Chapter One

Introduction

1.1 Background to the Study

Exposure of the general public, patients, and radiation workers to ionizing radiation must be mitigated to minimize the risk of harmful biological effects. In 1954, the National Committee on the Radiation Protection (NCRP) proposed the principle that radiation protection should be kept "as low as reasonably achievable" ALARA concept[1]. The concept is accepted by all regulatory agencies including International Commission on Radiological Protection (ICRP), the World Health Organization (WHO), and the European Commission. When human body is exposed to ionizing radiation, it damages living cells by ionizing atoms composing of the molecular structures, causing abnormalities in the functioning of the living cell and consequently health issues[2]. Despite the complex nature of human system, there is no organ that is immuned to ionizing radiation or has ability to innately detect its presence to the extent that any organ that is damaged by ionizing radiation can never be repaired. This makes ionizing radiation more deleterious and stochastic. In this regards, the most fundamental aim of radiation scientist is to ensure radiation protection and safety through scientific research and recommendation. To achieve this goal, effects of ionizing radiation emanating from different sources must be examined. The radionuclides are found in varying amount in environmental substances such as rocks, soils, water and air. The geological setting of an area dictates the spread and level of the radionuclides of the area. However, the presence of radionuclides in various environmental matrices has prompted the International Atomic Energy Agency (IAEA) to advocate for measurement and monitoring of radiation in human environment[3].

The presence of natural radionuclides in various environmental matrices has raised concerns and worries among radiation-scientists worldwide. The concerns have prompted many authors to embark on broad assessment of ionizing radiation and its effects on human health and environment in the last few decades. However, relevant agencies including United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR), International Commission on Radiological Protection (ICRP), Environmental Protection Agency (EPA) and International Atomic Energy Agency (IAEA) have similarly embarked on the control and regulation of exposure of human and environment to natural ionizing radiation.

Radiation is defined as the emission and propagation of energy in the form of waves in space. It can emanate from moving subatomic particles from the atoms and molecules of a radioactive substance that undergoes nuclear decay. Ionizing radiation is any form of radiation that initiates ionization atoms but non-ionizing radiation can only initiate excitation. Ionizing radiation may be emitted in the process of natural decay of some unstable nuclei, X-ray machines and nuclear reactors. The examples of ionizing radiations include alpha particles, beta particles, gamma radiation, X-rays, and neutron when expelled from atomic nuclei.

Natural radioactivity constitutes 96.1% as against the artificial radioactivity which maintains 3.9% of the world radioactivity[4]. The primordial source is about 85% of the natural radioactivity while cosmic rays continuously produces by cosmogonic radionuclides is about 15% of natural radioactivity. Natural radionuclides of uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K) are present in the earth crust and when these radionuclides and their serial daughters undergo decay, gamma rays, beta and alpha radiations are released to the environment[5] Therefore, human beings are continuously exposed to ionizing radiation both inside and outside their dwellings. Medical procedures involving X-rays administration also contributes to human exposure to ionizing radiation. Exposure to ionizing radiation is one of the risks faced by health care professionals working in radiological facilities and radiological departments. Numerous standards have been developed in this specific field, not only to limit occupational exposure to ionizing radiation and health incidents. Though individual irradiation from diagnostic X-ray radiation is normally low, there have been disquiets of possible cancer risk when people are irradiated. However, irradiations to patients from radiological procedures can be greatly reduced with decrease[6]. This can be brought to fruition by using a well-designed X-ray equipment which is installed, used and maintained by trained personnel and by making sure the standardized procedures are adopted. The X-ray beam must be constricted to outside for both controlled and uncontrolled area of X-ray departments by the lining with lead sheet, which is a high shielding material because of its high density. Personnel, patients and public must be carefully protected from accidental exposure to beam of X-ray[7].

Based on international commission on Radiological protection (ICRP) and International Atomic Energy Agency (IAEA) recommendation for annual limit of effective dose to members of the general public that are in uncontrolled areas such as patients, visitors to the facility, and personnel who do not work routinely with radiation sources, shielding designs should limit exposure to an effective dose that does not exceed 1 millisievert per year (1mSv/year). Radiologists are occupationally exposed to a low level of ionizing radiation which should not exceed 1mSv during normal working in a single year, with the maximum possible limit of 20mSv/year. If the dose level exceeds the specified limit, the probability of occurring cytogenetic abnormalities and fetal cancer risk for the employees performing diagnostic procedures would increase[8]. In Nigeria, the Nigerian Nuclear Regulatory Authority(NNRA) regulations 2003 and 2006, recommended that diagnostic X-ray facility have purposely-built control console(cubicle) which will greatly protect the radiographers[9].

The proportion of cancer case occurring in developing counties of the world is expected to increase from 56% in 2008 to greater than 70% in 2030, this means cancer rates will double in low-income countries where screening programs are scarce and awareness is limited[9]. Studies have shown that occupationally exposed workers are at risk of getting cancer due to the stochastic effect of radiation[10]. This has made it necessary for the shielding design of diagnostic X-ray facilities be adequate to forestall the danger associated with radiation[11].

With the understanding of fundamental principle of radiation protection, only patients who should get maximum benefits from ionizing radiation (justification), making sure that radiation dose as a result of medical exposure are only enough to achieve needed diagnoses (optimization) considering economic and societal factors and reducing time of exposure to source of radiation. Compliance to radiation protection practices helps to mitigate risk from unplanned exposure[12].

The exposure of personnel(s) who work in the facility and to the public due to inadequate shielding of the X-ray room or department allows scattered and leakage of ionizing radiations during medical imaging is to increase[13]. Currently limited study has been conducted in this facilities to assess shielding adequacy hence there is need to survey and assess the level of leakage from the X-ray rooms[14,15].

1.2 Statement of the Problem

It has been reported that the annual per capital effective dose has doubled worldwide over the past decade due to daily increase in diagnostics procedures. Due to detrimental side effects of X-ray, it has become very important to mitigate the radiation exposure to the patience and radiation workers taking ALARA (as low as reasonably achievable) concept into the consideration. Most radio-diagnostic-centers in Nigeria are not radiation safety compliant[16]. In Ibadan, radio-diagnostic centres found in different areas, majorly in the urban settlement, fall into this category. Hence, the study to investigate the shielding adequacy, design layouts and personnel dosimetry of some selected diagnostics centers in Ibadan is needed.

1. 3 Aim and Objectives of the Study

The aim is to assess the shielding adequacy of some radiological facilities to ascertain safety of personnel and public within and outside the radiological facilities.

The major objectives are to:

i. assess the design layout of the diagnostic centres selected for the study.

ii. measure the dose rates at specific point of radiation from different procedures (Computed Tomography and X-ray)

iii. calculate Annual Dose Rate (ADR) to occupationally exposed workers within controlled areas

iv. compare the result with international recommended safety guidelines.

1.4 Justification of the Study

Minimizing the increasing ionizing radiation exposure from medical exposure has been the principal task for many professional, societies, agencies and advisory groups over the last couple of years. Only few hospitals and radiological diagnostics facilities do quarterly or yearly check to assess the level of radiation protection practices and shielding adequacy in their centres, therefore the study is key to experimentally assess the shielding adequacy of radiological facilities to ascertain radiation safety in selected facilities across Ibadan city.

1.5 Significance of the Study

Radiation protection is the science and practice of protecting people and the environment from the harmful effects of exposure to ionizing radiation. The purpose of radiation protection is to provide an appropriate level of protection and preventing the occurrence of harmful deterministic and stochastic effects to human. Possible exposure to ionizing radiation is one of the risk faced by health care professionals working in radiological facilities. Shielding is very important in achieving this protection, especially when the source is too intensive. In situations, where shielding may not be in place or where it is compromised, the resultant effects of radiation exposure in the facility may, put personnel and the public in danger. At the end of this study we should be able to identify facilities where shielding is compromised, and professional advice will be offered with report of data obtained from respective facilities.

1.6 Scope of the Study

This research is focused on identified radiological/diagnostic facility within Ibadan city where approval have been given with functional X-ray machine and carries-out medical imaging (Computed Tomography, Mammography, Magnetic Resonance Imaging and X-ray) in the facility.

1.7 Limitation of the Study

Non acceptance, unwillingness to give approval by some of the management of radiological facility to carry out experimental study in their facility thereby reducing the sample size.

1.8 Operation Definition of Terms

(i) **Radioactivity**: Radioactivity is the spontaneous disintegration of unstable atomic nuclei to form more energetically stable atomic nuclei.

(ii) **Radionuclide:** A radionuclide is a radioactive element that undergoes nuclear decay.

(iii) **Half-life:** Half-life of a radionuclide is defined as the time required for the radionuclide to reduce to half of its original size.

(iv) **Activity:** Activity is the number of nuclear reactions occurring in a given quantity of radioactive substance per unit time.

(v) **Secular Equilibrium:** Secular equilibrium occurs in a radioactive decay chain when half-life of the daughter radionuclide is much shorter than the half-life of the parent radionuclide such that the decay rate of parent nuclide is approximately equal to the production rate of daughter nuclide

(vi) **Absorbed Dose:** Absorbed dose is the amount of energy per unit mass absorbed by irradiated object.

(vii) **Exposure:** Exposure is the amount of ionizing radiation that may strike an object (human) when in the vicinity of radiation source.

(viii) **Radiation**: Radiation is defined as the emission and propagation of energy in the form of electromagnetic waves in space.

(xi) **UNSCEAR:** United Nations Scientific Committee on Effect of Atomic Radiation

(x) **ICRP:** International Commission on Radiological Protection

(xi) **EPA:** Environmental Protection Agency

(xii) **IAEA:** International Atomic Energy Agency

(xiii) **ALARA:** as low as reasonably achievable

(Xiv) **AERB:** Atomic Energy Regulatory Board

(Xv) **NCRP:** National Council on Radiation Protection

Endnotes

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Chapter Two

Literature Review

2.1 Radiation

As a result of nuclear decay, radiation is the emission and propagation of energy in the form of waves or subatomic particles from the atoms and molecules of a radioactive substance. Radiation can be classified as either ionizing or non-ionizing. Ionizing radiation is any sort of electromagnetic radiation with sufficient energy to eject electrons from atoms or molecules, producing ions. Ionizing radiation is any particle or electromagnetic wave that possesses sufficient energy to ionize or remove electrons from an atom[1]. X-rays and gamma rays are electromagnetic waves that can ionize atoms. When atoms in living cells are ionized, the cells may perish, self-repair, mutate improperly, and develop cancer[2].

The use of radiation in diagnosing and treating patients has significantly advanced the field of medicine and have saved or extended numerous human live[3]. Radiation uses however, comes with risks. A careful balance between the benefits and the risks has to be involved in the practice of diagnostics and interventional radiation. X- rays have the potential for damaging healthy cells and tissues, after interaction of ionizing radiation with the biological processes. improper protection against high exposure of ionizing radiation can lead to death, cancer, skin burn, cataract and radiation triggered infertility[4].

Radiation protection is the scientific art of protecting people and environment from harmful effects of ionizing radiation. It also describes all activities directed towards minimizing radiation exposure of patients and personnel during x-ray exposure[5]. The main objectives of radiation protection are to protect individuals and subsequent generation against the risks of ionizing radiation. There are regulatory standards and the layout as to how diagnostics center should be constructed. However, Lead(Pd) is a good shield for gamma radiation, although concrete is often used due to its cheap nature and availability. Therefore, monitoring of radiation doses received by staff in radiological facilities is of great importance[6].

2.2 Radiation in Medicine

Diagnosing heart illness without opening the chest and observing the heart is comparable to attempting to determine what is wrong with an automobile engine without opening the bonnet. Even more troublesome is the treatment of cardiac disease without "body opening." However, physicians have developed a range of methods to evaluate the heart without entering the chest. Clogged arteries are opened without opening the chest, and malfunctioning valves are repaired in a similar manner. Radiation provides excellent diagnostic benefits for a vast array of diseases and conditions, from shattered bones to heart disease[7]. It is a standard treatment for some forms of cancer. Nevertheless, DNA (deoxyribose nucleic acid), the operating handbook of a cell, can be damaged by radiation. This damage can result in cancer-causing unregulated cell division. The greater the dose, the higher the likelihood of developing cancer. This delicate balance between benefit and risk necessitates the prudent and proper use of radiation for illness diagnosis and treatment[8].

2.3 Design Layout and Shielding for X-ray Facilities

The structural design of every X-ray imaging facility is just as crucial as the facility's intended use[9]. A well-designed and protected X-ray imaging room is crucial for the radiation protection of the patient, the personnel, and the general public. Prior to installing equipment, it is advised that surveys be conducted to confirm that the approved building plans have been adhered to and that the shielding and operating conditions in terms of design controls offer protection for all individuals[10]. The design arrangement of X-ray imaging facilities will either improve or hinder the primary goal of limiting radiation exposure to levels as low as is reasonably attainable (ALARA). A well-designed X-ray imaging facility will reduce radiation exposure by including design features such as shielding and distance. In low- and middle-income nations with limited resources and a lack of finances for standardized, purpose-built X-ray rooms, where the expense of lead shielding is significant, this is rarely accomplished. In studies conducted in limited-resource settings, 'un-optimized' structural design of X-ray rooms and siting of X-ray equipment within X-ray rooms with significant deviations from established standard norms were reported. It is advised that X-ray rooms' location, structural design, and equipment layout be carefully evaluated from a radiation protection standpoint. The goal of the structural design and shielding of X-ray rooms is to protect: the patient (when not being examined), the X-ray department, visitors, the general public, and those who work adjacent to or in close proximity to the x-ray facility[11]. The X-ray room must be created with consideration for its location and the rooms adjacent to it, as well as in conjunction with qualified professionals. It is intended that X-ray rooms are spacious enough to lower radiation intensity at the operator's console and allow for the free mobility of patients and personnel on trolleys. Radiation safety in projection radiography is governed by the cardinal concepts of time, distance, and shielding, and image sharpness is enhanced through geometric means in both film screen and digital radiography[12]. It is recommended that when optimizing design solutions, the cost and practical implications of distance against shielding should be considered[12]. This has significant ramifications for developing nations, where shielding costs are relatively high. Due to the fact that the strength of radiation decreases with distance from the source, shielding expenses can be minimized and the radiation protection of individuals at barriers close to X-ray rooms can be improved by maximizing the distance between the source and the room.

2.4 Radiation Shielding

There are mathematical formulas used to predict the shielding required for an X-ray tube running at maximum rated voltage or a gamma radiation source with set energy. This study will solely discuss the shielding needs for a various 150 kV constant potential X-ray device operating at or below the maximum rated voltage. For X-ray room shielding calculations, three types of radiation are taken into account: the primary radiation, the leakage radiation, and the dispersed radiation.

The X-ray equipment emits its primary radiation through the window in its shielded casing. The X-ray machine emits leakage radiation through the shield material of the housing, and scattered radiation is produced by the interaction of the main and leakage radiations with the surrounding materials. The shield barrier used to protect against main radiations is referred to as a primary protective barrier, whereas the shield barrier used to guard against secondary radiation, such as leakage and scattered radiation, is known as a secondary protective barrier.

For calculation of primary barriers, traditionally it is assumed that the primary beam hits the barriers without being previously attenuated. This is a fairly conservative assumption, since the intensity of the primary beam is significantly reduced by the attenuation produced by the patient and the image receptor. The procedure for calculating the thickness of primary barriers is described by the following equations;

$$K_p^1 = \sum_{kVp} k_w^1(kVp) \, . \, W_{norm}(kVp) \tag{2.1}$$

$$k_p(0) = \frac{K_p^1 . N.U}{d_p^2} \tag{2.2}$$

$$B_p(x_{barrier\,1}) = \frac{p}{T.k_p\,(0)} \tag{2.3}$$

$$x_{barrier1} = \frac{1}{\alpha\,.\gamma} \text{In}\left[\frac{\left(\frac{1}{B_p}\right) 7 + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}}\right] \tag{2.4}$$

Where;

$k_w^1(kVp)$ is air Kerma of the primary beam per unit of workload (mSv/mA.min) at one-meter distance from the X-ray emitting source. It is called performance of the X-ray tube at each kVp.

W_{norm}(kVp) is the workload depending on the operating potential.

K_p^1 is the Air Kerma one meter of the RX per patient, for distribution of workload($W_{norm}(kVp)$) unshielded.

N is the average number of patients examined per week.

U is used factor

d_p is distance from the RX source to the primary barrier.

$k_p(0)$ is total air kerma at the distance d_p corrected by the use factor *(u)*.

$B_p(x_{barrier\,1})$ is maximum transmission allowed to the shielding so as not to exceed the maximum value of the kerma in air allowed *(p)*, corrected by the occupancy factor *(T)*

p is air kerma limit, according to the type of adjacent area.

T is occupancy factor

2.5 Radiation Sources

The earth has always been bombarded by high energy radiation (particle and electromagnetic). For instance, the cosmic rays from the outer space that generate secondary particle showers in the lower atmosphere. Radiation is the energy that travels through space or matter in form of a particle or wave that can be able to penetrate various materials[12]. They include alpha particles, beta particles gamma radiation, x-rays, and neutron when expelled from atomic nuclei. Ionizing radiation may be emitted in the process of natural decay of some unstable nuclei or excitation of atoms and their nuclei in x-ray machines, nuclear reactors or other instruments. Ionizing radiation carries more than 10eV which is enough to ionize atoms, molecules and break chemical bonds as expressed by quantum equation given below in equation 2.1

$$E = \frac{hc}{\lambda} \qquad (2.5)$$

Where E = is the energy in electron volts (eV)

h = is the Planck's constant

c = is the speed of light *(m/s)*

λ = is wave length

2.6 Ionizing and Non Ionizing Radiation

Radiation is basically classified as being either ionizing or non-ionizing. Radiation with short wavelength and high frequency is known as ionizing radiation. Ionizing radiation has high energy to produce ions in matter at the molecular level. While non-ionizing is extremely low frequency (radio frequency, microwave frequency, lasers, infrared, visible spectrum and ultraviolet). This is not to say that non-ionizing radiation cannot cause injury to human but the injury caused by non-ionizing radiation is generally limited to thermal damage such as burns. However not all electromagnetic radiation is ionizing. Only the high frequency portion of the electromagnetic spectrum which includes X-rays and gamma rays is ionizing.

2.6.1 Ionizing radiation (IR)

Ionizing radiation is atom-emitted energy that moves as an electromagnetic wave. People are exposed to both natural and man-made sources of ionizing radiation, such as soil, water, and vegetation, as well as X-rays and medical devices. Exposure to ionizing radiation is mainly from natural sources and man-made sources, although the health effect from both sources is the same. Natural sources include radionuclides of uranium, thorium and potassium in rocks and soils which is also known as terrestrial source and the cosmic ray from outside the Earth's atmosphere known as extra-terrestrial source. Man-made radiation is as a result of human activities such as mining, technological advancement, medical treatments, irradiated materials, nuclear related occupations, nuclear fall outs and use in nuclear weapons during war. Radon gas is the largest natural source of radiation exposure for humans. Although radon gas has always been present in the environment, its contribution to human radiation exposure has increased during the past several decades[13]. The principal route for radon is through the soil, the basements of homes and other buildings, and the air that humans breathe. Depending on the soil and rock structure underlying buildings, radon exposures might vary. Electromagnetic radiation is the most prevalent form of radiation due to its extensive use in medical procedures. They have high energy, unlike the other types of radiation. It has the ability to penetrate depending on its energy no mass. Level of energy deposited by ionizing radiation in a defined mass of material is termed the absorbed does and is measured in J/kg and the unit is Gray(Gy). The heaviest particles are alpha particles, each of which is made up of two neutrons. There is a limited range for the alpha particle due to its massive mass and high charge. While alpha particles emitted from outside the body won't penetrate the skin, they can reach sensitive internal organs like the lungs if they are inhaled or ingested. Since radon is an Alpha emitter, having a lot of it in your house is bad news. The capacity to deflect alpha particles is put to good use in smoke detectors, where even a trace of smoke in the detection chamber is enough to set off the alert[14].

A beta particle is a free electron that has very little mass and a negative charge. Beta radiation is emitted by tritium, which is abundant in the environment and is created by cosmic rays in the atmosphere[15].

In the nucleus of an atom, the changeless particles known as neutrons. The release of neutrons is a common byproduct of uranium fission in nuclear reactors. Nuclear power plants rely on neutrons to keep their electricity-generating nuclear reactions going. It travels far, has no charge, and has minimal interaction with other substances. They can be defeated only by a massive application of water or any other material composed of very light atoms.

2.6.2 Non Ionizing Radiation (NIR)

The effects of non-ionizing radiation, defined as electromagnetic waves that lack the pre-quantum energy to ionize atoms or molecules, have been the subject of a great deal of research. Radiant energy is defined as any form of energy that can pass through matter without generating charge ions yet still has enough energy to excite the substance it passes through[16].

Sunlight and lighting discharge are the natural sources of non-ionizing radiation while man-made sources are wireless communication, transmission lines industrial, scientific and medical application. Non-ionizing radiation encompasses the long wavelength (> 100nm), low photon energy (< 12.5eV). Non-ionizing radiation cannot penetrate the human body but can increase the risk of damage to the skin eyes. The non-ionizing spectrum shows how non-ionizing radiation is being grouped into two main regions; the optical and the electromagnetic fields. The optical is further sub-divided into ultraviolet, visible and infra-red, while the electromagnetic is sub-divided into radiofrequency (microwave, very high frequency and low frequency radio wave).

2.7 Biological Effect of Non- Ionizing Radiation (NIR).

Biological impacts from non-ionizing radiation are possible, but they occur only when a measurable shift in a biological system follows the introduction of specific stimuli. However, the presence of health impacts is not proof of a biological effect, it becomes a safety hazard when it causes detectable impairment of the health of the individual or of the offspring. Biological effect of NIR could be physiological, biochemical or behavioral changes induced in the organism, tissue or cell, which will depend on many factors. There may be both short-term and long-term effects on the skin, eyes, and immune system from prolonged exposure to the sun's UV rays. The most obvious short-term impacts of over-exposure to UV light are sunburn and tanning. Ultraviolent radiation induced degenerative changes in cells, fibrous tissues and blood vessels leads to premature skin ageing[17]. Over the past few years, there has been a substantial amount of discussion about radio frequency radiation. One hundred eighteen measurements were obtained at seventeen distinct based station sites, and the average exposure was found to be 0.00002% of the public exposure standards established by the International Conference on Non-Ionizing Radiation Protection (ICNIRP)[18]. Mobile phones emit radio frequency radiation in all directions, with some of it being absorbed by the human body. When a call is made, it does not always use the same amount of electricity. During calls, the maximum output power of a 900 MHz or 180 MHz mobile phone can be decreased by a factor of 100 to 2W or IW, respectively.

2.8 Interaction of Radiation with Matter

When radiation passes through absorbing medium, its transfers part or all its energy to the absorbing atoms. The mechanism of interaction that occurs depends on the type and the energy of the radiation as well as the nature of the absorbing medium[19,20].

2.8.1 Interaction with Heavy Charged Particles with Matter

Alpha particles, fission fragments and protons are heavy charged particles which interact with matter through coulomb forces between the positive charge of particle and the negative charge of the orbital electron of the absorbing medium, and thus become a free particle with kinetic energy.

K.E = (Energy given by a particle) – (Ionization potential)

The electron freed from the atom may cause secondary ionization of another atom if its energy is high enough. It will interact with matter, lose its kinetic energy, and finally stop. On the other hand, excitation occurs when the electron acquires enough energy to move to an empty state in the orbit of higher energy. The electron is still bound, but it has moved from a state with energy E_1 to one with E_2, thus producing an excited atom[21].

$$\mathrm{E} = hv \tag{2.6}$$

$$E \Rightarrow h \ \left(\frac{c}{\lambda}\right) \tag{2.7}$$

2.8.2 Compton Scattering

Compton scattering is the collision between photon free electron (bound back of electron after collide with proton particle). under normal conditions, all the electrons in a medium are not free but bound. If the energy of the photon is of the order of keV or more, while the binding energy of the electron is of order eV. However, the electron may be considered free. The photon does not appear after a Compton scattering only its direction of motion and energy change.

