which will be used for the FBC test and TLD badges instead of your name. Your research code number should be kept safely because this number will be used by YOU through this study.

BENEFITS OF THE RESEARCH – This study will help the participants to know the relationship between the absorbed dose of radiation measured by the TLD badge worn by radiation workers and the effect on their hematological parameters. This study will serve as a baseline for future purposes. The results from the study will help the participants to take proactive measures against cancers. It can serve as a routine monitoring process for the participant and the Radiology Department. This research will be beneficial to initiate awareness among occupational ionizing radiation workers to mitigate the effect.

HOW INFORMATION WILL BE PROVIDED – Information will be obtained through filling a questionnaire, from the Thermo luminescent Dosimeter Reading and the Laboratory Results.

HOW INFORMATION WILL BE SHARED TO THE PUBLIC – Information will be shared through local and International Journals.

IN CASE OF COMPLAIN – If there are areas of concern or assuming you have a complain, you can contact the Researcher on the address and phone number given below.

WITHDRAW FROM THE STUDY – It is NOT compulsory that you take part in this research, even though your involvement is beneficial. You are free to withdraw from the study at any point in time and you will not be victimized for the decision.

HOW TO GET ACCESS TO THE RESULT OF THIS RESEARCH – In case you want you want to know the outcome of this study, you can reach me (efejack@yahoo.com), Thanks for your time

Name of Researcher – **EFE OMITA** (08063479832/08169866387

Address of Researcher – Department of Physics, FUTO, Owerri, Imo State

(PhD student Radiation and Health Physics)

INFORMED CONSENT DOCUMENT

I, Efe Omita a PhD. Student in the Department of Radiation and Health Physics, Federal University of Technology, Owerri. Imo State. I am carrying out a research the "The Health Effects of Ionizing Radiation on Professional Diagnostic Radiation Workers in Some Selected Health Institutions in southern-Nigeria. This research entails your signature and honest response to the Questionnaire.

Confidentiality and Consent

This study will be used only for academic purpose and information given shall be treated strictly with confidentiality. Your participation in this study is entirely voluntary and you may decide to stop being a part of the research study at any time.

Thank you very for your participation.

Having been well explained to me, I fully understand the content of the study, I am willing to take part in the study.

…….. **……**

Signature/ Date Participant **Signature /Date Researcher**

THE QUESTIONNAIRE

Radiation and Health Physics,

Department of physics,

Post Graduate School,

Federal University of Technology,

Owerri, Imo State.

11th April, 2019.

Dear Sir/Madam,

This questionnaire is part of the requisite to complete my PhD Degree in radiation and Health physics at the Federal University of Technology, Owerri, Imo State. A research work Titled **"THE HEALTH EFFECTS OF IONIZING RADIATION ON PROFESSIONAL DIAGNOSTIC RADIATION WORKERS IN SOME SELECTED HEALTH INSTITUTIONS IN SOUTHERN-NIGERIA".**

RESEACH CODE: /2019

Name of Institution / Centre _____

Sex: Male ☐ Female ☐

Age group in years: 30 and below ☐ 1-35 ☐ 36-40 ☐ 41-45 ☐ 46-50 ☐

51 and above ☐

Length of practice (in years): 1-10 ☐ 11-20 ☐ 21 and above ☐

Do you smoke YES ☐ NO ☐

Do you work in ionizing Radiation Environment? YES ☐ NO ☐

If yes to question (6) above, which equipment? Please tick X-Ray Machine ☐
CT Machine ☐ Mammography Machine ☐

How long do you spend in the ionizing radiation room? 2-4hrs ☐ 4-6hrs ☐
6-8hrs ☐

How many patients do you attend to in a day? Please specify:

How many days in a week do you work in the ionizing radiation room, please specify: _____

Do you wear a radiation dosimeter while working as a radiation professional? YES ☐
NO ☐

If NO to question (11) above, what is your reason? Not provided for ☐ I don't like wearing it ☐ don't think it is necessary to wear it ☐ forgets to wear it ☐

If Yes to question (11) above, why do you wear it?

Please specify: _____

What type of dosimeter do you wear? TLD ☐ Film badge ☐ Insta-dosimeter ☐

Do you have a Designated Radiation Safety Officer attached to your Department/Centre?

Yes ☐ No ☐

If No to question (15) above, how is the occupational Radiation dose in your Department/Centre been monitored? Please Specify: _____

Do you know working with ionizing radiation could have effects on your blood cells? YES ☐
NO ☐

If Yes to question (17) above, have you ever done a blood test as a result of your working in ionizing radiation environment? YES ☐ NO ☐

If Yes to question (18) above, what other methods, procedure and devices do you as a radiation professional use in protecting yourself against the effects of ionizing radiation while working in the radiation room,

Please Specify:

……
……
……
……
……
……
……

If No to question (17) above, have you ever consider finding out the effects of ionizing radiation to the blood cells YES ☐ NO ☐

If you have done a blood test, what type of test did you do?

Full blood count ☐ Complete blood count ☐ Bioassay ☐

How often do you carry out the test? Yearly ☐ Every two years ☐ only once ☐

Was the outcome of the blood test within the normal value? YES ☐ NO ☐

If No to question (23) above, what procedure did you use to restore the parameter to normal values?

Use of medications ☐

Personnel removed from the ionizing radiation environment for some period of time ☐

Both procedures ☐

Any other procedures please specify: _____

COST IMPLICATION

COST IMPLICATIONCOST IMPLICATION

A: COST OF ETHICAL APPROVAL0	
HOSPITAL/CENTRES	FEES
UBTH FEES	NGN10000
UPTH FEES	NGN8000
DSUTH OGHORA	NGN10000
NDUTH	NGN5000
FMC OWERS	NGN5000
FMC ASABA	NIL
FMC YANEGOA	NGN5000
NOH	NIL
IMAGE DIAGNOSTIC	NIL
INTERCONTINENTAL DIAGNOSTIC	NIL
SUB TOTAL	NGN43,000

FEES FOR LABORATORY TEST AND TLD DEVICE NEEDED			
	NUMBER OF PARTICIPANTS	UNIT COST	TOTAL COST
FBC Per Annual FBC Before Anset OF Study	200	2000	NGN 400,000.00
FBC After the TLD Reading lent of 2 Year of Study	200	2000	NGN 400,000.00
Cost of TLD for Every 3 Months Per Annual (12 months)	100 *4	1000	NGN 400,000.00
Second Year Reaching (12 months)	-	400	NGN 400,000.00
TOTAL			NGN 1,600,000.00

DATA PROCESSING			
ITEMS	UNIT	COST PER UNIT	TOTAL COST
OVEN CONTROL SOFT WARE THERMOSOFT	NGN 1.00	NGN25000	NGN25000
CALIBRATION OF TLD	NGN 1.00	NGN25000	NGN25000
PHOTOCOPIES	NGN 10.00	NGN15000	NGN150000
TOTOL			NGN200000

GRAND TOTOL = NGN43, 000 + NGN 1,600,000 + NGN200, 000 = NGN 1,843.000