2.9 Radiation Exposure

Sunlight is the natural source of radiation and we also receive exposure from man-made radiation, such as x-rays, radiation used to diagnose diseases and for treatment. Small quantities of radiation materials released to the environment from coal and nuclear plants and fallout from nuclear explosives testing are also sources of radiation exposure to man[22]. Every day, low-level radiation exposure poses no threat to human health since our bodies are built to handle it. On the other hand, excessive radiation can alter cell architecture and cause DNA (deoxyribose nucleic acid) damage, causing tissue damage. As a result, this can lead to life-threatening diseases like cancer. What extent radiation causes harm is determined by:

i. The type of radiation.
ii. The amount of dose an individual is exposed to.
iii. How the individual was exposed (such as skin contact, ingestion, inhaling or having rays pass through the body).
iv. How long radiation lingers in a given area of the body.

The effects of radiation are most severe on an unborn child. Infants, children, the elderly, pregnant women, and those with impaired immune systems are more susceptible to the negative health impacts than those who are otherwise healthy.

Human protection has been primarily concerned with radiation exposure, and for this purpose, three forms of exposure have always been considered: public, occupational, and medical. Only intentional, emergency, or existing exposure scenarios can lead to exposure.

2.9.1 Occupational Exposure

Occupational exposure is exposure incurred by a member of staff or workers in the radiological facility, work associated with different stages of nuclear fuel cycle, scientific research, agriculture and industry[23]. Exposure to radiation in the workplace is limited to a maximum of

20mSv per year on average (100mSv in 5 years) and 50mSv in any one year[24]. Worker exposure to artificial sources often results in a dose of less than 1mSv per year. For this reason, this is significantly greater than the norm in the nuclear business, while it is slightly lower for the medical staff. At work, you could be exposed to harmful substances owing to a variety of unplanned, unexpected, or ongoing circumstances. However, precautions are taken for the patients' health and safety before they begin the activity in question. Good shielding, equipment and operational procedures are the primary measures of controlling exposure in a planned setting. In addition, there is the possibility of an emergency exposure, which is defined as an exposure situation that emerges as a result of an accident or other unanticipated incident and necessitates immediate action to avoid or mitigate harmful consequences. After an emergency exposure scenario has developed, however, only protective measures will be effective in lowering exposures.

When deciding whether or not to implement a control measure, it is necessary to consider existing exposure scenarios. One example is when people are exposed to radiation found in the earth's background. In addition, there are scenarios where people are exposed to radioactive substances because of outdated procedures that were either never regulated or were regulated but did not meet the needs of modern safety standards[25].

2.9.2 Public Exposure

Public Exposure refers to the exposures sustained by members of the public as a result of sources in both planned and emergency exposure circumstances. This occurs to those who reside near radioactive facilities. The major sources of public exposure to national radiation has been identified by United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR) which are: Cosmic radiation, terrestrial radiation and inhalation[26].

2.9.3 Exposure from Cosmic Radiation.

Cosmic radiation consists of fast-moving particles that exist in space and come from a multitude of sources, constantly bombarding Earth's outer atmosphere. Stars, planets, and the sun. Natural radiation exposure occurs when ionizing radiation from space enters the earth's atmosphere and is absorbed by humans. From the conclusion of world war II until the late 1980s, fallouts were thrown into the air during atomic weapon tests; these materials eventually became a part of the environment once they settled to the ground. Some of the fallouts have extended decay half-lives and are still around today[27].

2.9.4 Exposure from Terrestrial Radiation

One of the most important sources of background radiation is the make-up of the Earth's crust. The principal sources are the earth's uranium, potassium, and thorium reserves, which, via their natural decay processes, emit trace amounts of ionizing radiation. There is an abundance of both uranium and thorium. Indoor exposure to natural radiation is possible as well, as traces of these minerals are found in construction materials[28]. Radioactive gases are created by radioactive materials in the earth and bedrock, and indoor exposure occurs mostly by inhalation. Radon (Rn) is the most common natural occurring gas found in our environment today, it colorless and odorless radioactive gas that is produced by the decay of uranium-238. It does not react with surrounding matter which makes it an inert gas. Radon gas poses a health risk not only to uranium miners but also to home owners if it is left to accumulate in the home. On average, it is largest source of natural radiation exposure. Naturally occurring radioactive isotopes, such as potassium-40 and carbon-14, have the same chemical and biological properties as their non –

radioactive isotopes. These radioactive and non- radioactive elements are used in building and maintaining our bodies. Natural radioisotopes continuously expose us to radiation[29].

2.10 The Radiation and Radioactive Decays

The rate of disintegration that takes occur in a radioactive atom per second is measured by what is known as its activity. The curie was the traditional SI unit for measuring radioactivity (3.7 x 10^{10} disintegrations per second). On the other hand, the Becquerel (Bq), which is defined as one disintegration per second, is the new SI unit. The amount of activity that a radioisotope produces relative to the amount of mass that it contains is referred to as the specific activity of that radioisotope. If the half-life is increased, then the specific activity will decrease. The amount of time needed for a radionuclide to lose half of its initial activity is referred to as its half-life. Radioactive isotopes have half-lives. The formula for calculating the half-life is 0.693 divided by the decay constant (λ) of the particular radioactive isotope being studied at a specific time (t)[30].

$$\mathrm{A} = A_0 e^{-\lambda t} \tag{2.8}$$

$$\mathrm{A} = A_0 e^{-0.693/t_{1/2}} \tag{2.9}$$

From equation 2.9, A_0 is the initial activity at time 0, λ is the physical half-life, and t is given time.

Biological half-life is the time it takes for a living organism to get rid of half of the chemical compound. While effective half-life is used for pharmaceutical procedures as it incorporates both physical and biological half-life of radioactive chemical.

$$Te = \frac{Tp \times Tb}{Tp + Tb} \tag{2.10}$$

Where Te is effective half-life, Tp is Physical half-life and Tb is Biological half-life.

A stable nucleus is one that has sufficient binding energy to retain the nucleons together permanently. Most nuclei in nature are quite stable, and the vast majority of them were produced during the beginning of the universe. However, for radioactive nuclei, the strong nuclear forces do not create enough binding energy to hold the nucleus together permanently[31]. These radioactive nuclei's isotopes are known as radioisotopes. Neutron-proton balance is one of the most significant markers of the stability of a nucleus, despite the fact that there are numerous causes of instability. The majority of stable nuclei contain an equal amount of protons and neutrons. Therefore, the ratio of neutrons to protons in a stable nucleus is thus 1:1 for small nuclei ($Z < 20$) is one to one. There are various types of radioactive decay, including alpha, beta, gamma, and neutron decay, which turn radioactive nuclei into stable nuclei.

2.10.1 Alpha (α) Decay

In 1903, Rutherford made the discovery of the alpha ray, which was influenced by both electric and magnetic fields. Alpha particles are a kind of helium that have a positive charge and are composed of two protons and two neutrons. In its initial attempt to attain stability, a radioactive nucleus will first decay into gamma rays. Alpha rays are subatomic particles that have four nuclei of the element helium each (two protons and two neutrons). In general, nuclei with an atomic number that is more than 83 are more likely to decay into an alpha particle. The human body and the cells of some plants can be penetrated by cosmic alpha rays that originate in space. When a person ingests alpha particle, it causes dangerous and serious damage to human tissues but do have a low penetrating power (cannot penetrate the human skin)[32]. It's most dangerous daughters are the α-emitters (^{218}Po and ^{241}Po) which emits α-particles with high energy of 6.0MeV and 7.69MeV respectively. The continue deposition and interaction of such high energy particles with the lung leads to its damage and the incidence of lung cancer. Alpha particles are composed of positively charged helium ions and have limited penetrating power due to their charge and relatively large particle size. However, they are highly ionized and could cause severe internal damage to sensitive body organs if radionuclides that emit alpha particles are ingested (Encyclopedia Britannica). Alpha particles are composed of a stable combination of two protons and two neutrons, and their only natural source is nuclear decay. During decay, the nuclei of several heavy radioactive atomic nuclei emit alpha particles.

Alpha particle emission is exclusive to elements with a heavy atomic weight. Due to the presence of two neutrons and two protons, it has a mass of four units, making it an exceedingly massive particle[33]. This suggests that the emission of an alpha particle from a radioisotope results in the production of an element with four mass units less mass and two atomic numbers lower. This type of radioactive decay is illustrated by the change of ^{226}Ra to ^{222}Rn. Low penetrating power is possessed by the alpha particle. Alpha particles with 5 MeV of energy can travel no further than 0.04 m before being stopped. Due to its massive mass and substantial charge, however, alpha particles are extremely interacting in the region where they are created. When particles go through a substance, they lose energy through collisions.

$$^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\mathrm{He} \tag{2.11}$$

Where,

$^{A}_{Z}\mathrm{X}$ is the parent nucleus

A is the total number of nucleons

Z is the total number of protons

${}^{A-4}_{Z-2}Y$ is the daughter nucleus

${}^{4}_{2}\mathrm{He}$ is the released alpha particle.

2.10.2 Beta (β) Decay

Nuclear beta decay is a relatively slow process involving the emission of electrons and neutrinos by nucleus. Basically a proton is transformed into a neutron or vice versa inside the nucleus of the radioactive sample. If a proton is converted to neutron, its known as β^+ decay. Similarly, if a neutron is converted to a proton its known as β^- decay. Due to the change in the nucleus, a beta particle is emitted. Treatment of health conditions such as eye and bone cancer and are also used as tracers. Beta particles, which are electrons with greater penetrating strength than alpha particles, are not as destructive to live cells due to their reduced ability to ionize. Both electrons and positrons can be beta particles[34]. Some radioactive atomic nuclei undergo a spontaneous nuclear process called beta decay, during which they are converted into more stable nuclei[35]. If a nucleus contains an excessive number of neutrons, it will eventually become unstable and decay by emitting an electron. As a result, the number of protons in the nucleus is increased by one and the charge is shifted toward the positive side. In a similar vein, a nucleus with an abnormally high proton count emits a positron when a proton is converted to a neutron during decay. During beta decay, there is no net gain or loss of neutrons or protons (Encyclopedia Britannica). You can find beta emitters in nature, typically near crystalline rocks that contain heavy metals like uranium, thorium, and actinium. For example, thorium is a key ingredient of a few minerals, including thorite and monazite (a mixed rare-earth and thorium phosphate). Radioactivity is a property shared by the heavy elements of the uranium, thorium, and actinium groups, all of which have an excess of neutrons and therefore decay by the emission of electrons. The actinide elements are the fourteen chemical elements that follow actinium in group IIIB of the periodic table.

$$ {}^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z+1}Y + {}^{4}_{2}\mathrm{Y} + e^{-} + \bar{\nu} \tag{2.12} $$

$$ \mathrm{N} = P + e^{-} + \bar{\nu} \tag{2.13} $$

2.10.3 Gamma (γ) Decay

Electromagnetic radiation of an extremely high frequency is the emission of gamma decay. Giving out energy in the order to stabilize the unstable nucleus. Gamma ray emitted is of a very high energy of the order MeV, just like the x-rays. Unlike the alpha and beta decay, the gamma decay the parent nucleus does not undergo any physical change in the process, the daughter and parent nuclei are the same. Gamma rays can be used to treat cancer. Radiotherapy uses high energy gamma ray to kill cancer cells and shrink tumors. Gamma radiation from radionuclides which are characterized by half-lives comparable to the age of the earth, such as ^{40}K and the radionuclides from the ^{238}U and ^{232}Th series, and their decay products, represents the main external source of irradiation to the human body. Naturally occurring radioactive elements including uranium, radium, and thorium were the earliest sources of the electromagnetic radiation now known as gamma rays. Although gamma rays have neither charge or mass, they are a particularly penetrating form of radiation. It shares many of the same characteristics as x-rays, however these are produced by atomic processes rather than their nuclear counterparts. The gamma rays in the environment come from a variety of places. The daughter nucleus created when an alpha or beta particle is emitted from a parent nucleus may have more energy than it would have in its normal state. Emission of gamma rays, which carry the excitation energy, causes the nucleus to de-excite. The fusion of a neutron and a proton to create a deuteron is an example of a nuclear reaction that generates gamma radiation[36].

Gamma rays interact with materials in a wide variety of ways across a broad spectrum of energies. An atomic electron may completely absorb low-energy gamma radiation before emitting. The photoelectric effect describes the process by which an electron is emitted from a light source. The Compton Effect occurs when gamma rays interact with an electron in an atom, releasing the electron while scattering away some of the gamma ray's energy. A Compton electron is what you'd call an unusual type of electron. Electrons and positrons can be created when high-energy gamma rays contact with the electric field of a positively charged nucleus. Pair production is the name for this occurrence. Due mostly to these three processes, the strength of a beam of gamma radiation that penetrates matter and then emerges is reduced. Extremely powerful gamma rays have the potential to trigger nuclear fission and release a neutron or proton. Extremely high-energy gamma radiation's interactions with atomic nuclei can also generate a wide variety of mesons. The particles of energy emitted by gamma rays are called photons[37].

Gamma radiation emitted from naturally occurring radioisotopes (also called terrestrial background radiation) existing at trace levels in all ground formations, such as ^{40}K and the radionuclides from the ^{232}Th and ^{238}U series and their decay products, represents the main external source of irradiation to the human body. More specifically, natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world.

2.11 Radionuclide Production

Particle fission or bombardment that results in an unstable shift in the proton-to-neutron ratio of the nucleus can be produced through Radioisotopes. The production of a radioisotope by bombardment with neutrons and radiation emission, notably gamma radiation, is depicted here.

$$\begin{matrix}\mathrm{A}\\\mathrm{Z}\end{matrix}\mathrm{X} + {}^{1}_{0}n\ \text{(neutron)} \rightarrow \begin{matrix}\mathrm{A+1}\\\mathrm{Z}\end{matrix}\mathrm{X} + \Upsilon \qquad (2.14)$$

$$\begin{matrix}98\\42\end{matrix}\mathrm{Mo} + {}^{1}_{0}n\ \text{(neutron)} \rightarrow \begin{matrix}99\\42\end{matrix}\mathrm{Mo} + \Upsilon \qquad (2.15)$$

The nuclear fission of uranium-235 results in the production of fission isotopes such as iodine (^{131}I), strontium (^{90}Sr), and cesium (^{137}Cs), amongst others.

Another method for the production of isotopes is the use of cyclotrons, which typically include either electron capture or positron emission. Iodine-123, fluorine-18, gallium-67, indium-11, and thallium-201 are some examples of radioactive isotopes[38].

2.12 Biological Effect of Ionizing Radiation

Damage to molecular structure may result from ionizing radiation's transfer of energy into biological tissues. Transferred energy has the potential to alter the genetic code of cells or disrupt the functions of living beings (hereditary effect). Cellular modifications can be classified as either deterministic or stochastic in nature[39]. Dose proportionality between the intensity of the deterministic impact[40]. Therefore, only under extreme conditions, such as accidents, would deterministic effects occur. A single damaged cell has the potential to trigger far-reaching, far-reaching, far-reaching repercussions (such as cancer and hereditary impacts). The likelihood of stochastic effects increasing as the tissue dose is raised from a low level is proportional to the number of cells destroyed. Deterministic effects (acute effects, cataracts, malformations) only occur beyond threshold levels, in accordance with radiobiological and clinical research, with dose limits and reference values used in radiological protection being above 100mSv. Nonetheless, only genetic and carcinogenic effects are anticipated for modest dose ranges of less than 100mSv. The link between low-dose radiation exposure and cancer induction remains unclear, despite the best efforts of epidemiology[41]. Exposure of an embryo or fetus to ionizing radiation can have negative health consequences for the developing infant. There is an increased risk of leukemia and severe mental retardation and fetal abnormalities can result from exposure above the threshold dosages at specific stages of pregnancy. Low radiation effects, such as those caused by environmental/background radiation doses, are notoriously difficult to pin down because of the myriad of confounding variables that can obscure or distort their true nature.

When trying to understand the health effects of radiation, it is challenging to account for factors such as location, lifestyle choices, and individual sensitivities. For example, people who are exposed to high radon levels and cigarette smokers are much more likely to get lung cancer than non-smokers. This means that there are numerous variables that influence how much of an effect radiation has [42,43]. Both deterministic and stochastic processes can be at play when radiation affects living things.

2.13 Stochastic and Non Stochastic Effects

This category represents exposure to low doses of radiation over an extended period of time producing chronic or long term effects like cancer. Stochastic effects are those whose probability of occurrence increases with dose. We cannot say that a stochastic effect will definitely occur or not occur, we can only give the probability of such an effect occurring. The greater the dose, the greater the number of exposed cells and the greater the chance that one of them will survive and ultimately result in cancer. This is why the probability of these effects is related to dose. For the purpose of radiation protection, stochastic effects are assumed to be possible with the smallest of doses. In other words, stochastic effects are not assumed to have thresholds, i.e. doses below which the effects will not occur[44]. Whether or not this assumption is valid is not known. The severity of a stochastic effect is not increased by the dose. The severity of a stochastic effect (i.e. cancer) only depends on its location and type, something that is independent of the dose. Since the exposed cell must survive for these effects to occur, the probability of stochastic effects decreases above the dose at which cell killing becomes significant. This dose is often on the order of 300 to 400 rads. At such high doses, acute effects are a more immediate concern than cancer20. The U.S. regulatory agencies limit the possibility of stochastic effects for workers by restricting the annual total effective dose equivalent to 5 rem (0.05 Sv). The ICRP recommendation is to limit exposures to 0.1 Sv (10 rems) over five years which more or less equates to 2 rem per year. The Nature of Cancer is a non-contagious disease involving malignant tissues of potentially unlimited growth. These tissues usually form discrete masses called tumors. In the case of leukemia, a special type of cancer, no tumors are formed[45]. Approximately one in five will die of cancer. Roughly twice that many develop cancer. The older adult is, the more likely to die of cancer. Not all types of cancer appear to be induced by radiation. When a cancer has been induced by radiation, there is nothing unique about it that identifies radiation as the cause.

2.13.1 Deterministic (Non-Stochastic)

Deterministic (non-stochastic) effects are those whose severity, but not probability, increases with dose. Deterministic effects primarily result from cell killing, but delays in cell division, cell sterilization, severe changes in cell function, replacement of functional cells with fibrotic tissue, and damage to the supporting blood vessels can also play an important role. The result is the gradual atrophy of the tissue. In some cases, the loss of function may eventually reverse, e.g., a decrease in glandular secretion may only be temporary if the damaged tissue can be replaced by fully functional cells. Deterministic effects have a threshold dose below which they will not occur. In other words, it is possible to say that the effect will definitely not occur at doses below the threshold and the effect will definitely occur above a certain dose[46]. This “threshold” is the dose (or range of doses) above which the severity of the effect is large enough to be diagnosed. For example, the severity of cataracts depends on the number of cells in the lens of the eye that are killed. Cells might have killed below the threshold, but if not enough have died for cataracts to be observed we say that the effect has not occurred. Early (acute) effects are non-stochastic because they are primarily brought about by cell death. Late (delayed effects) can be deterministic or stochastic. Deterministic effects can be avoided for workers by restricting the annual dose equivalent to a single tissue to 50 rem. The dose equivalent to the lens of the eye is restricted to 15 mrem[47].

2.13.2 Delayed Effect

Delayed effect (late effect) are considered to be those effects that appears later after at least two months (in some cases, years) after exposure. This occurs usually as a result of doses exceeding the threshold value. Depending on which area and the radiation dose received. Problem caused includes: memory loss, stroke-like symptoms and poor brain function[48]. The most important long-term evaluation of populations exposed to radiation is the epidemiological study of the survivors of the atomic bombings. Due to the large sample size that is statistically representative of the population at large and the wide range of doses administered in a relatively uniform fashion, this study can be considered the most comprehensive ever conducted on the subject. Dose estimates for this population are also fairly well known. The research has found several hundred more cases of cancer in this group than would be expected if they had never been exposed to radiation. Researchers are still collecting data from atomic bomb survivors because so many of them are still alive.

Nearly 20% of all deaths can be attributed to cancer, making it the second leading cause of death in developed nations, behind only cardiovascular disease. Even without radiation exposure, about 40% of the general population will get cancer sometime in their lives. Lung, prostate, colorectum, stomach, and liver cancer have been the most common types of malignancy in men in recent years, while breast, colorectum, lung, cervix, and stomach cancer have been the most common types of malignancy in women. Cancer is a multi-step disease with a complex development process. There appears to be a series of events that must take place before a cell can become malignant and a tumor can form, but the first of these is an initiating phenomenon that affects at most a single cell. Cancer typically does not manifest until a long time has passed after the initial damage has been done. If a population were exposed to a high enough dose of radiation to cause an increased occurrence of cancer that would overcome the statistical and other uncertainties, then the probability of cancer occurring following radiation exposure could be calculated for the population as a whole. Nonetheless, the extent to which radiation is a contributor to the development of cancer is still unclear. In contrast to cancers like leukemia, thyroid cancer, and bone cancer, which typically manifest within a few years of radiation exposure, most other cancers don't show up for at least ten years, and often several decades, later. However, radiation exposure does not exclusively cause any one form of cancer, so it is not possible to tell radiation-induced tumors apart from tumors caused by any of the other many possible causes. However, a reliable scientific basis for establishing exposure limits necessitates that we estimate the likelihood of developing cancer after exposure to specific doses of radiation. The cornerstone of the knowledge about the link between cancer and radiation exposure comes from studies of patients who had medical treatment using radiation, those who were occupationally exposed, and most importantly, survivors of the atomic bombings[49]. These studies include sizable populations of persons that were exposed systemically and were tracked for substantial amounts of time. However, several studies had significant limitations, including a non-typical age distribution of participants and evidence that many irradiated patients were already ill and receiving treatment for cancer. Even more fundamentally, nearly all the findings come from studies of persons who have been exposed to radiation doses of one grey or higher, either all at once or over very brief periods of time. Little is known about the long-term effects of low dosages. Almost no direct information is available about the effects of exposure to which the general public is frequently subjected, and there are only a handful of studies on the effects of the range of doses normally received by people working with radiation. Research would have to follow a sizable sample of people over a long period of time, and even then it might be insufficient to detect changes in cancer rates above background rates. Radiation exposures above 100mSv are associated with an increased risk of cancer death by an estimated 3–5 per hundred per Sievert, as stated in a review of the literature undertaken by UNSCEAR.

2.14 Genetic Effects of Ionizing Radiation

The genetic material in reproductive cells could be damaged by exposure to ionizing radiation which results into mutations that are treated from generation to generation. The mutagenic effects of radiation were initially recognized in the 1920s, and ever since then, radiation has been a crucial tool in genetic research to generate novel mutations in experimental organisms.

The large sources of radiation from nuclear industry, the fallout from the atmospheric testing of atomic weapons and the rapidly increasing use of radiation in medical diagnosis and therapy has motivated the concerns over the effects on ionizing radiation form all this sources[50]. The genetic effect of radiation is expressed, not in irradiated persons but in their immediate or remote offspring.

Similarly, to how radiation-induced mutations can happen naturally, they might happen unintentionally as well. It is challenging to estimate what percentage of mutations in people is caused by radiation exposure as opposed to spontaneous background radiation when individuals are exposed to low levels of radiation. There is no reason to believe that humans are immune to radiation's mutagenic effects, despite the fact that it has been found to be mutagenic in all creatures investigated thus far. Because the vast majority of newly occurring mutations with measurable consequences are deleterious in experimental organisms, it is presumed that humans are equally afflicted by these mutagenic effects. Indeed, it is widely recognized that spontaneous human mutations often have detrimental implications in the form of genetic illness.

Radiation's genotoxic effects must be recognized by the study of specific outcomes, such as overt chromosome abnormalities, proteins with altered conformations or alterations, spontaneous miscarriages, congenital deformities, or early mortality. Furthermore, mutations caused by radiation may have varying effects on various endpoints. For instance, there's no rule that says the dose of radiation needed to twice the incidence of one endpoint has to be the same as the dose needed to double the incidence of another.

It is well established that exposure to ionizing radiation poses a substantial risk of cancer, and that reducing one's exposure to such radiation reduces one's risk of cancer while also considerably reducing the genetic influence[51]. As a result of advancements in technology and methodology, people are now exposed to less radiation during medical imaging and diagnosis, with less going to any organs that aren't directly being examined.

2.14.1 Effect on Offspring

If the reproductive cells either the sperm or the ovum are harmed by radiation, the consequences could be passed down the generations. Exposure of an expecting mother to ionizing radiation can harm the developing embryo or fetus. The effects of radiation on children and adults vary depending on physical characteristics. This is due to the fact that children's bodies are naturally more vulnerable because they are smaller and have less protective tissue covering them. Their internal organs will have a bigger dosage effect than those of an adult. Radiation exposure to the thyroid can occur from a variety of sources, but accidents involving releases of radioactive iodine-131 can be particularly dangerous. Children receive around nine times the adult dose to the thyroid for the same consumption[52]. Thyroid cancer has been linked to iodine-131, which is highly concentrated in this organ, as stated in research conducted after the Chernobyl nuclear power plant disaster. Young people under the age of 20 appear to be nearly twice as likely as adults to acquire leukemia after the same radiation exposure, in accordance to epidemiological studies. To add insult to injury, kids under the age of 10 are the most vulnerable. Research had confirmed that, their risk of dying from leukemia is three to four times that of an adult. Girls exposed before the age of 20 have roughly double the risk of developing breast cancer compared to women of reproductive age, as established by a number of other studies. Radiation exposure increases the risk of cancer in children, who may not show symptoms until they reach the age at which the disease typically manifests. Data analyzed by UNSCEAR, the incidence of cancer in children varies more than in adults, depending on factors such as tumor type, age, and sex. Sensitivity to radio waves. Radiation exposure to an unborn child can occur either internally (via the mother's food and drink) or externally (through the mother's environment). Fetuses receive a lower radiation dose than their mothers during most radiation exposure events due to the protective environment of the uterus. But the embryo and fetus are very vulnerable to radiation, and exposure can have serious health repercussions even at radiation doses lower than those that immediately impact the mother[53]. Negative effects on growth, deformities, brain function, and even cancer are all possible. Mammal embryonic development can be divided into three broad phases. Radiation exposure during the first two weeks of pregnancy in humans, from the time of conception until the embryo settles into the uterine wall, is known to be a potential cause of embryo death. Although research at this point is extremely challenging, data gathered primarily from animal tests verifies the deadly effect of radiation doses above certain thresholds on the early fetus[53]. During the subsequent phase, which lasts from the human embryo's second to eighth week of development, radiation poses the greatest risk of causing malformations to the developing organs and, in extreme cases, death before or shortly after birth. Animal studies have indicated that irradiating a growing organ (such as the eye, brain, or skeleton) can cause serious malformations. After week eight, when the third and final trimester of pregnancy begins, the central nervous system appears to be most vulnerable. Insight of how radiation affects developing brains in pregnant women has come a long way. Thirty out of around 1600 children born to survivors of the atomic bombings who were exposed prenatally to a dose of 1 Gy all suffered from severe intellectual impairment. Whether or not cancer can develop as a result of embryos being exposed to radiation has been the subject of debate. No significant association has been found in animal tests. The United Nations Scientific Committee on the Impacts of Atomic Radiation on the Environment has attempted to calculate the cumulative hazards to unborn children from a variety of ionizing radiation effects, including death, deformity, intellectual disability, and cancer. Overall, it predicts that no more than 2% of 1,000 live-born children exposed to a dose of a hundredth of a grey in utero may be impacted, compared to 6% of those who get the same effects naturally.

2.14.2 Radiation Effects on Animals and Plants.

In recent decades, it was widely assumed that protecting human life would automatically result in protecting other forms of life, such as plants and animals. But UNSCEAR evaluated the effects of radiation exposure on plants and animals and it was found that a theoretical dose range of 1-10Gy was unlikely to result in effects on animal and plant population.

2.15 Radiation Safety

Exposures of healthcare professionals to radiation come from a variety of sources, including diagnostic imaging procedures including computed tomography, mammography, and nuclear imaging. The purpose of radiation protection is to limit exposure to ionizing radiation where it can do the least amount of harm. The International Atomic Energy Agency has released a plan of action to ensure the safety of patients and medical personnel during interventional procedures involving ionizing radiation. Ionizing radiation is increasingly used in the medical field for the diagnosis and treatment of a wide range of conditions. The cumulative dose of radiation received by both medical professionals and their patients has increased alongside the technology's expansion into more and more fields. Many x-ray techs who work in a radiological facility do not go through residency or fellowship training on radiation dose reduction, despite the fact that adhering to radiation guidelines might be challenging[54]. Signage and posting; public dose limits; occupational dose, area surveys; sealed source inventory and leak testing; package ordering, receiving, and opening; patient dosage determination and preparation; contamination and spill minimization; waste decay in storage and disposal; reporting; record keeping; and radiation protection program audits are all elements of a comprehensive radiation protection program. The government of any given country is responsible for establishing and enforcing radiation safety standards. The guiding principle of radiation safety is “ALARA” (As Low as Reasonable Achievable). This principle simply means even if it a small dose, if receiving that dose has no direct benefit to you, you should try to avoid it. To achieve these three basic protective and precautionary measures of radiation protection plays a major role. The three measures are: Time, Distance and Shielding[55]. However good radiation protection practices require optimization of the three fundamental techniques in use as all three can be put into use at once. Exposure to individuals, should only to those who will derive maximum benefits from it (justification), making sure that radiation doses as a result to medical exposures are only enough to achieve needed diagnoses (optimization) is taken into account.

2.16 Precautionary Measures of Radiation Protection

2.16.1 Time

The amount of radiation exposure can be reduced by spending less time near a radiation source[56]. Meaning the amount of radiation an individual accumulates will depend on time the individual stays in the radiation source, because;

$$\text{Dose (mrem)} = \text{Dose Rate (mrem/hr.)} \times \text{Time (hour)} \qquad (2.16)$$

Radiation exposure can be accumulated over the time of exposure. In an X-ray procedure, the longer the exposure time the more radiation exposure to the radiographer or technician who operates the machine. Therefore, it's important to minimize the time from a radiation source. In limiting time from the source the technician has to improve his skill in intervention. As a result, being exposed to radiation for too long should be avoided.

2.16.2 Distance

The strength of the radiation drops off dramatically as distance increases. Minimize your distance from the source as much as possible. Distance is relevant to radiation protection given that ionizing radiation is known to obey the inverse square law. thus, exposure is inversely proportional to the square of the distance[57]. Therefore, keeping yourself further away from the x-ray machine is very effective approach for radiation safety, reducing your exposure by not half but $\frac{1}{4}$ (one fourth) for every doubling of the distance between you and the radiation source[58].

2.16.3 Shielding

When reducing the time or increasing the distance may not be possible, one can choose shielding material to reduce the external radiation hazard. This strategy entails interposing a substance between the radiation source and the target. By properly insulating gamma emitters, the dose can be reduced exponentially, and the dose from beta emitters can be reduced almost completely.

Therefore, the complexity of the calculations involved in the shielding design is determined by the characteristics of the radiation being blocked, the energy and frequency of emission, the source and room configurations, and the number of occupants in the space[59]. Therefore, in planning stages of any experiment or clinical procedure the selection of appropriate shielding material is highly recommended. Nuclear Regulatory Authority ACT 895 of 2015, section 91(m) individuals or group who intend to set up any diagnostic X-ray facility must satisfy the requirements for design and performance criteria for radiation emitting devices which includes the structural and room layout requirement[60].

2.17 Dosimetry

Due to the interaction with radiation and matter ionization occurs in the radiated material (energy transfers high energetic photon or particle to the atomic ionization). The ionization can thus be used as a measure for the amount of exposure with material.

2.17.1 Radiation Dose Limit.

Persons who work with sources of ionizing radiation will be monitored so that doses received by individuals do not exceed the applicable limit. The International Commission on Radiological Protection has given their recommendations about dose limits (ICRP). They have been put in place with the intention of preventing people from being unduly subjected to excessive levels of ionizing radiation. The establishment of dose limits is an essential part of radiation protection. The general population and personnel who are exposed on the job make up the two primary categories for which limitations have been established.

The public effective dose is 1mSv per year; however, greater values are permitted as long as the average over the course of 5 years is not higher than 1mSv per year.

Dose equivalent to that which would be received by the lens of the eye; 15mSv per year

The dose that would have the same effect on the skin; (average over 1 cm2) 50mSv per annum. Medical exposures are not subject to dose limitations; however, the principle of radiation shielding is still in effect[61]. For occupational exposed workers, Effective dose is 20 mSv a year, average over defined period of 5 years with no single year greater than 50 mSv. The equivalent dose to the lens of the eye is 20 mSv a year, average over defined period of 5 years with no single year greater than 50 mSv[2]. The equivalent dose to the skin is 500 mSv in a year, the equivalent dose to the hand and feet is 500 mSv in a year.

2.17.2 Count Rate

Count rate is the most basic measurement, which the number of radiation interactions that occur in a detector in a certain time. The measurement is measured in count per second or count per minute. It is very important for measuring particulate radiation and can also be used in x-ray or gamma radiation.

Radiation Quantities and Units

The amount of radiation absorbed by a person is measured in dose. A dose is amount of radiation energy absorbed by the body. Natural sources of radiation account for about fifty percent of the total annual dose, while man-made sources account for the remaining fifty percent[62].

2.17.3 Activity, A

The activity of a radioisotope is described as the number of atomic transformations per unit time. The international unit of Activity is Becquerel (Bq) and old unit is Curie (Ci). 1 Ci is equivalent to 3.7 x 10 Bq

2.17.4 Exposure, E

Exposure is a measure of the ionization caused by radiation in a medium and it is defined as charge liberated per unit mass.

To put this in perspective, the higher the energy absorbed in a medium per unit mass, the higher the ionization and therefore, the higher the risk of biological damage.

$$E = \frac{Q(coulomb)}{M(kg)} \qquad (2.17)$$

Where E is exposure in $^{C}/_{Kg,}$Q is charged measured in Coulombs and M is the mass in Kg.

The unit of Exposure is Coulomb/kg

2.17.5 Dose

Energy (E) imparted by radiation to a unit of mass irradiated matter (m).

1 Gy = 1J/kg.

2.17.6 Dose Rate

Basically dose rate is the quantity of radiation absorbed per unit of time. The ratio of an incremental dose, dD in a time interval dt. Its measured in micro Sieverts per hour.

$$D' = \frac{dD}{dt} \qquad (2.18)$$

2.17.7 Equivalent Dose (H_T)

Because alpha dose can inflict greater damage than beta dose and gamma dose, the absorbed dose (D), which is radiation energy per unit mass, does not convey the complete picture. The potential weighted to induce a given sort of biological damage is needed to compare the absorbed doses of various forms of radiation[63,64]. The weighted dose is equivalent dose and has unit of Sievert (Sv). 1 Sievert = 100rem.

Equivalent dose is a measure of radiation dose to tissue where an attempt has been made to allow for the different relative biological effects of different types of ionizing radiation.

$$H_T = \Sigma W_R D_{T,R} \qquad (2.19)$$

Where W_{R} is the radiation weighting factor, $D_{T,R}$ is the mean absorbed dose from radiation R in the tissue or organ.

2.17.8 Effective Dose

The reproductive organs are of special concern because to the danger of genetic consequences, and it is known that a given equivalent dosage of radiation is more likely to induce cancer in the lung than in the liver. However, the effective dose is calculated by weighting the equivalent dose to various areas of the body in order to facilitate dose comparisons[65]. Measured in Sievert (Sv).

1Sv = I joule/Kg or $1JKg^{-1}$

$$E_{eff} = \Sigma W_T H_T \tag{2.20}$$

Where W_T is tissue weighting factor H_T is equivalent dose with organ.

2.17.9 Collective Effective Dose

Radiation exposure to a population or group of people is measured in terms of their cumulative effective dosage. Human Sieverts are the unit of measure. The annual effective dose received by the entire human population is nearly 19 million Man-Sievert, or an average of 3mSv per person[66].

The collective effective dose is often used to estimate the total health effects of a process or accidental release involving ionizing radiation to an exposed population.

$$S = \Sigma_I E_I N_I \tag{2.21}$$

Where E_i is the average effective dose for a subgroup *i* and N_i is the number of individuals in the subgroup *i*.

2.17.10 Committed Equivalent dose

Committed dose is the quantity that measure the stochastic health risk due to an intake of radioactive material into the human body. It allows to determine the biological consequences of irradiation caused by radioactive material, that is inside the body.

$$H_T\,(T) = \int_{t0}^{t0+T} Ht(t)\,dt \qquad (2.22)$$

Where t_0 is time intake and H_T (t) dt is the equivalent dose rate at time T in the organ T

T is normally taken as 50/years.

2.18 Maximum Permissible Dose of Ionizing Radiation.

Acceptable levels of radiation exposure to a human body or its parts can be used to define the upper limits of the maximum safe dosage. The International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Council on Radiation Protection and Measurement (NCRP), the International Commission on Radiological Protection (ICRP), and the National Research Council's Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) are just some of the international regulatory bodies that oversee radiation safety. The population is divided into the general public and the radiation employees in the endeavor to establish maximum allowed dose. For the general population, the National Council on Radiation Protection and ICRP have established a limit of 1mSv/yr. However, the dose received by a radiation worker in the course of performing their job responsibilities is considered occupational exposure, while the dose received by members of the public from sources such as a planned exposure situation, emergency exposure situation, or existing exposure situation is considered public exposure.

Medical exposure is defined as the amount of dose incurred by patients during the course of their planned radiation examination. Dose limit varies by category in terms of age, body part as giving in the table 2.1

Table 2.1 Dose limit of different parts of the body

Parts of the body	Occupational exposure	Public exposure
Whole body	20mSv/year averaged over 5 years. 50 mSv/yr (maximum)	1mSv/year
Lens of eyes	1501mSv/year	15mSv/year
Skin	5001mSv/year	15mSv/year
Hands and feet	5001mSv/year	50mSv/year
Pregnant women	1mSv/year	1mSv/year

Source: The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

2.19 Activity of A Radionuclide

Activity, is measured in terms of the number of nuclear changes taking place in a given quantity of radioactive substance per unit time, is affected not only by the composition of the parent rock or soil but also by the local geological processes at work. The number of disintegrations per unit time (disintegration rate) of a radionuclide at any time is proportional to the total number of radioactive atoms present at that time.

$$dN/dt=\lambda N \qquad (2.23)$$

Where N is the number of radioactive atoms and λ is a decay constant which is the probability of disintegration per unit time for the radioactive atom and dN/dt is the activity of radionuclide.

2.20 Half Life of a Radionuclide

The amount of time it takes for a given radionuclide to decay to half its initial concentration is known as its half-life. Every radioactive substance has a certain property called half-life and it denoted by$t_{1/2}$.

Half-life is related to decay constant by

$$\lambda = \frac{0.693}{t_{1/2}} \tag{2.24}$$

2.21 Secular Equilibrium

Secular equilibrium occurs in a radioactive decay chain when half-life of the daughter radionuclide is much shorter than the half-life of the parent radionuclide such that the decay rate of parent nuclide approximately equal to the production rate of daughter nuclide[68]. It can also be termed successive decay and is given by the equation 2.25.

$$\frac{dN_d}{dt} = \lambda_p N_p - \lambda_d N_d \tag{2.25}$$

$\lambda_p N_p$ is the growth rate of the daughter from the parent, and $\lambda_d N_d$ is the decay rate of the daughter.

2.22 Radiation Detection

Presence of radiation in the environment can be detected through radiation detecting devices. No single device can detect all kinds of radiation, specification of each device can be based on the types of radiation, the ranges of radiation energy (Kv, Mv) and counts per unit time (minute or second).

2.22.1 Gamma Scintillating Detectors

Gamma Scintillation Detector is a machine that measures energy of gamma particles. The principle of scintillation detector is based on the interaction of gamma particles (photon) with electron which is photon-absorption and Compton scattering. Detection of gamma radiation yields information on various properties of the States in nuclei such as excitation energies, angular moments, and decay properties. Crystal scintillation detectors are the most effective tools for detecting gamma particles. This is due to the fact that scintillation crystals are solid, and their increased density and atomic number make them particularly efficient and sensitive instruments for the measurement of x-rays and gamma rays[69,70].

2.22.2 The NaI Multi-Channel Analyzer

The MCA system detects gamma and X-ray radiation by determining the energy of gamma and X-ray particles. The MCA system consists of three main parts: the detector, the amplifier (power-supply) and a computer. The detector is made up of two components: a scintillation crystal made of sodium iodide (NaI), which emits a light flash when it absorbs a gamma particle (-particle), and a photo-multiplier tube, in which light photons cause the ejection of electrons (photo-effect) from the surface of an electrode. Both of these components are housed inside a single tube[71].

The photo-multiplier tube increases the amount of these ejected electrons with the help of a dynode chain and high voltage (there is a potential difference between the two neighboring dynodes and this potential difference accelerates electrons released from the previous dynode). A photomultiplier tube has a minimum voltage below which the tube doesn’t give any signal out in which the total accelerating voltage ranges from 550 to 1000 volts. The scintillator only needs a small number of photons to generate a pulse of electric current that is significant enough to be recognized by the MCA and displayed on the computer, which is running a versatile spectrum analysis application. This pulse's amplitude is related to the number of photons that are emitted by the scintillator, which is, in turn, proportional to the energy of the particle that is absorbed. Before a scintillation detector paired with an MCA can be used to evaluate an unknown gamma spectrum, it must first be calibrated with radioactive isotopes of known types for which the energy of the emitted -particles are known[72]. This must be done using known radioactive isotopes. After the calibration, the unique lines in the gamma spectrum of each individual isotope that emits gamma rays can be used to identify the particular isotope.

2.22.3 Radiation Instruments

Radiation cannot be seen, felt, heard tasted or smelled. To addresses this problem, scientists have developed specific instrument for detecting specific kinds of radiation. But majorly grouped in to two types of instruments: counting equipment (used to determine number of Becquerel and the radiation quality) and the dosimeters (used to determine radiation dose).

Personal Radiation Detector (PRD)

Handheld Survey Meter

Radiation Isotope Identification Device (RIID)

Radiation Portal Monitor (RPM)

A personal Radiation detector can be worn, it's a gamma and/or neutron detector. It is small in size, smaller than most mobile phones. They are of different types designed by different companies but in some cases the device alarms with flashing lights, tones and or vibration on it detection of high radiation. it numerically displays the detected radiation intensity on a scale of 0 to 9. It can also be used to locate a radiation source.

2.22.4 Handheld Survey Meter

This is a handy detector it designed to detect amount of radiation present in a particular area and provide the information numerically in units of counts per minute, count per second, micro roentgen (μR) or microrem (μrem) per hour. This device particular detects gamma and beta radiation only. However, the detector is designed specifically to detect gamma and x- ray radiation. it has the ability to measure dose rate ranging from 0 – 1,000 rad per hour.

2.22.5 Geiger – Muller (GM) Detector

The Geiger–Müller detector is a typical detector that can detect alpha, beta, and gamma emitters. This detector was developed in the 19th century. It may be moved about easily and is a suitable option for a review of typical laboratory materials. GM is able to detect beta emitters with medium to high energy levels, such as phosphorus-32 and phosphorus-33, as well as chlorine-36 and calcium-45. However, GM is ineffective when it comes to detecting low energy beta emitters like Hydrogen-3, Carbon-14, or Sulfur-35. These are examples of such emitters.

2.22.6 Nal Scintillation Detector

In standard laboratory radioactive material assessments, Nal scintillation can be performed in a portable setting. A Nal detector is an excellent device for detecting Chromium-51, Iodine-125, Iodine-131, and Iron-59. Nal detectors are able to detect low-energy gamma radiation and are capable of doing so. Due to the fact that it is not very good at detecting certain kinds of radiation, it is not very good at detecting beta emitters like hydrogen-3, caron-14, phosphorus-32, phosphorus-33, chlorine-36, or sulfur-35. These are all examples of beta emitters.

2.22.7 Radiation Isotope Identification Device

Radiation Isotope Identification is a radiation detector with the ability to analyze the energy the energy spectrum of radiation in order to identify the specific radiation material. This device can be used as survey instrument to locate radioactive material.

2.22.8 Ionization Chamber

This chamber is filled with air and has a low voltage electrical current running through its inner wall and central anode. The central anode catches the electrons released by the formation of primary ion pairs in the air volume due to x-ray or gamma radiation interactions in the chamber wall, thereby generating a modest current. In turn, this is read by an electrometer circuit and displayed either digitally or on an analogue meter. These devices, when properly calibrated against a known radiation source, can offer a reliable measurement of the dose to air, which can then be converted into a dose to tissue using the right conversion factors. Since most ion chambers are exposed to the elements, they need to have their settings adjusted to account for variations in humidity, temperature, and atmospheric pressure. Mill-roentgens (mR) and roentgens per hour (R) are the units.

2.22.9 Neutron REM Meter, with Proportional Counter.

Neutron radiation interacts with the gas in a boron trifluoride or helium-3 proportional counter tube to generate an electrical pulse when a high voltage is applied. Atoms of boron-10 and helium-3, when they absorb neutrons, promptly release nuclei of helium-4 and a proton. Similar to the GM tube, the ionization of the gas caused by these charged particles can be captured as an electrical pulse. This proportional neutron counter needs a lot of hydrogen around it so that the neutron can decay to a thermal energy level. Neutrons can be detected by a sufficient number of surrounding filters, yielding a flat-energy response with regard to dosage equivalent. These devices are made with specific properties that allow for a secondary charge collection rate that is directly proportionate to the amount of primary ions generated by the radiation.

Thus, electronic discriminator circuits allow for the independent measurement of several forms of radiation. Neutron counters, for instance, can easily filter out gamma radiation even at very high doses.

2.22.10 Radon Detectors

Radon can be measured in a variety of environments, including homes and workplaces, using a variety of different methodologies (e.g., uranium mines). These include the collection of radon decay products on an air filter and their subsequent counting, the exposure of a charcoal canister for several days followed by the performance of gamma spectroscopy to identify absorbed decay products, the exposure of an electret ion chamber followed by its read-out, and the long-term exposure of CR-39 plastic followed by chemical etching and alpha track counting. Each of these methods has a unique set of benefits and drawbacks that has to be weighed carefully before being put into practice.

The following is a list of the most common laboratory instruments: Liquid Scintillation Counters; A typical laboratory device known as a liquid scintillation counter (LSC) is comprised of two PMTs that face each other and are aimed at a vial that holds a sample and a liquid scintillator fluid, also known as a cocktail. A flash of light is produced by the cocktail, which serves as the detector, whenever the sample releases a radiation (often a beta with a low energy level). The count is tallied if both PMTs detect the light at the same time, which is a coincidence. It is possible to produce very low background counts and, as a result, low minimum detectable activity through the utilization of shielding, cooling of PMTs, energy discrimination, and this approach to counting coincidental events (MDA). The vast majority of contemporary LSC machines are equipped with the potential to collect multiple samples as well as automatic data capture, reduction, and storage.

2.22.11 Proportional Counter

The standard proportional counter is a popular device seen in laboratories. It consists of a sample counting tray and chamber in addition to an argon/methane flow through counting gas. The majority of the units have windows that are extremely thin (measured in micrograms per square centimeter), while some have none at all. When combined with electronic discrimination, these devices are able to differentiate between alpha and beta radiation and obtain low MDAs. Shielding and identical guard chambers are employed to limit background radiation, and both of these techniques help reduce MDAs. Comparable to the LSC units described earlier, these proportional counters provide an automatic data collecting, reduction, and storage system in addition to their multiple sample capability. These kind of counters are typically utilized in the counting of smear/wipe samples or air filter samples. In addition, large-area gas flow proportional counters that have thin Mylar windows (milligrams per square centimeter) are utilized for the purpose of counting workers for external contamination as they leave a radiological control area. These counters are used for counting the whole body in addition to the extremities.

2.22.12 Multichannel Analyzer System

Counting liquid or solid matrix samples or other prepared extracted radioactive samples is a task well suited to a laboratory MCA equipped with a sodium iodide crystal and PMT (mentioned above), a solid-state germanium detector, or a silicon-type detector. Although silicon detectors are utilized for alpha radiation, most systems are designed for gamma counts. Bioassay measures including the counting of internally deposited radioactive material in organs or tissue can be performed with the use of these MCA systems when combined with properly insulated detectors. The MCA's capacity to sort counts into bins due to energy level makes it possible to pinpoint the source of emissions in every scenario. Once again, automated data collection, reduction, and storage is a standard feature of modern systems.

2.22.13 Radiation Monitoring

Employees who regularly handle radioactive materials should have their radiation exposure quantified. Radiation exposure to humans are broadly classified as internal or external exposure. Radiation monitoring is carried out to:

i. evaluate work environment and individual exposures.
ii. ensure acceptable safe and satisfactory radiological condition in work environment
iii. Maintain long term monitoring records for compliance with regulations or industry best practices.

Radiation monitoring equipment can be utilized for both area monitoring and individual monitoring of a person's exposure to radiation. Area survey meters, also known as area monitors, are the instruments that are used to measure the levels of radiation in an area. Personal dosimeters, on the other hand, are the instruments that are used to record the equivalent doses that are received by individuals who are exposed to radiation in their line of work (or individual dosimeters). Calibration of all instruments must be performed in accordance with the relevant amounts that are utilized in radiation protection.

2.22.14 Regulatory Authority

A regulatory authority is an authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorization, and thereby regulating nuclear, radiation, radioactive waste and transport safety practices. It is recommended that all member state of the International Atomic Energy Agency (IAEA) established a regulatory body to oversee all activities involving radiation and radioactive material. In light of this need, the Nigerian government established a nuclear safety committee charged with developing a law for nuclear safety and radiation protection and conducting a comprehensive survey of all facilities that make use of radioactive materials.

A sufficiently competent and independent nuclear regulatory institution for assuring protection and safety was not incorporated when the law was established in January 1995, therefore it has not been able to do its intended job. The Federal Radiation Protection Service (FRPS) and the Nigeria Nuclear Regulatory Agency (NNRA) are two examples of recent regulatory agencies that have emerged in Nigeria. Act 19 of 1995 created the National Institute for Radiation Protection and Research (NIRPR) in 2005. In addition to its regulatory duties, NIRPR also serves as a training center in collaboration with the Physics Department at Nigeria's University of Ibadan.

2.23 Existing Knowledge in Diagnostic Facilities in Nigeria

A very few studies have been carried out on shielding layout of diagnostic facilities in Nigeria due to many factors including politics. A good number of players in the X-ray diagnostic sector are private investors who have little or no knowledge of research. Sometimes government-owned diagnostic centers subject research proposals to Ethical Review Committee(ERC)to assess the relevance and importance of the research work. This committee, in some centers sits once in six months which make it very difficult for postgraduate students at Master’s Degree to carry out research works due to time constraints.

Despite the findings of a recent study on the radiographic room design and layout of radio-diagnostic facilities in the state of Katsina, measurement-wise, the rooms in the investigated centres that were designated as X-ray rooms were not among them.

Strong evidence points to inadequate radiation protection for the operator, as well as maybe other people present in the regulated area at the time of operation. In accordance to the findings of this research, the suggested value for the distance between the X-ray machine and the examination room was lower than the actual distance. This indicates that the operator of the X-ray machine in the facility would be exposed to a greater amount of radiation. On the other hand, he noted that there was sufficient use of lead aprons in all of the X-ray rooms, and that people were sufficiently monitored using thermoluminescent dosimeters[73].

The University of Maiduguri Teaching Hospital is conducting a study on occupational radiation dose evaluation with the goal of evaluating worker exposure to X-rays by measuring (using the Radiation Alert Monitor "4") and sampling (using questionnaires) X-rays both within and outside the Radiology Unit. As compared to the effective dose equivalent of 50 mSv/y for whole-body exposure advised by the National Council on Radiological Protection and the International Commission on Radiation Protection, the average radiation dose around radiology units was found to be 0.0225 mSv/y. This suggests that there was no chance of radiation-related illnesses for the radiation workers at the Radiology Unit as a result of their employment. Nevertheless, the Code of Practice of X-ray Radiation questionnaire indicated that not all relevant radiation safety laws were followed in the Unit[74].

RADSHIELD software was used to evaluate the shielding effectiveness of traditional X-ray rooms at ten radio diagnostic centers located in Kano Metropolis. The study was conducted using a prospective, cross-sectional design using RadShield software version 1.1. The shielding design goal was entered into the program along with other parameters like the average number of patients per week, the distances between each wall and a radiation source, the occupancy factor, and the use factor. In the radiology department of every conventional X-ray room used in the investigation, the design barrier thickness was sufficient[75] though Room III had the largest room size of 49.2 m2 while room X had the least room size of 12.8 m2. Room II had the longest source image distance (SOD) of 180cm while room IV had the shortest (120cm). Structural shielding evaluation: a case study of the radiography room of a rural hospital in Jos, In north central Nigeria. This study evaluates the shielding barriers radiography room. The workload information, generator voltage waveform, anode material, filtration, and anode angle with XRAYBARR calculation model were used to estimate the thickness of lead, concrete, gypsum, steel, plate glass, and wood required to shield the X-ray facility installed in the hospital. The design dose limit was compared to the estimated shielded dose, and the calculated shielded barrier thickness to the design shielded barrier thickness was also compared. The unshielded radiation doses inside the X-ray room were high, indicating that the radiological department of the study area is not minimizing radiation doses to patients. The calculated doses beyond the barriers were greater than the design dose limit, indicating that the shielded barriers in place were not adequate and did not comply with the international standard[76]. The tested X-ray rooms did not comply with international recommendations for shielding thickness.

Assessment of effectiveness of radiation shielding materials for X-rays facilities in a federal teaching hospital in Gombe State. This was achieved with the use of rados 200 survey meter to measure scattered radiation exposure at a prescribed distance during radiological examinations. The shielding materials considered in the conventional X-ray machine room in the radiology department of the Federal Teaching Hospital, Gombe, during examination and measurements of exposure were concrete plus lead, wood, wood plus glass respectively. The measurements were carried out by positioning the survey meter at five different points. The result obtained for the concrete plus lead, wood, and wood plus glass shielding barriers ranged from 0.05 ± 0.01 to 0.12 ± 0.01 μSv/hr, 0.08 ± 0.01 to 0.13 ± 0.01 μSv/hr and 0.08 ± 0.01 to 0.15 ± 0.01 μSv/hr respectively. Annual Effective Dose Equivalent (AEDE) values for concrete plus lead, wood, and wood plus glass shielding barriers ranged from 0.2428 to 0.5826 mSv/y, 0.3884 to 0.6472 mSv/y and 0.4044 to 0.7283 mSv/y respectively. All the radiation shielding barriers are all effective with the concrete plus lead barrier being the most effective. Based on the results obtained, the AEDE were within the recommended permissible limit of 1 mSv/y[77].

An investigation was carried out in the Southeastern region of Nigeria with the purpose of analyzing the structural design of diagnostic X-ray imaging facilities as well as compliance with shielding design goals. The results of the study agreed with those found in the previous research, which indicated that the majority of X-ray rooms used for diagnostic purposes in developing nations are not created in accordance with the suggested standard specifications[78]. There were three distinct structural designs of diagnostic X-ray rooms provided by the radio- diagnostic centres that were covered in the study by There were also three distinct types of shielding materials employed and levels of radiation transmission through barriers. One of the centre had a distance of only 100 centimeters between the X-ray tube and the chest stand, which is significantly shorter than the recommended distance of between 140 and 200 centimeters for a typical chest X-ray. As a result of these findings, the designs of radiology rooms need to be standardized, and they need to undergo regular radiation safety assessments as advised by regulatory organizations.

Shielding assessment in two computed tomography facilities in South-South Nigeria: How safe are the personnel and general public from ionizing radiation. The equipment used in this study consisted of two newly installed General Electric (GE) Revolution ACTs CT machines. Technical parameters used were a thoracic/dorsal spine scan, which was rarely done in both facilities. A calibrated Inspector USB (S.E. International, Inc.) survey meter was positioned < 50 cm from each barrier at various points to determine the average shielded air kerma The average ADR to the controlled and supervised areas in CT1 was 0.563±0.25 and 0.369±0.11 mSv/yr, respectively. Also, the average ADR to the controlled and supervised areas in CT2 were

0.410±0.28 and 0.354±0.04 mSv/yr, respectively. The average shielding design goal to the controlled and supervised areas for CT1 was 0.00898±0.0041 and 0.0059±0.0028 mSv/Week, respectively. Similarly, the average shielding design goal for the controlled and supervised areas for CT2 was 0.0066±0.0044 and 0.0057±0.0019 mSv/Week respectively. The average ADR and shielding design goals in the controlled and supervised areas from both CTs were within acceptable limits for radiation staff and the public[79].

Investigating the protective effectiveness of the shielding parameters for diagnostic X-ray rooms in some selected hospitals in Agbor metropolis in Delta state. In this study, a radiation detector, Geiger Muller Counter 320 plus was used for the measurement of radiation in the selected X-ray centers which was chosen in other to ascertain the degree of exposure of X-ray machines at exactly 1m from the primary source. The researcher examined a total of three hundred and eighty (380) patients. Results obtained from the three hospitals investigated were found to be inconformity with the recommendations of National Commission on Radiological and Protection (NCRP) (70) and (116) protocols. Protective shielding parameters' results obtained in this study were founded lower than the standard recommended maximum values. The study showed that the walls of the X-ray rooms of the hospitals investigated have adequate shielding parameters. It was therefore concluded that the X-ray shielding facilities for diagnostic X-ray rooms in the selected hospitals were adequate and safe for patients and staff[80].

Safety of Ionizing Radiation in Selected Conventional X-ray Diagnostic centres in Calabar and Uyo metropolises. Radex 1212 A-A battery-powered survey meter was used, Radiation measurement was taken at three different spots, and the recorded data were analyzed. The mean calculated effective dose per week in mSv/week for each diagnostic center was given as 0.130 ± 0.0068mSv/week. Also, the mean calculated effective dose per year in mSv/year for each center was given as 0.66 ± 0.35mSv/year. These values are below the National Commission on Radiation Protection (NCRP) recommendations of 0.02mSv/week and 1mSv/year respectively. From the results, the mean calculated chance of developing cancer was 3.66 ×10-3%, which was lower than the NCRP recommendation for continuous public exposure of 5.5×10-3%. It's concluded that the integrity of the shielding designs and their dimensions assessed are safe[81].

The current research is a structural survey of ten X-ray imaging facilities in a setting with limited resources. It evaluates the structural designs of the X-ray rooms and the adequacy of the shielding, with an emphasis on the x-ray room dimensions and layout, relative distance from the tube to various protective walls within the room, and location of the x-ray tube and control console. This is followed by a radiation safety assessment of these areas. From the tube to the numerous protective walls located within the room, as well as the placement of the X-ray tube and control console, a radiation safety evaluation will then be performed on these regions[74].

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Chapter Three

Methodology

3.1 Research Design

Private diagnostic centres were selected for the study because a lot of the government- owned facilities are not in good conditions and patients are referred to the private centres. This has created more traffic for these centres and there is an urgent need to ensure safety and regulatory compliance in such places. It is also important to note that a lot of these private centres are not aware of the regulation and practices of NNRA, thereby trivializing radiation protection practices. The present study was conducted in ten of the eighteen mapped diagnostic X-ray facilities in Ibadan, southwestern Nigeria. The facilities were randomly chosen. The information required from each diagnostic centre mainly includes the machine specification, kilo-voltage peak (kVp) and milliampere-seconds (mAs), machine location, year of installation, year machine was manufactured, room size, distance from tube to patient bed, wall, door, control panel barriers status, wall thickness, status of entrance door and attenuated dose. Radiation doses were recorded at different locations by radiation dose-rate meter. The dose-rate meter was calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) of the National Institute for Radiation Protection and Research.

The ionizing radiation meter that had been calibrated (a RADEYE G-10) was used for area monitoring of various strategic locations around the radiographic room when the X-ray machines were exposing at working capacity per centre studied. The meter's serial number was RDS-01921, and it had been calibrated on the 17th of December, 2021. The information on recorded radiation that was collected from each point within the rooms as well as the diagnostic X-ray rooms themselves was compiled and analyzed.

A flexible, non-elastic meter-rule was utilized in order to take accurate measurements of the X-ray examination room.

A calibrated radiation survey meter with serial number RDS-01921 was used to assess the dose rates at different points of concern. The same survey meter was used to estimate annual effective dose to personnel in all centres. Measurements were taken three times at each point and the mean readings were recorded. To facilitate entry into the facilities, letter of introduction (with underlined benefits for the diagnostic centre) was written and issued to all 18 mapped diagnostic facilities seeking permission to carry out the experimental survey in their respective facilities.

The underline benefits for the radiological facilities include:

i. Ascertain the level of radiation safety for personnels in the facility
ii. Ascertain the level of radiation protection for the public

iii. Provides professional guidance and services in instances where radiation safety is compromised or inadequate.

iv. Improve compliance of facility to radiation safety guidelines thereby enhancing the image of the centre.

The experimental assessment survey of radiation level during radiological procedures took place in ten (10) of eighteen diagnostic facilities. This is because the eight of the facilities didn’t give me approval to carry out the study in their centre. In each of these facilities, before the commencement of the survey, X-ray machine tube was warmed up and the model, manufactured date, installation date were all recorded. The Maximum and minimum kilo-voltage peak (kVp) and milliampere-seconds (mAs) vary in each center, but the distance of the tube to the dummy object were all 1.5m across all facilities. Empty carton was used as dummy object in the each of the room where exposure took place in all the facilities. Background radiation before exposure in all centres were also measured and recoded accordingly.

3.2 Research Instrument

The following material and device were used in carrying out the research work:

Three radiation survey meters, (two Rad TRACE) and one RADEYEG – 10 gamma survey Meter. (The two Rad Trace meter were relatively new, year 2020 and 2019 models).

A measuring tape, a dummy carton (used to represent a human) and recording materials.

3.2.1 RadTRACE Survey Meter

In measuring radiological facility or industries, a wide range of devices have been manufactured for monitoring ionizing radiation and radioactive contamination. Specific instruments have not been developed specifically to be used in radiological facilities but instruments which are capable of detecting X-rays and gamma energies in a particular location are available. Survey meter are used to monitor radiation levels in and near laboratories where radioactive materials or other radiation sources are present. RadTrace survey meter is a reliable dose rate meter designed to improve the safety of workers exposed to ionizing radiation. They are generally battery operated and portable. It's easy to use, and allows measurement of gamma dose and dose range with a very fast responds time of one second.

When switched on the device detects the presence of X-ray or gamma within the location. It automatically displaces a reading on the LCD backlit interface with an auto scale function switching between µSv/h and mSv/h for accuracy. It is small enough to fit in a pocket, yet large enough to be mounted on a belt or hung on the wall. RadTRACE can be used with professional applications regardless of whether they are managed by experts or novices. Infrared interfaces allow for the storage and transport of data to a computer. Ultra-low power technology allows the gadget to function reliably and efficiently for extended periods of time. Up to a thousand hours of independence can be expected from using only AAA batteries (about 125days on 8 hours per day). It works in temperatures as low as -20 degree Celsius and as high as +50 degrees Celsius. Up to 650 values of measurement information can be saved and evaluated with the available data display program[1].

The GM tube in RadTRACE is energy adjusted, therefore the device can monitor radiation rates from 0.1 Sv/h to 100 mSv/h. The dose and dose rate can be recorded and retrieved at a later time thanks to the built-in memory and vibration alarm.

3.3.2. The Thermo RADEYE G-10 Personal Dose Rate Monitor.

The thermo Radeye G-10 is a sensitive and very rugged device designed for quick and reliable for measurement of X-ray and gamma radiation dose rates. Very easy to use and it measures very low gamma energies, even the smallest change in radiation rate are displayed immediately. The feature of this device is the use of sophisticated low power technology components and microprocessor based, completely automatic self-checks. No maintenance is required. It has a time clock which is provided to add a time stamp to all buffer data. All measurement/data are stored in the memory and can also be transferred to a computer. It has measurement range of 0.5μSv/h to 100mSv/h and weight of 0.18kg. sufficient battery life (900hours) operation of 2AAA battery. The Radeye G-10 is designed with a sensitivity count rate for Cs-167(662KeV) 1.7 cps per μSv/h. The device has a bright backlit LCD display and vibrates on detecting a high range radiation[2].

Figure 3.1 RadTRACE radiation survey meter.

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Figure 3.2 Thermo RADEYE G-10 Survey Meter[2]

https://www.fishersci.com/shop/product

3.3 Data Collection

Reading of dose rate per radiological facility is designed to be carried out in the available office and area within the facility and behind the facility. Different days was allocated for data collection to make sure all necessary areas and protocols are not jumped. The background dose rate was checked across all facility and all tube was wormed before the commencement of experimental survey.

3.4 Annual Personnel Dose Estimation

The survey meter measures in micro Sievert ($\mu Sv/h$)$per\ hour$. An Excel Spreadsheet (2016 version) was used to calculate the annual dose a radiation worker is exposed to as well as the shielding accuracy

$$D(eff) = D(p).h.n.T \tag{3.1}$$

Where, D(eff) is the effective dose to a person in a single year, D(p) is the measured survey meter reading at a particular position, h is the number of hours an individual spends in the measured point. n is the number of days an individual works in a year and T is the occupancy factor. The occupancy factor is conservatively chosen to be one (1) for the purpose of this study. The result of each procedure will be discussed from the scientific point of view and proper recommendations will be given based on the result obtained. Six of the 10 diagnostic facilities had their floor plans drafted in order to demonstrate their size and the relationship of adjacent structures (such as offices, reception area, toilets, X-ray archive etc.) In addition, the chest-stand, the X-ray machine, and the control panel were depicted in the schematic, and the distances between each of these components were measured.

3.5 Description of the Study Area

Three out of the general diagnostic centers involved in the study were purpose- built; the remaining seven were only converted to suit the purpose. Figures 3.1 to 3.6 are sketched layouts of six out of the ten centres studied. Diagnostic Centre A has a room dimension of 5.0m x 4.0m with a minimum and maximum distance 100cm and 280cm from the X-ray tube to the nearest wall or protective barrier. A 2.23mm lead sheet bonded to plywood was used as the shielding material. Diagnostic Centre B has a room dimension of 8.0m x 5.0m with a minimum distance of 3.8m to the console area. This centre is purpose-built with a minimum wall thickness of 0.3m around the X-ray room. Diagnostic centre C has a room dimension of 4.0m x 3.2m. the walls of the X-ray room were made with ordinary hollow blocks thereby offering no protection for the workers and patients. Diagnostic Centre D has two X-ray rooms with dimensions 3.3m x 3.8m and 3.0m x 3.8m. Diagnostic Centre E and F have room dimensions 3.5m x 3.4m and 4.0m x3.2m respectively. Both centres were purpose- built and a 2mmPb were bonded with plywood on the wall of the rooms.

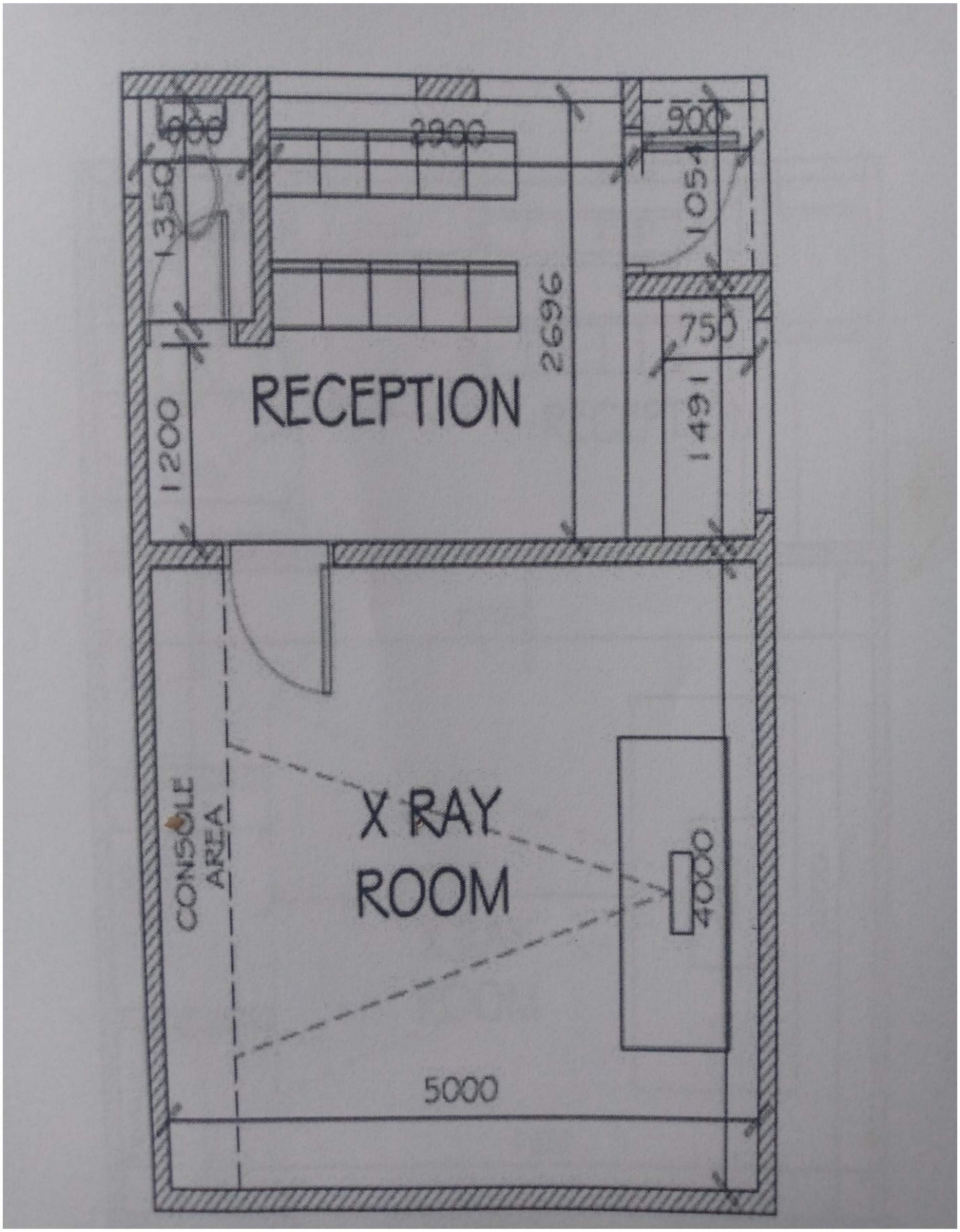

Figure 3.3: Design layout of diagnostics center A

Researcher: Okereke Igwe Chigbo 2022

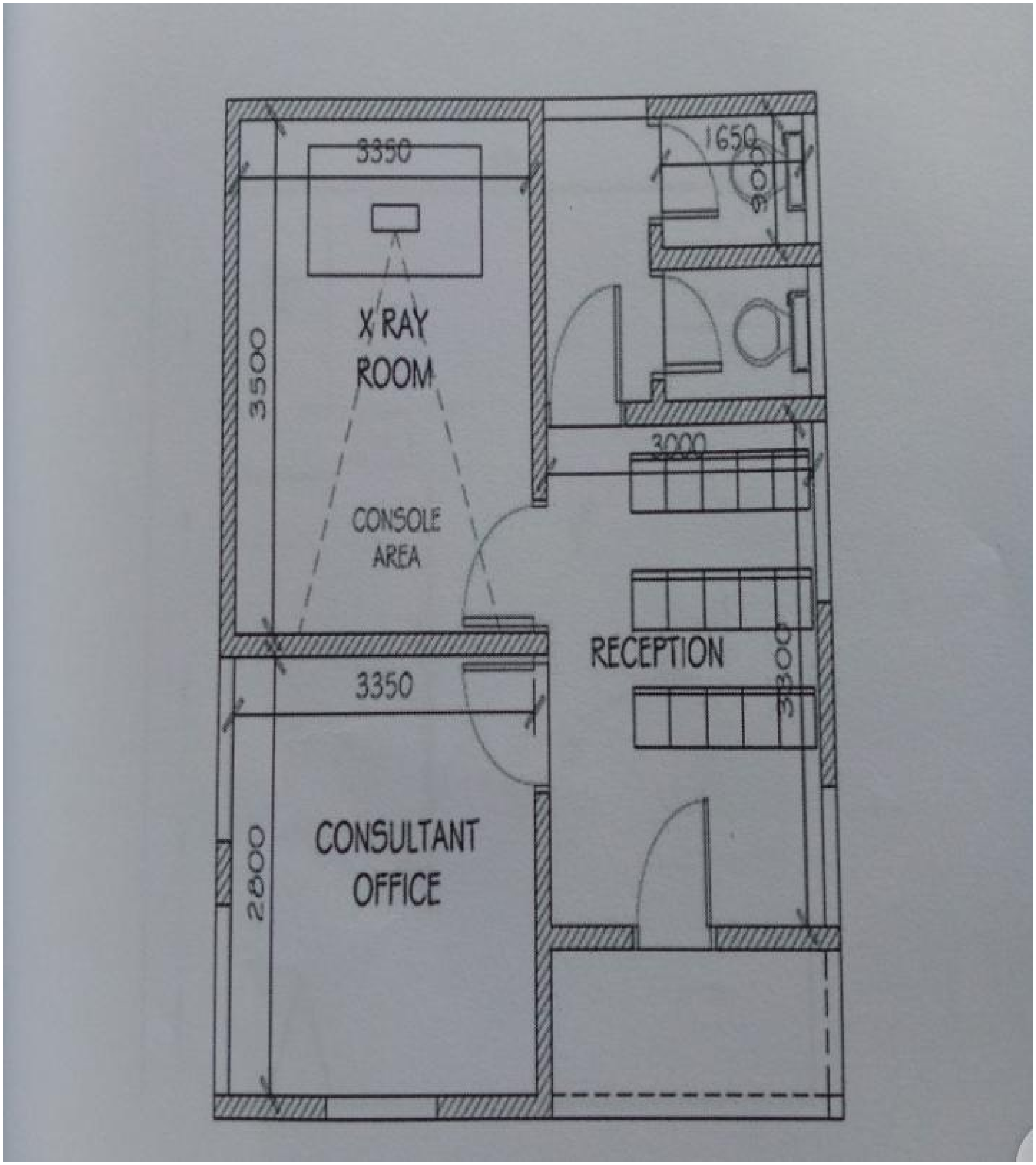

Figure 3.4: Design layout of diagnostics center B

Researcher: Okereke Igwe Chigbo 2022

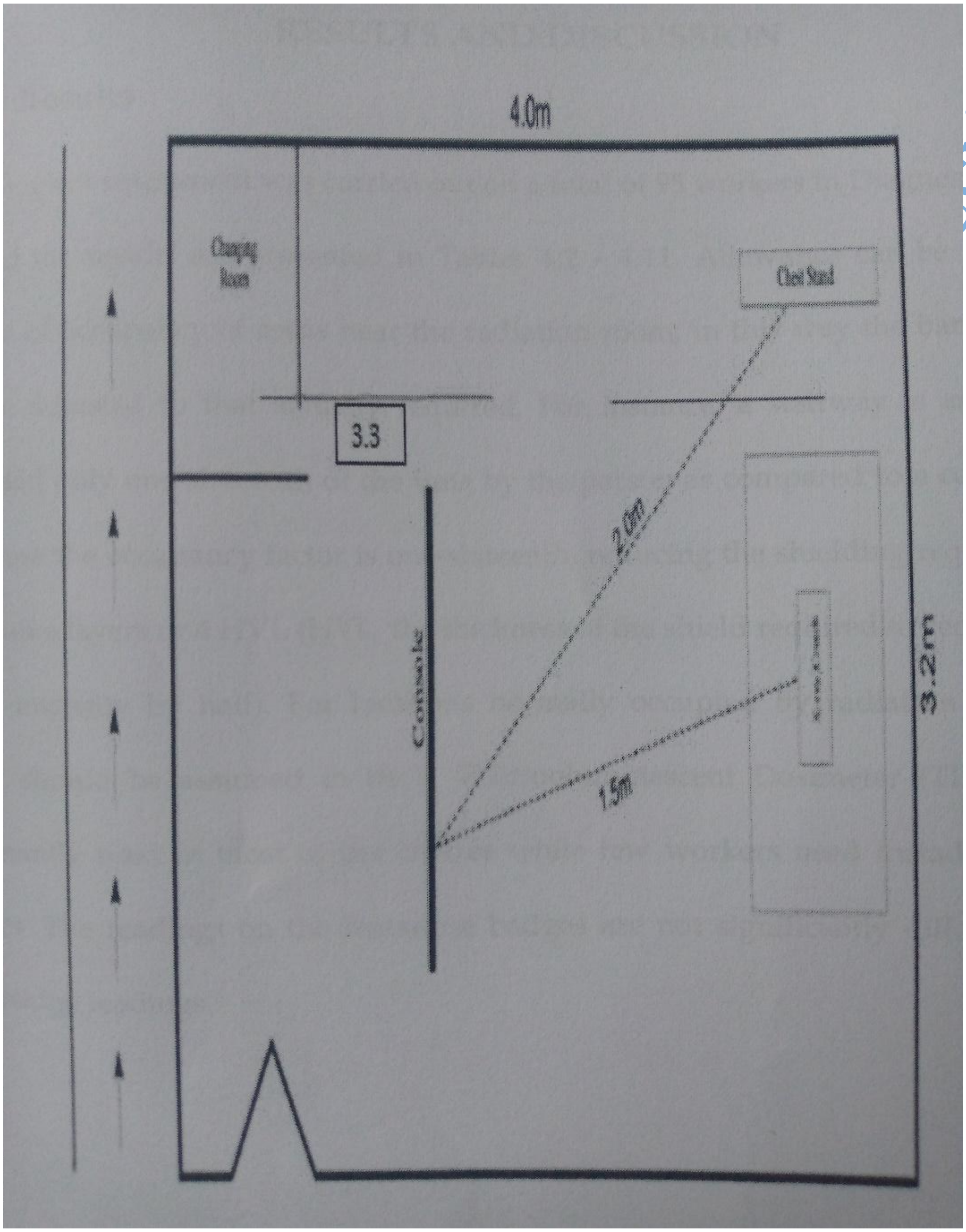

Figure 3.5: Design layout of diagnostics center C

Researcher: Okereke Igwe Chigbo 2022

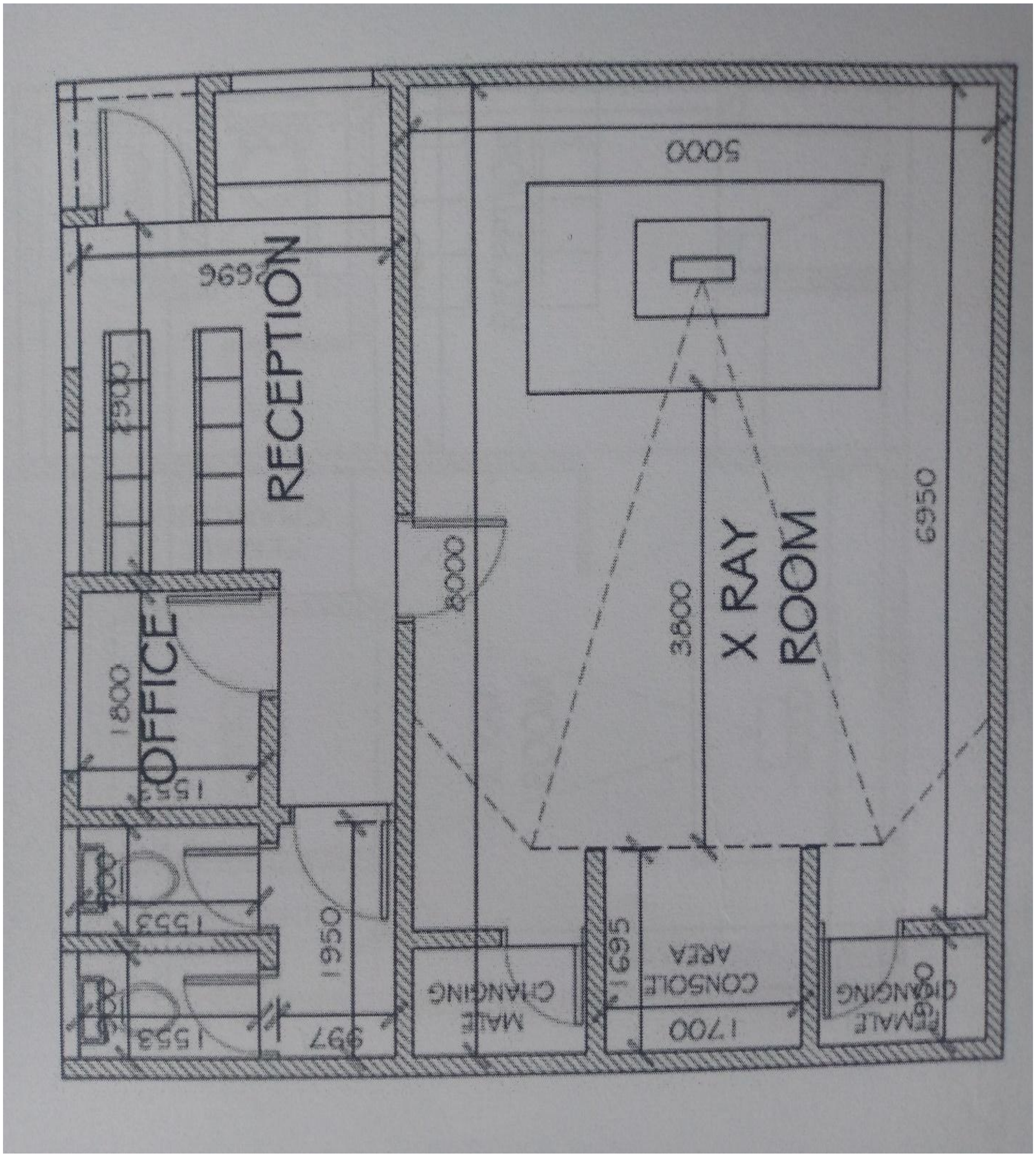

Figure 3.6: Design layout of diagnostics center D

Researcher: Okereke Igwe Chigbo 2022

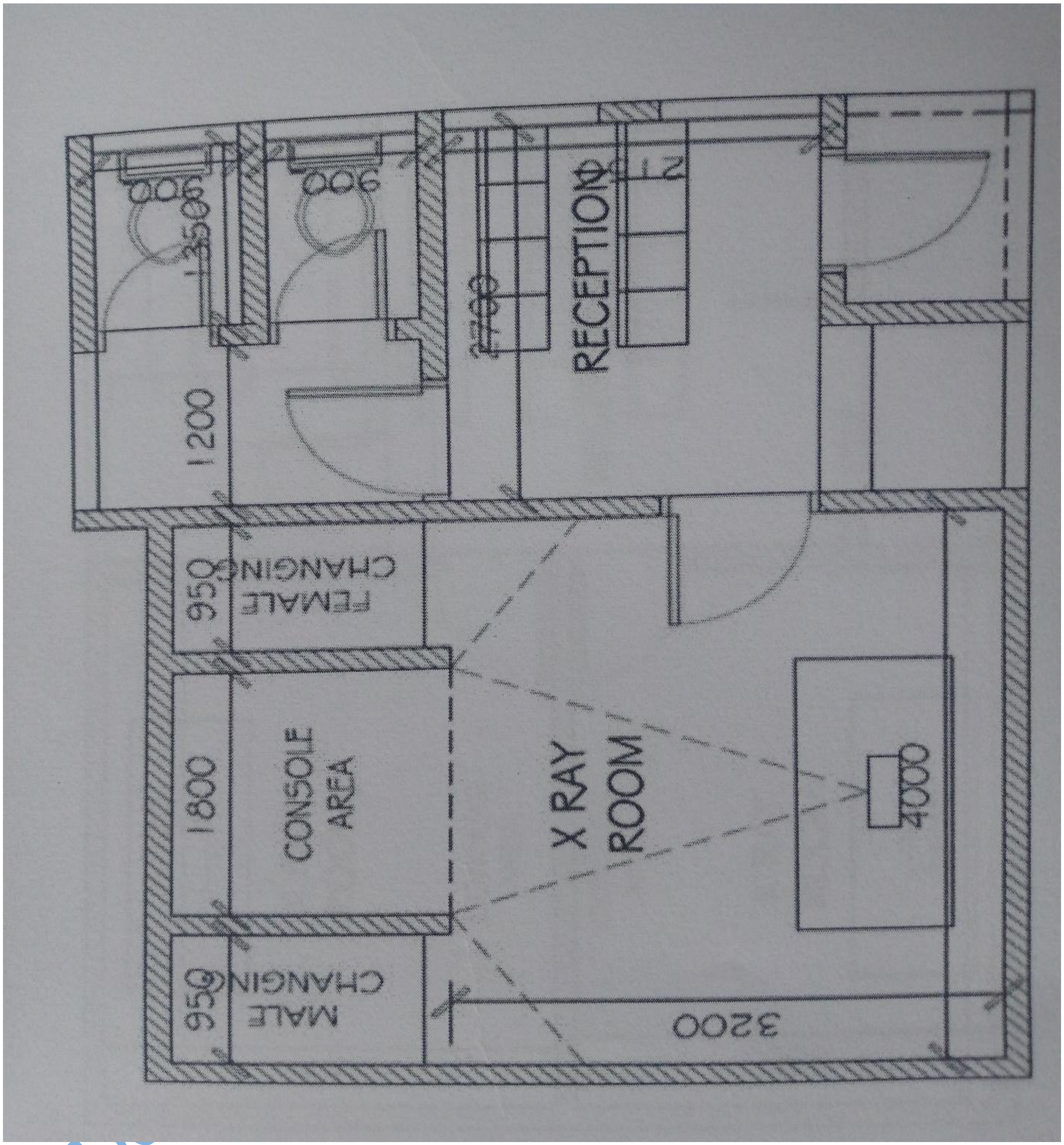

Figure 3.7: Design layout of diagnostics center E

Researcher: Okereke Igwe Chigbo 202

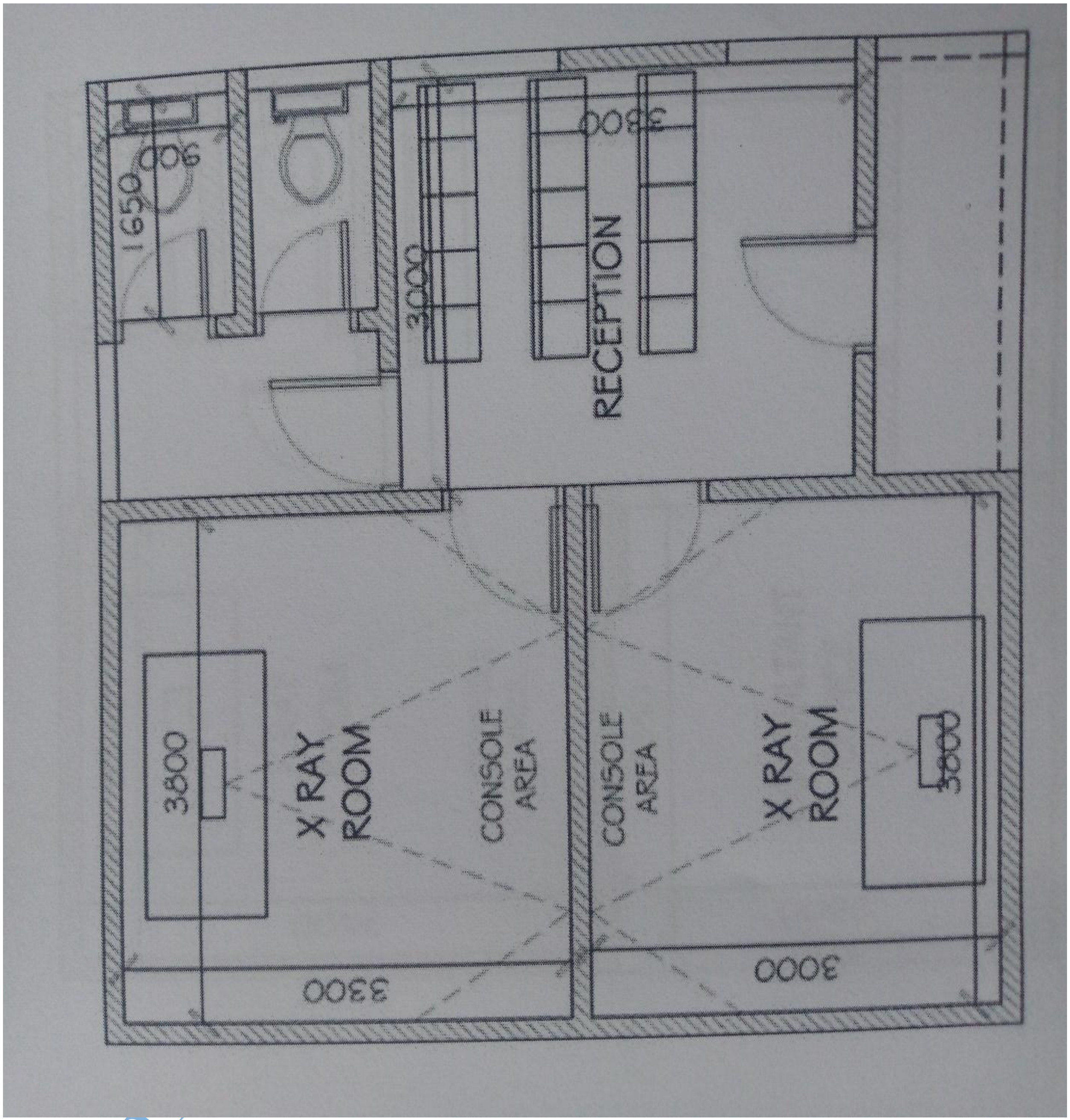

Figure 3.8: Design layout of diagnostics center F

Researcher: Okereke Igwe Chigbo 2022

Figure 3.9: Picture from Centre F showing the dummy object before exposure.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.10: Picture from Centre G show the dummy object before exposure.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.11: Picture from Centre G, showing the wooden door without any lead lining

Researcher: Okereke Igwe Chigbo 2022

Figure 3.12: Picture from Centre H, with the chalk indication.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.13: Picture from Centre H, no sign of radiation protection was seen in this facility.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.14: Picture from Centre H, showing the back window covered with carton.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.15: Picture from Centre D, showing the X- ray machine.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.16: Picture from Centre E, during a lumbosacral procedure.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.17: Picture from Centre E, showing the CT in a well shielded room.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.18: picture from Centre H showing the curtain used to demarcate the waiting area from the X-ray room.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.19: picture of door indictor in facility J.

Researcher: Okereke Igwe Chigbo 2022

Figure 3.20: picture of door with well lead lining in facility E.

Researcher: Okereke Igwe Chigbo 2022

Endnote

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Chapter Four

Results and Discussion of Findings

4.1 Results

Radiological assessment was carried out on a total of 10 (A-J) diagnostic facilities, which four (4) are purposed built and six (6) are converted. Total of 98 workers were sighted in this diagnostic facilities. The results are presented in Table 4.1 – 4.10. From the table, years of manufacture of equipment used in the various facility is indicated, year of installation, position where the readings were taken, model of the machine, working hours, were all noted. The annual effective dose (D_{eff}) to workers is also calculated. However, allowance can be made for the degree of occupancy of areas near the radiation room; in this way the barrier thickness can be adjusted to that actually required. For instance, a stair way is assumed to be occupied only one-sixteenth of the time by the person as compared to a controlled area. Therefore, the occupancy factor is one sixteenth, reducing the shield requirement by 4 half value layers of 4 HVL (HVL, the thickness of the shield required to reduce the initial beam intensity by half). For locations normally occupied by radiation workers, this factor is assumed to be 1. Radiation dose meter was dominantly used in all the centres to take reading at different locations. The readings are taken as the exposures are being made using a dummy to represent human and the distance from the tube to the object were all subjected to be 1.5m with a measuring tape except diagnostic Centre I which was 1.01m.

Table 4.1 Center A

Machine information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp & mAs**	**m**	**Location**	**IDR**	**WH/ D**	**T**	$D_{(eff)}$
Allengers E7239X / Sept 2007 (2017)	125 - 40kVp & 500 - 0.1mAs	80kVp/ 40mAs	1.5	Background	0.10	10 /6	1	0.006
				Console area	2.75	10/6	1	0.165
				X-Ray Door	1.05	10 /6	1	0.063
				Reception area	0.23	10 /6	1	0.0138
				Behind X-ray room	0.21	10 /6	1	0.0126
				Laboratory	0.14	10 /6	1	0.0084

Researcher: Okereke Chigbo 2022

Key for the table:

EQ/MD &(ID) - Equipment Model/Manufactured Date (Installation date),

Max/Mink kVp & mAs - Maximum/Minimum rang of kVp and mAS,

m - Distance from the tube to object

WH/D - Working Hour /Day,

T - Occupancy Factor,

IDR (µSv/h) - Instantaneous dose rate

$D_{(eff)}$(mSv/week) - DATA Estimated annual dose to workers.

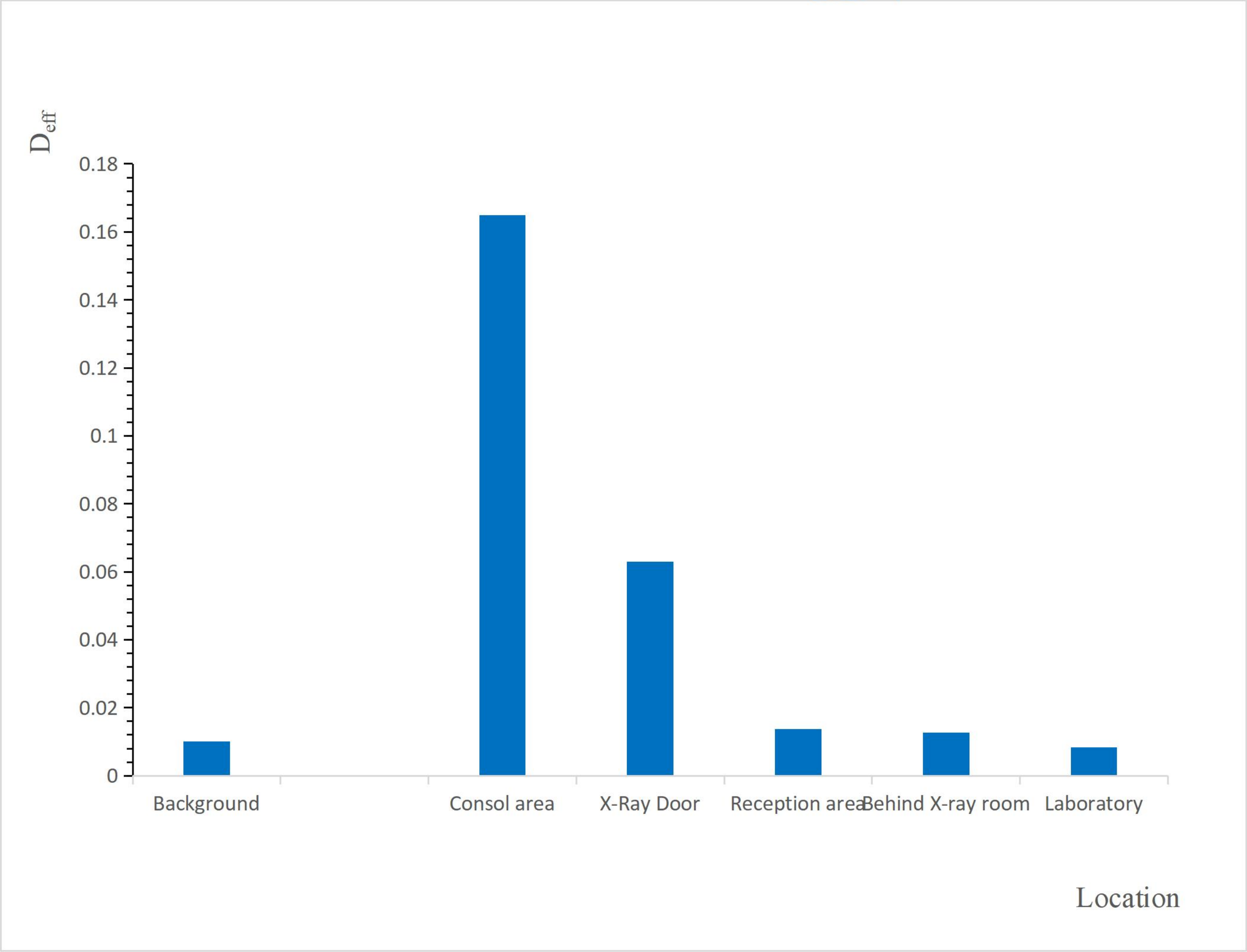

figure 4.1. Annual effective dose at different locations in the study area A.

Researcher: Okereke Chigbo 2022

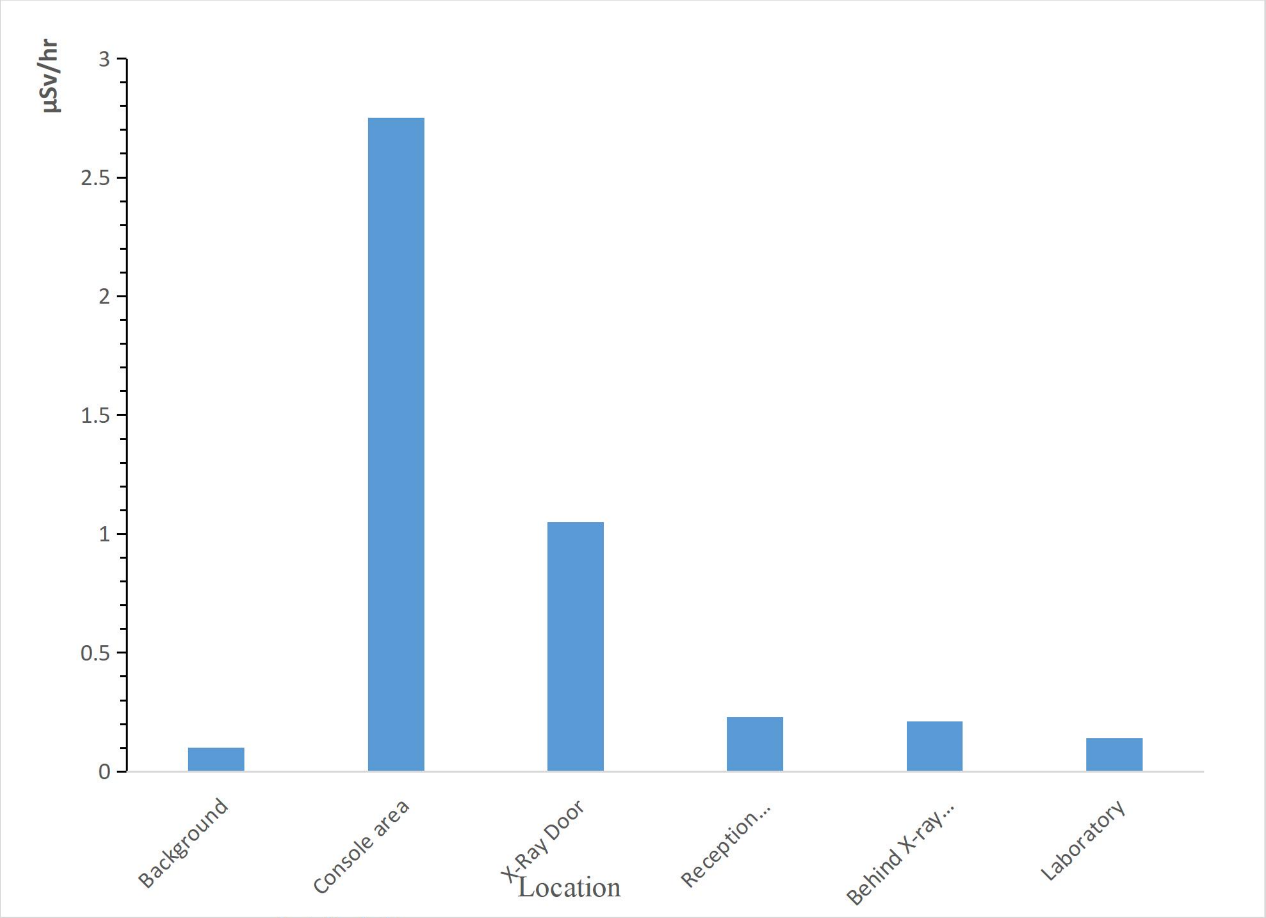

Figure 4.2. Radiological facility A Radiation Dose rate at different locations

Researcher: Okereke Chigbo 2022

Table 4.2 Center B

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
300Ma Medical Diagnostic X-Ray Machine	120 -20kVp 300-50mAs	100KvP/50 mAs	1.5	Background	0.10	10 /6	1	0.006
				Consol area	1.28	10 /6		0.0768
				X - Ray room Door	0.31	10 /6	1	0.0186
				Next room X-ray room (general LAB)	0.25	10 /6	1	0.015
				Reception Area	0.57	10 /6	1	0.0342
				Corridor	0.19	10 /6	1	0.0114

Researcher: Okereke Chigbo 2022

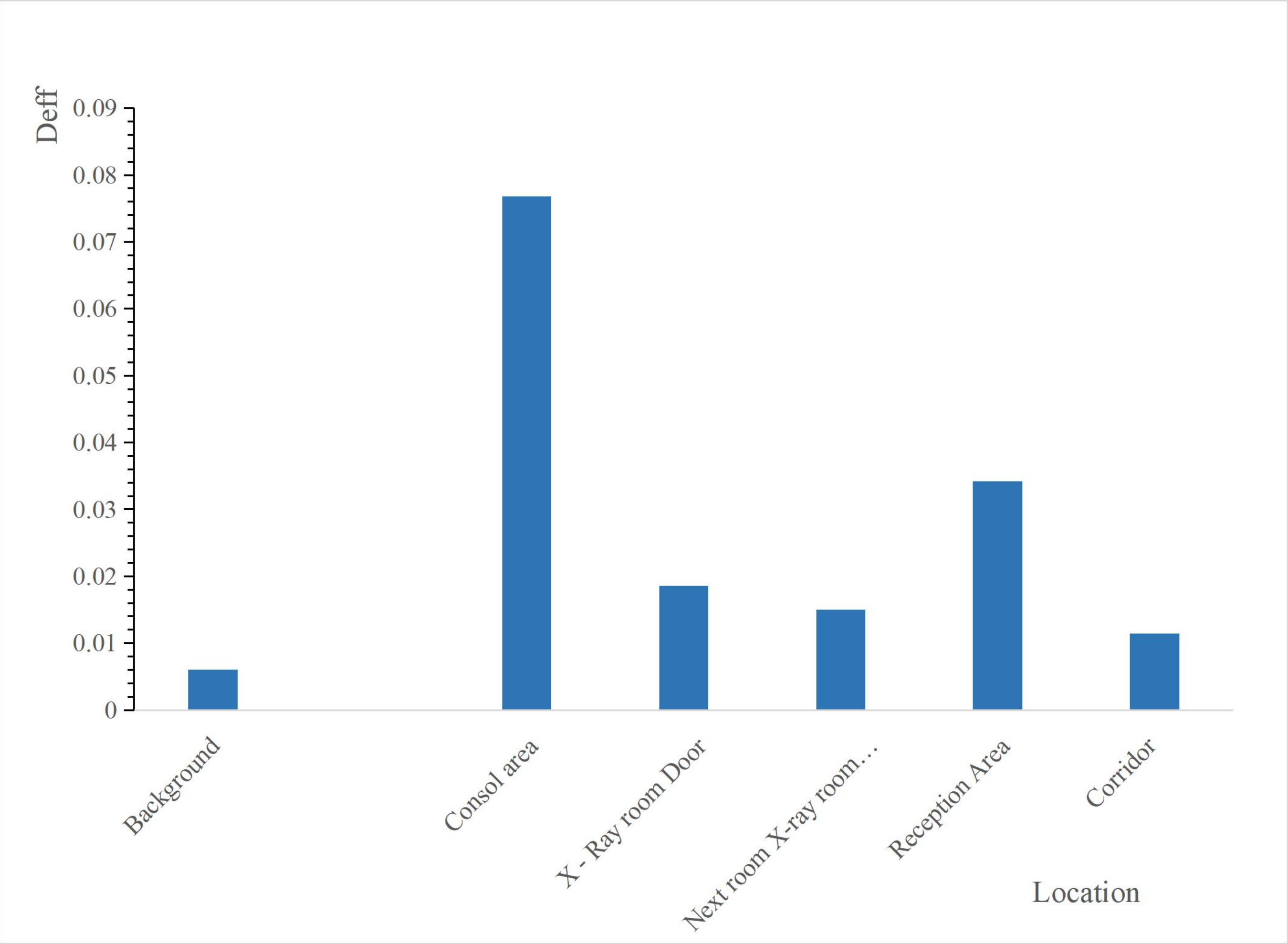

Figure 4.3. Annual effective dose at different locations in the study area B

Researcher: Okereke Chigbo 2022

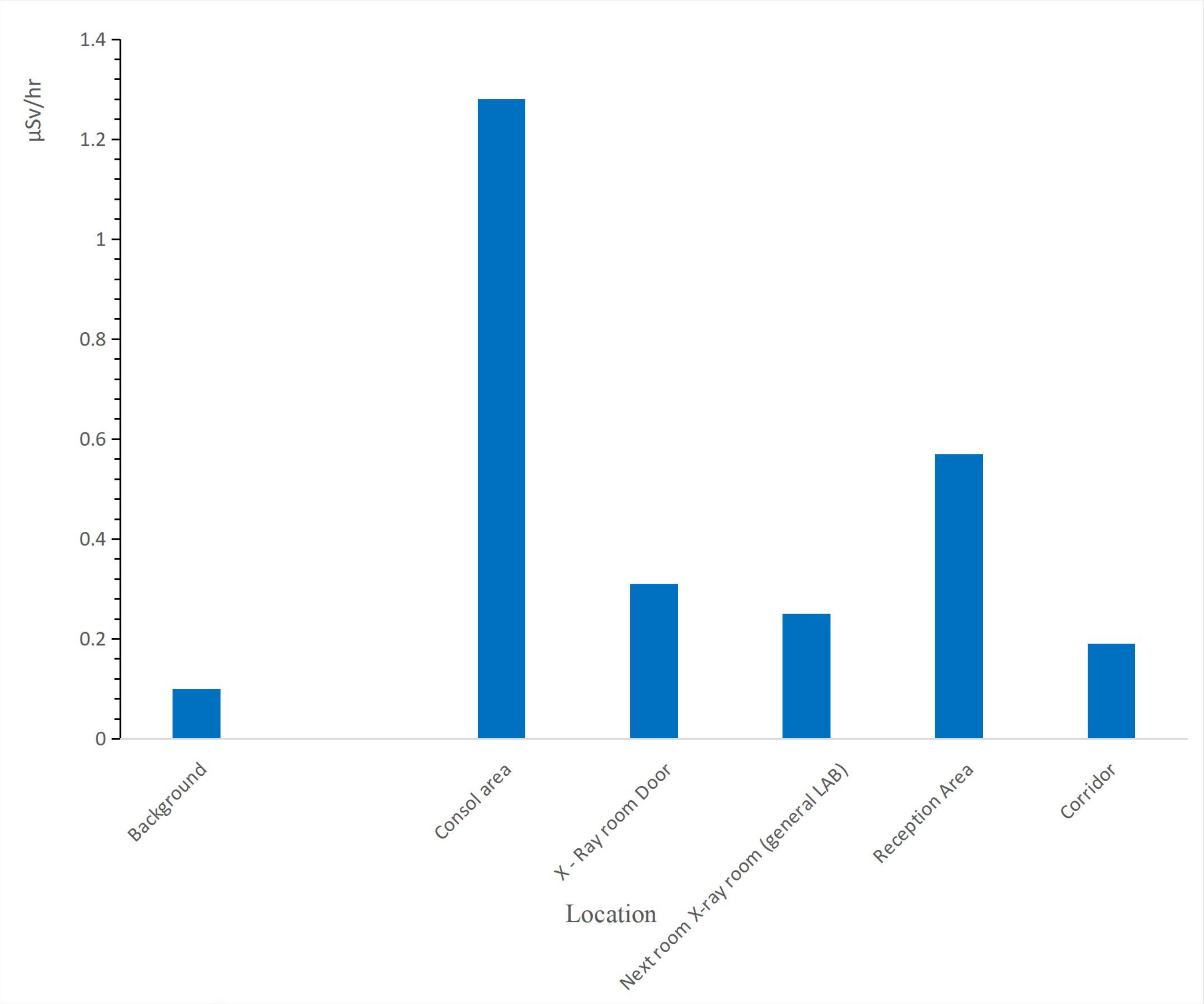

Figure 4.4. Radiological facility B Radiation Dose rate at different locations

Researcher: Okereke Chigbo 2022

Table 4.3 Center C

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
300Ma Medical Diagnostic X-Ray Machine (Oct.2012)	120 -20kVp 300 - 50mAs	50KvP/ 0.5mAs	1.5	Background	0.08	10 /6	1	0.0048
				Consol area	3.01	10/6	1	0.1806
				x-ray room door	1.06	10 /6	1	0.0636
				Reception area	0.23	10 /6	1	0.0138
				Laboratory	0.2	10 /6	1	0.012
				Managers Office	0.15	10 /6	1	0.009
				Outside back of the building	0.23	10 /6	1	0.0138

Researcher: Okereke Chigbo 2022

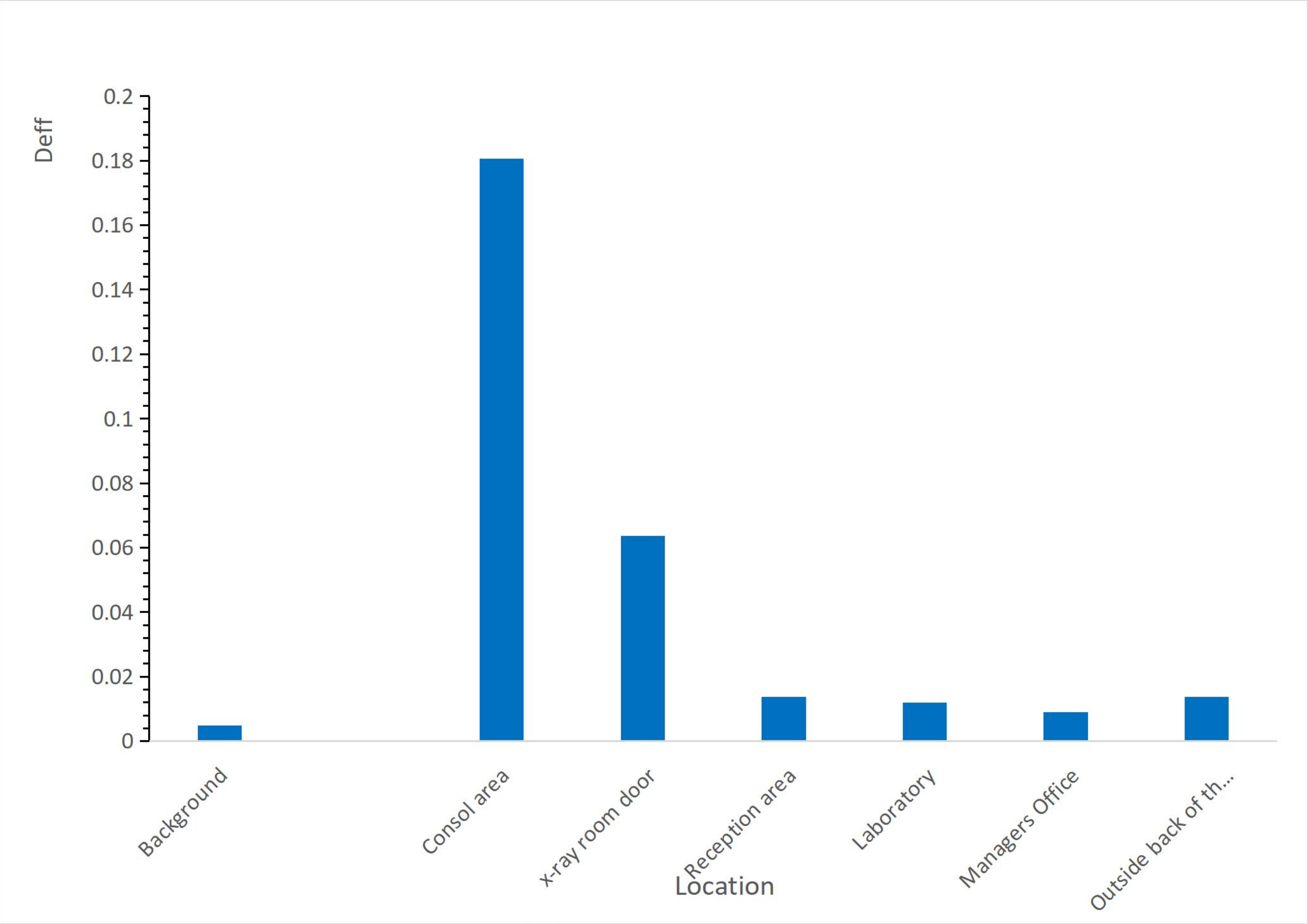

Figure 4.5. Annual effective dose at different locations in the study area C

Researcher: Okereke Chigbo 2022

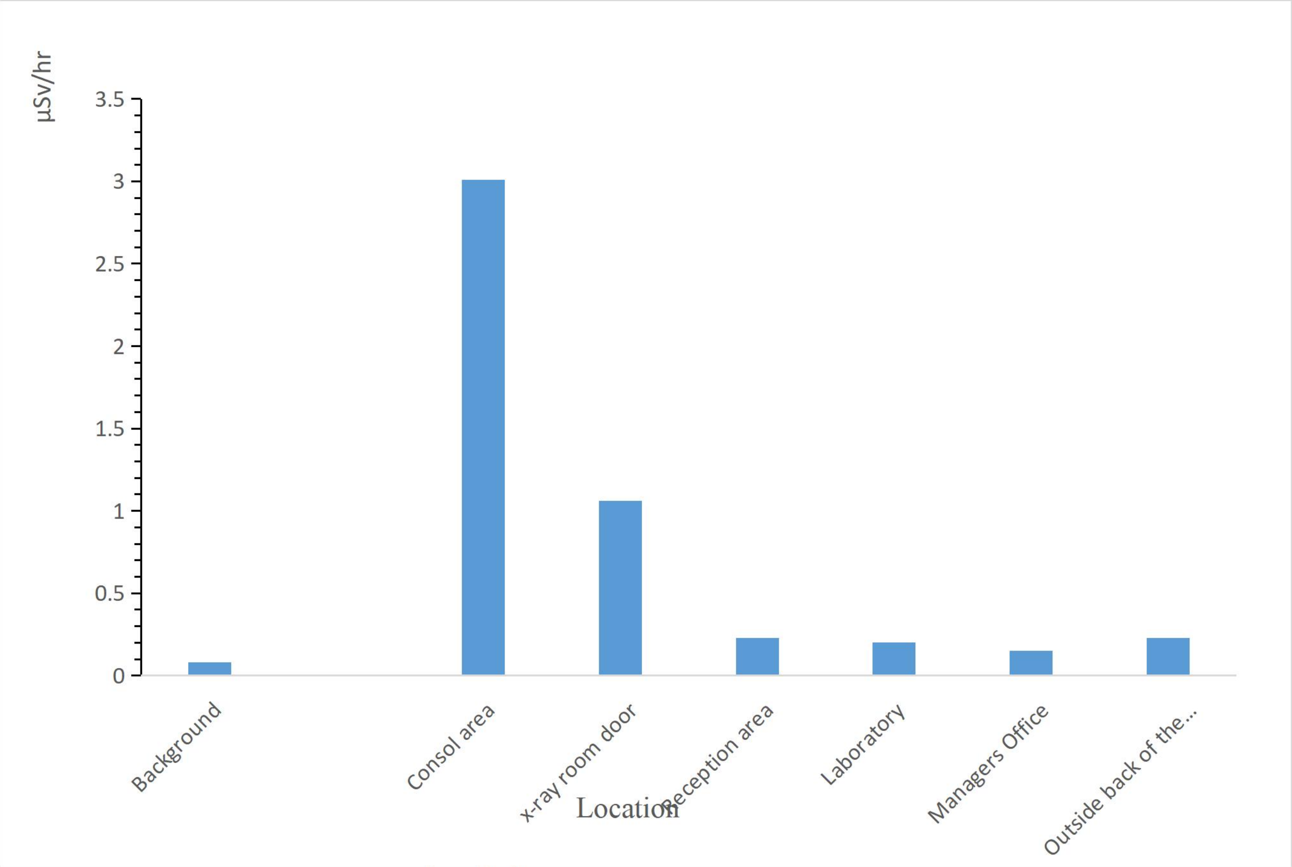

Figure 4.6 Dose rate at different locations in the study area C

Researcher: Okereke Chigbo 2022

Table 4.4 CENTER D

Machine Information				**Data**				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
Allengers High Voltage Double Tank manufactured Oct 2015.		60kvP/ 10mAs	1.5	Background	0.11	10 /6	1	0.0114
				Consol area	0.19	10 /6	1	0.0066
				Radiographs office	0.16	10 /6	1	0.0096
				X- Ray Door	0.12	10 /6	1	0.0072
				Rest room	0.09	10 /6	1	0.0054

Researcher: Okereke Chigbo 2022

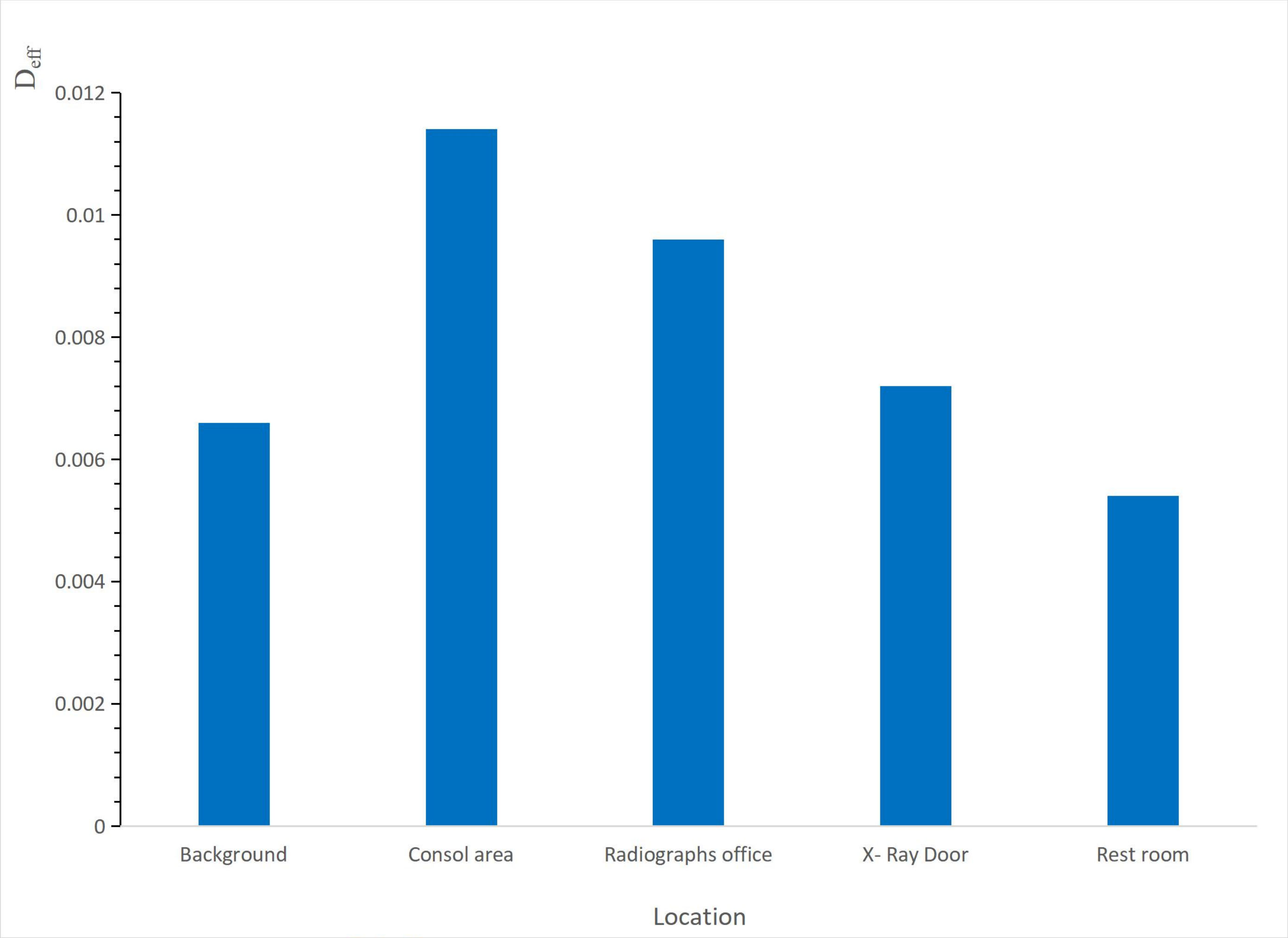

Figure 4:7. Annual effective dose at different locations in the study area D

Researcher: Okereke Chigbo 2022

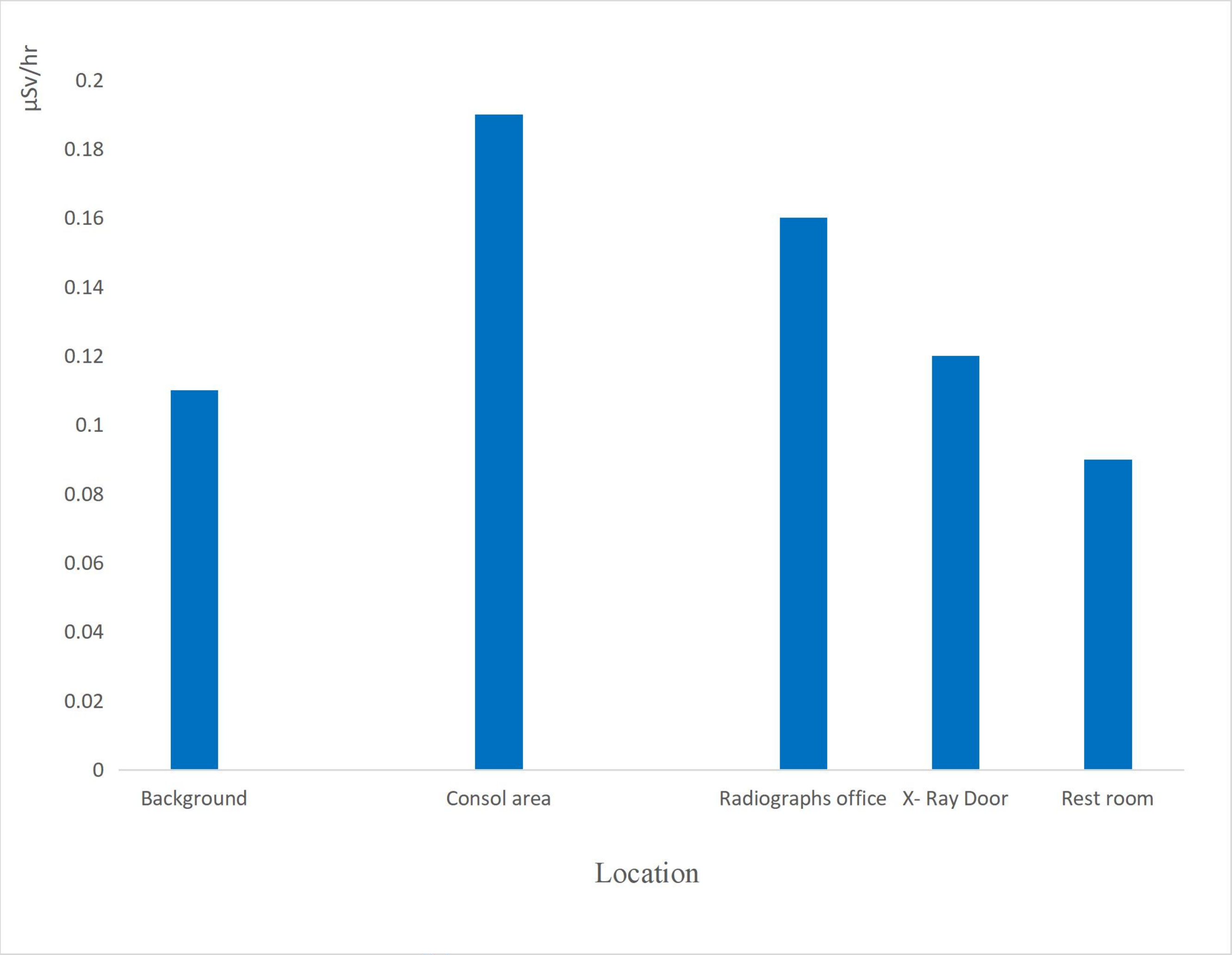

Figure 4.8 Dose rate at different locations in the study area D

Researcher: Okereke Chigbo 2022

Table 4.5 CENTER E

Machine Information				**Data**				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
Siemens Somatom Sensation 16. 2005 09/2015	140-50 kVp 400-100mAs	120 KvP /90mAs		Background	0.09	10 /6	1	0.0054
				Consol area	7.51	10/6	1	0.4506
				CT door	13.5	10 /6	1	0.81
				Waiting area	5.75	10 /6	1	0.345
				Outside the building	0.18	10 /6	1	0.0108
				Front of CT rest Room door	0.27	10 /6	1	0.0162

Researcher: Okereke Chigbo 2022

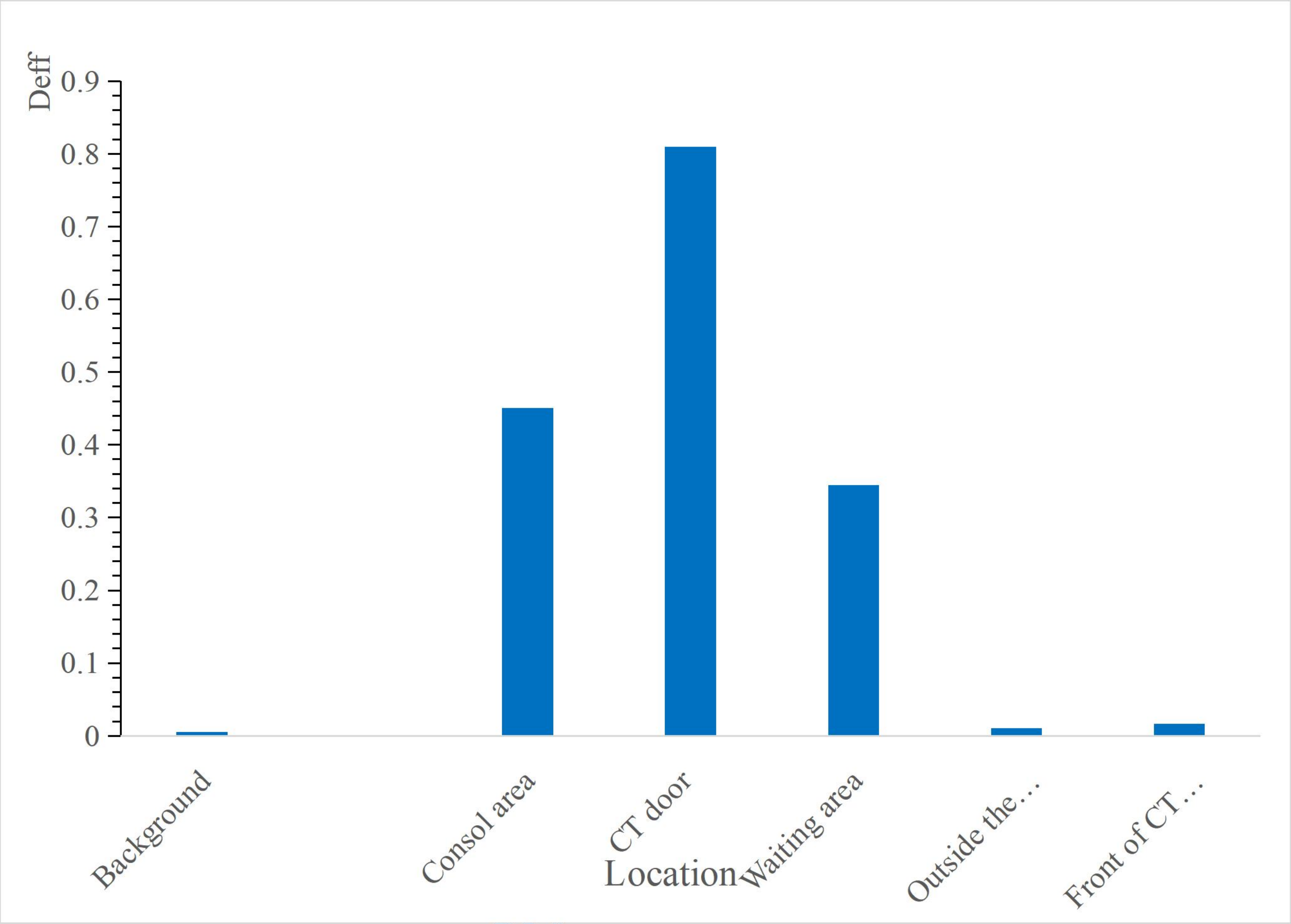

Figure 4.9 Annual effective dose at different locations in the study area E

Researcher: Okereke Chigbo 2022

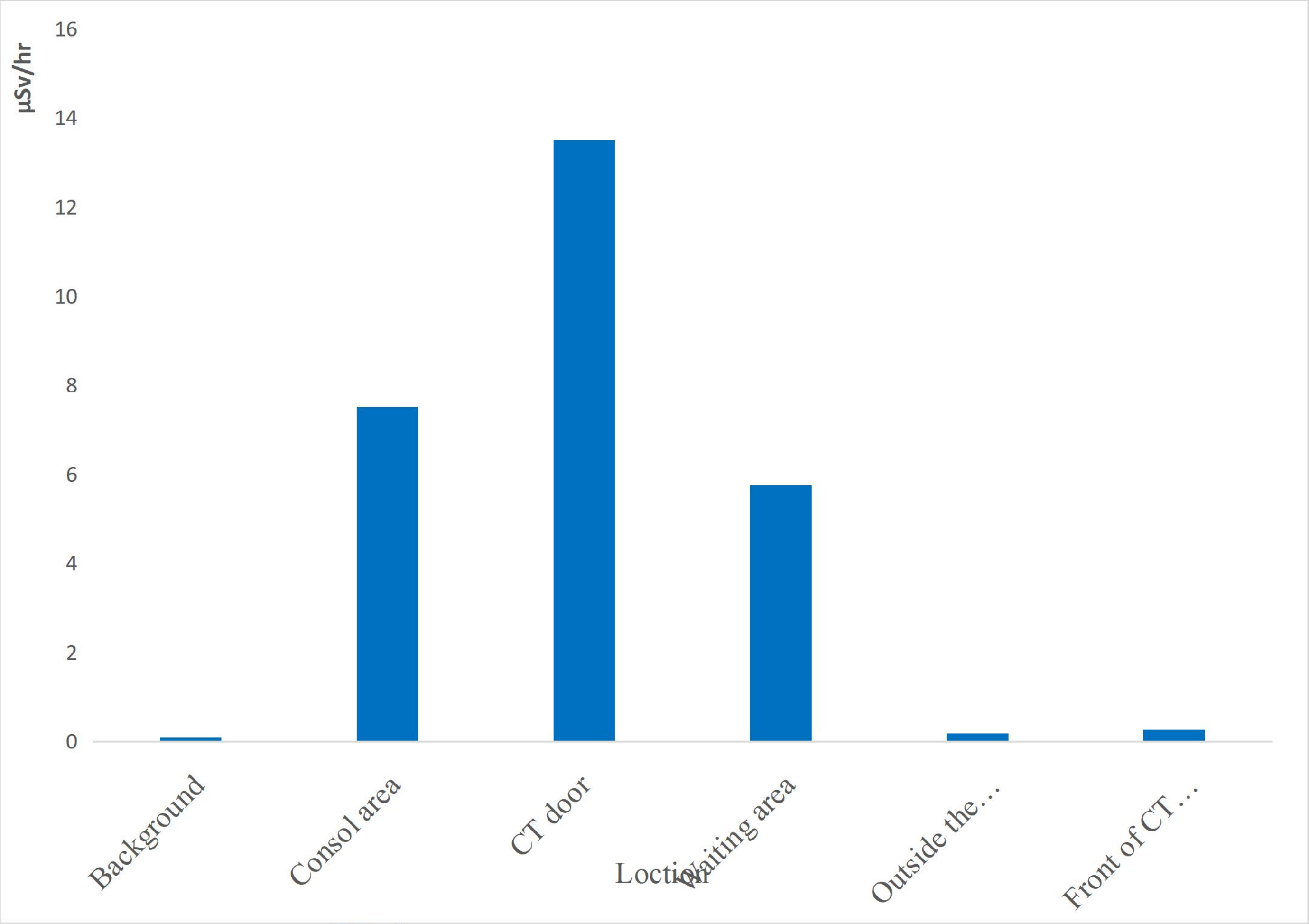

Figure 4.10 Dose rate at different locations in the study area E

Researcher: Okereke Chigbo 2022

Table 4.6 CENTER F

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
PX-20N/April 1990	50 – 80 kVp 2 – 20 mAs	80kVp, 20mAs	1.5	Background	0.11	10 /6	1	0.0066
				X-Ray Room Door	67.57	10 /6	1	4.05
				Office Opposite X-Ray room	0.11	10 /6	1	0.0066
				Corridor Opposite X-ray room	35.0	10 /6	1	2.1
				Reception area	0.13	10 /6	1	0.0078
				Laboratory Room	0.17	10 /6	1	0.0102
				X-ray room outside window	99	10 /6	1	5.94

Researcher: Okereke Chigbo 2022

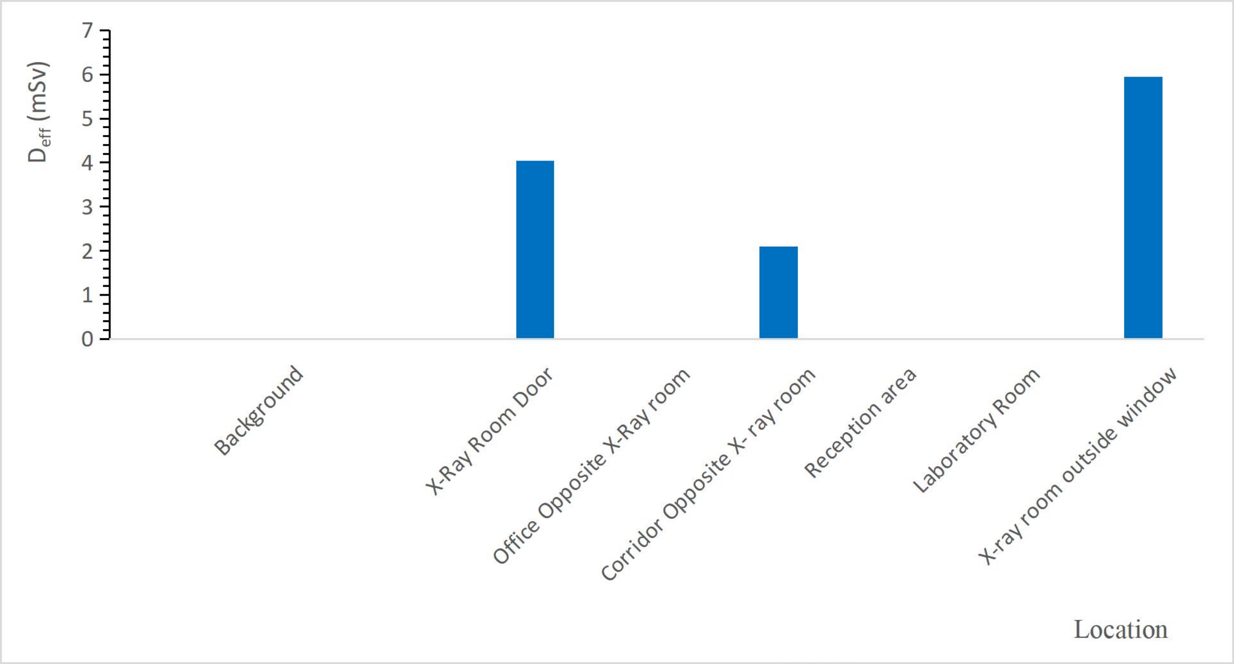

Figure 4.11: Annual effective dose at different locations in the study area F

Researcher: Okereke Chigbo 2022

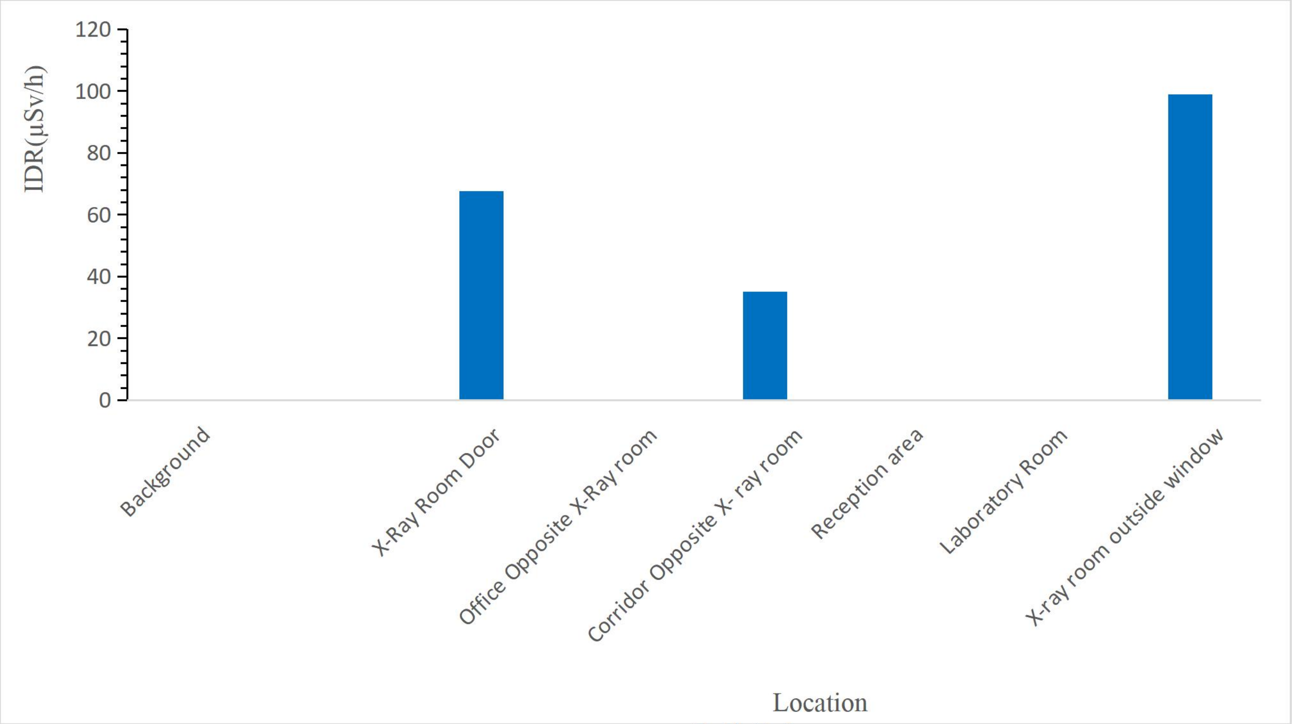

Figure 4.12: Radiological facility F Radiation Dose rate at different locations.

Researcher: Okereke Chigbo 2022

Table 4.7 Center G

Machine Information				**Data**				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
AMX 4 Plus/July 2003 (March 2020 installation date)	125kVp 200mAs	120kVp 64mAs	1.5	Background	0.09	10 /6	1	0.006
				X-Ray room	17,580	10/6	1	1054.8
				X-Ray room console area	18,450	10 /6	1	1107
				X-Ray Room Door	86	10 /6	1	5.16
				Behind X-Ray room	41	10 /6	1	2.46
				X-ray back window	1500	10/6	1	90
				Window 2	1,360	10/6	1	81.6
				Building close to X-ray room	631	10 /6	1	37.86

Researcher: Okereke Chigbo 2022

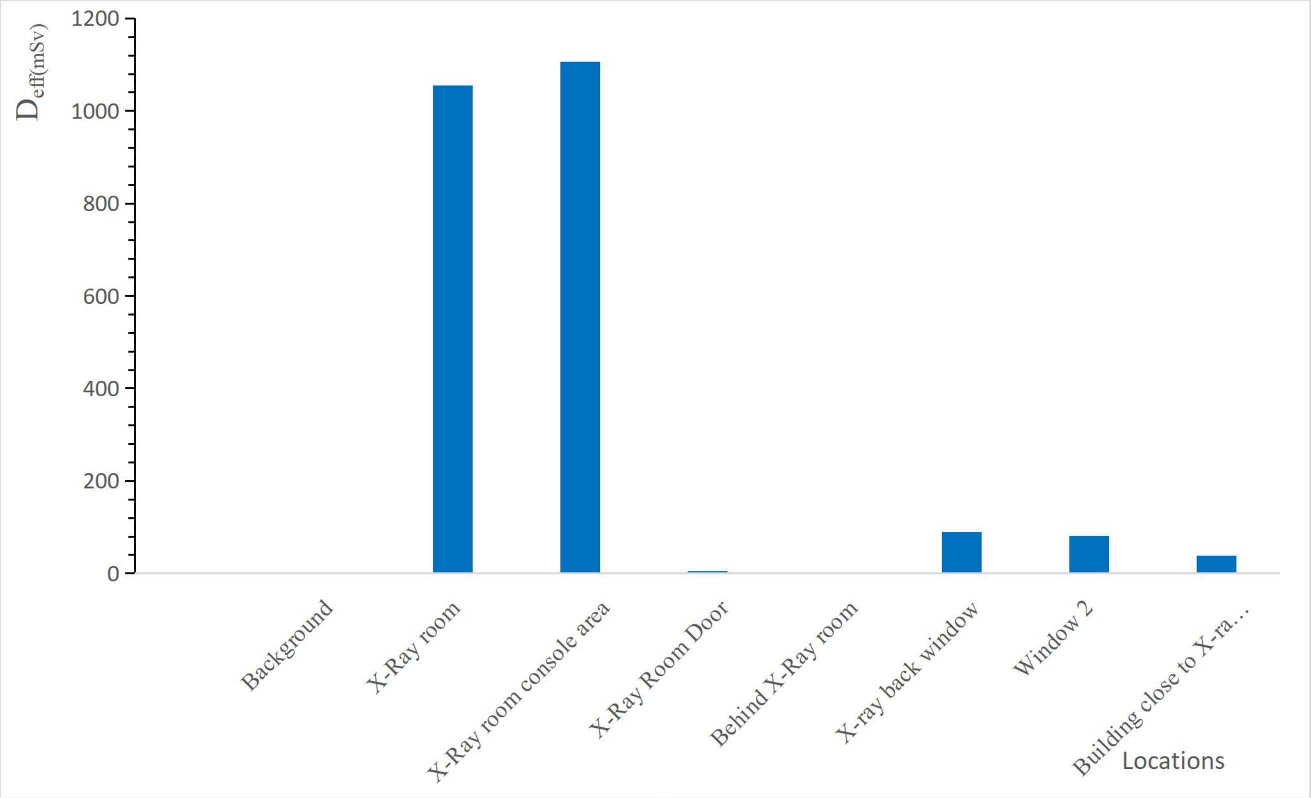

Figure 4.13: Annual effective dose at different locations in the study area G

Researcher: Okereke Chigbo 2022

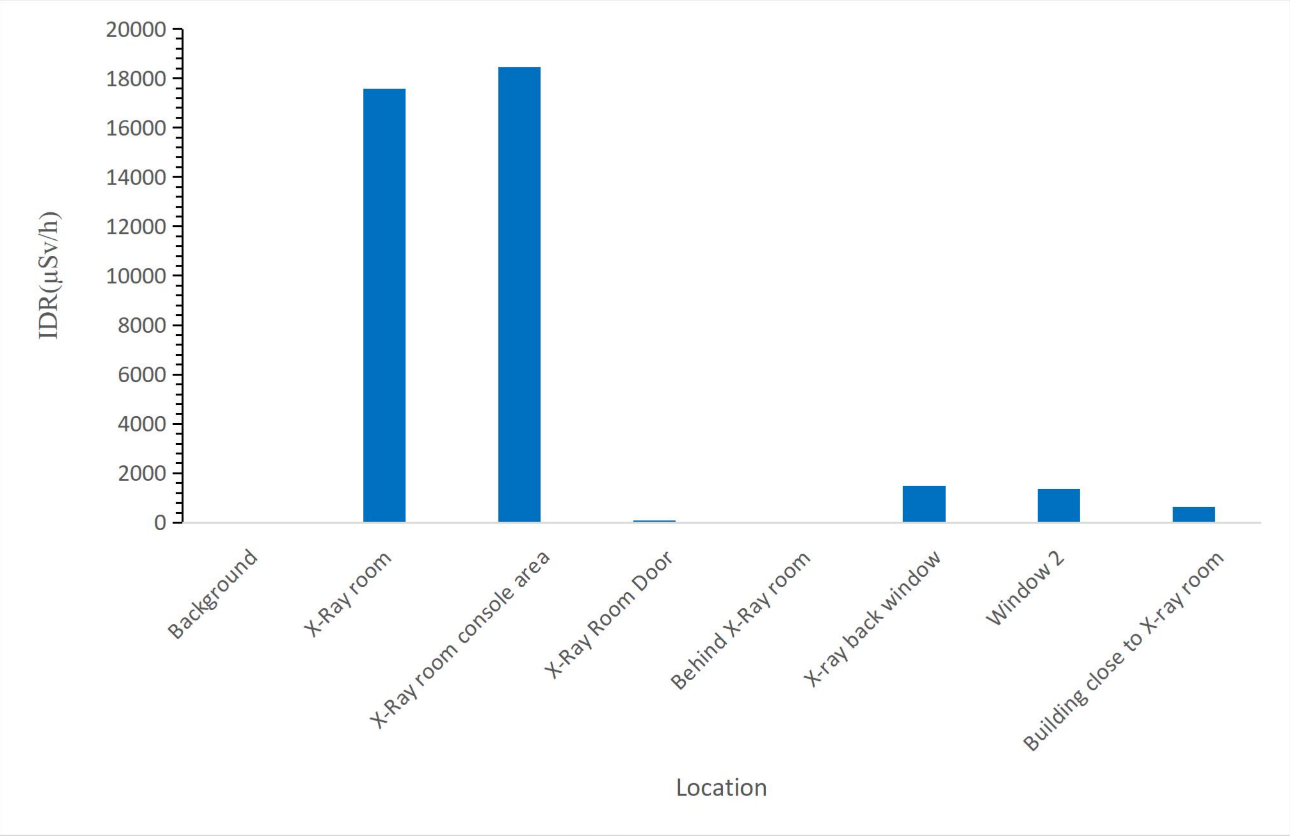

Figure 4.14: Radiological facility G Radiation Dose rate at different locations

Researcher: Okereke Chigbo 2022

Table 4.8 Center H

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
F100 Surgicare England August 2007 2020	40 – 80 kVp 15 – 60 mAs	80 kVp 60 mAs	1.5	Background	0.10	10 /6	1	0.6
				Behind X-Ray Room Curtain	55.48	10/6	1	3.3288
				Reception Area	19.40	10 /6	1	1.164
				Walkway Opposite reception Area	19.40	10 /6	1	1.164
				Behind X-Ray Room window outside	3,560	10 /6	1	213.6
				Chief Nurses Officer Office next to X-Ray room reception	0.25	10 /6	1	0.015

Researcher: Okereke Chigbo 2022

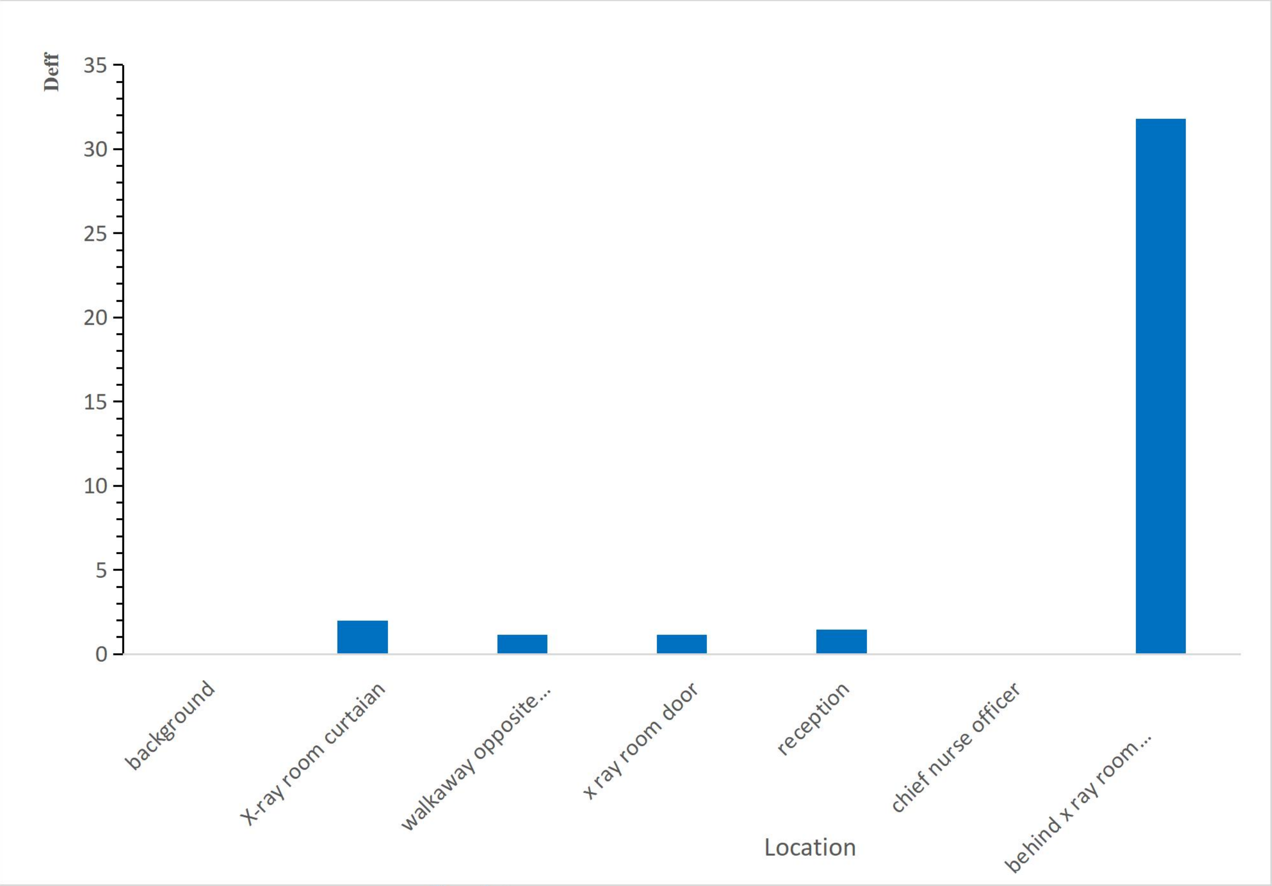

Figure 4.15: Annual effective dose at different locations in the study area H

Researcher: Okereke Chigbo 2022

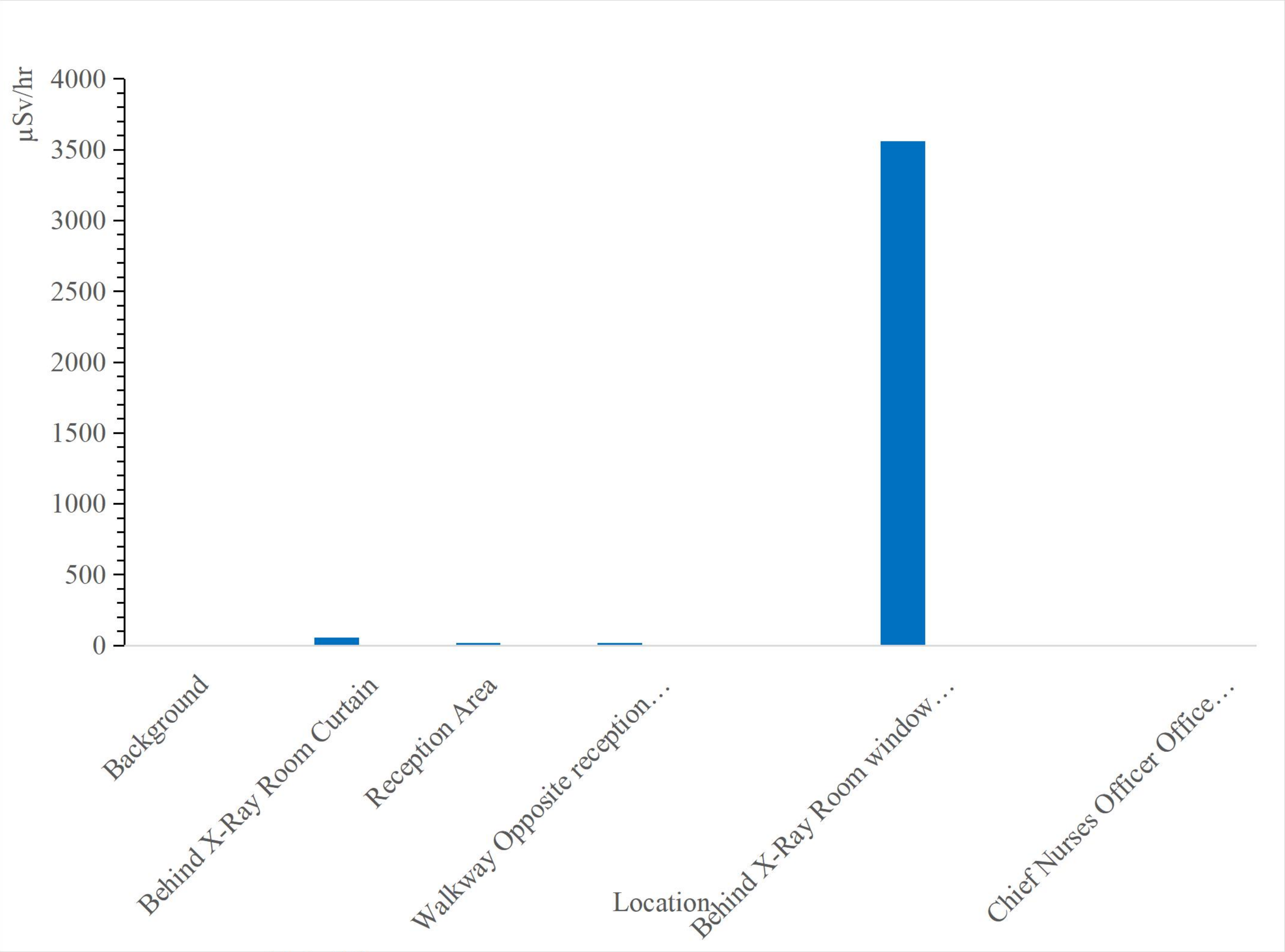

figure 4.16 Radiological facility H Radiation Dose rate at different locations

Researcher: Okereke Chigbo 2022

Table 4.9 CENTER I

Machine Information				**Data**				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
MARS 6R Allengers /July 2020 November 2016	40 -125 kVp 1- 200 mAs	120kVp 80 mAs	1.01	Background	0.09	10 /6	1	0.0054
				X –Ray Room consol area chest	12.7	10 /6	1	0.0054
				X-Ray Room Door	1.76	10 /6	1	0.003
				Laundry room next to X-ray room (table top)	0.09	10 /6	1	0.054
				Laundry room next to X-ray room (chest)	12.85	10 /6	1	1.185
				Reception area	1.11	10 /6	1	1.0488
				H/R Office area	1.10	10/6	1	2.34
				X-ray room window outside	45.2	10/6	1	2.52
				Floor above the X-ray room	0.08	10 /6	1	0.762

Researcher: Okereke Chigbo 2022

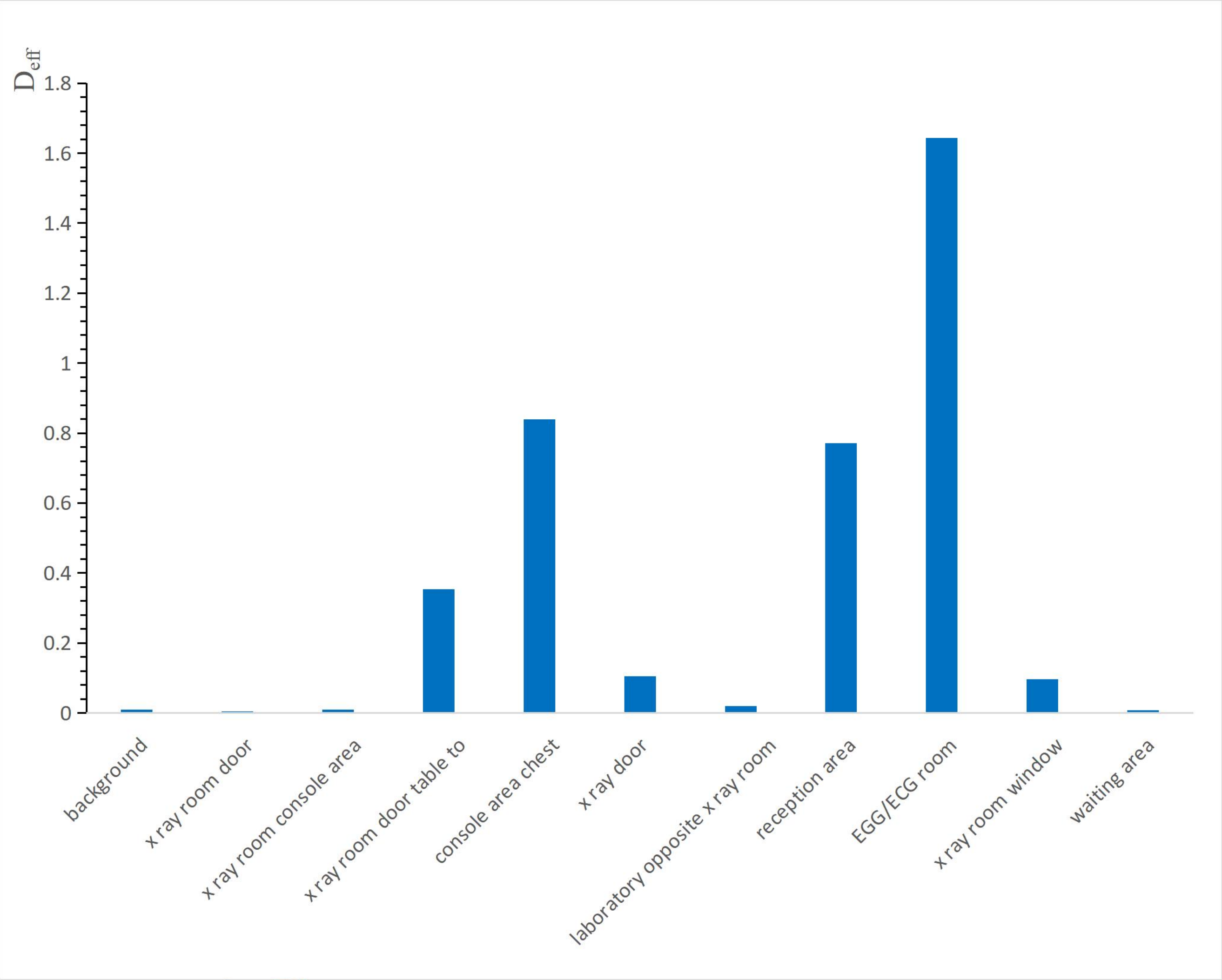

Figure 4.17: Annual effective dose at different locations in the study area I

Researcher: Okereke Chigbo 2022

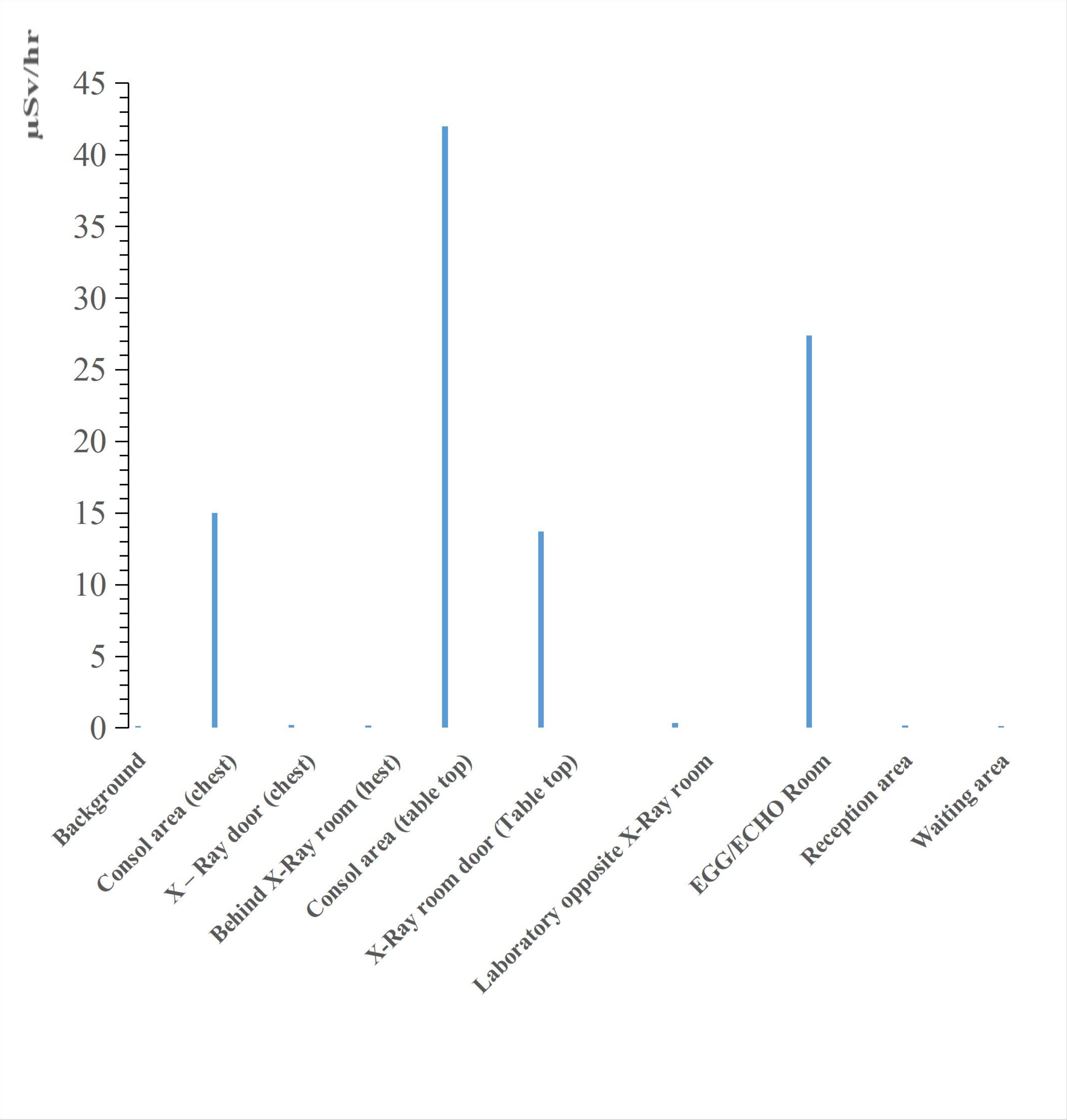

Figure 4.18: Radiological Facility Radiation Dose Rate

Researcher: Okereke Chigbo 2022

Table 4.10 CENTER J

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/ Day**	**T**	$D_{(eff)}$
SIEMENS Mobile ETT Plus Hp/ 2003 (2017 installation date	40 – 133 kVp 0.50 – 32 mAs	81 kVp 28 mAs	1.5	Background	0.15	10 /6	1	0.009
				Consol area (chest)	10.3	10/6		0.618
				X – Ray door (chest)	0.15	10 /6	1	0.009
				Outside the building	0.15	10 /6	1	0.009
				Behind X-Ray room (Chest)	0.16	10 /6	1	0.0096
				Consol area (table top)	42	10/6	1	2.52
				X-Ray room door (Table top)	13.7	10 /6	1	0.822
				Laboratory opposite X-ray room	0.33	10 /6	1	0.0198
				EGG/ECHO room	27.4	10 /6	1	1.644
				Reception area	0.16	10 /6	1	0.0096
				Waiting area	0.14	10 /6	1	0.0084

Researcher: Okereke Chigbo 2022

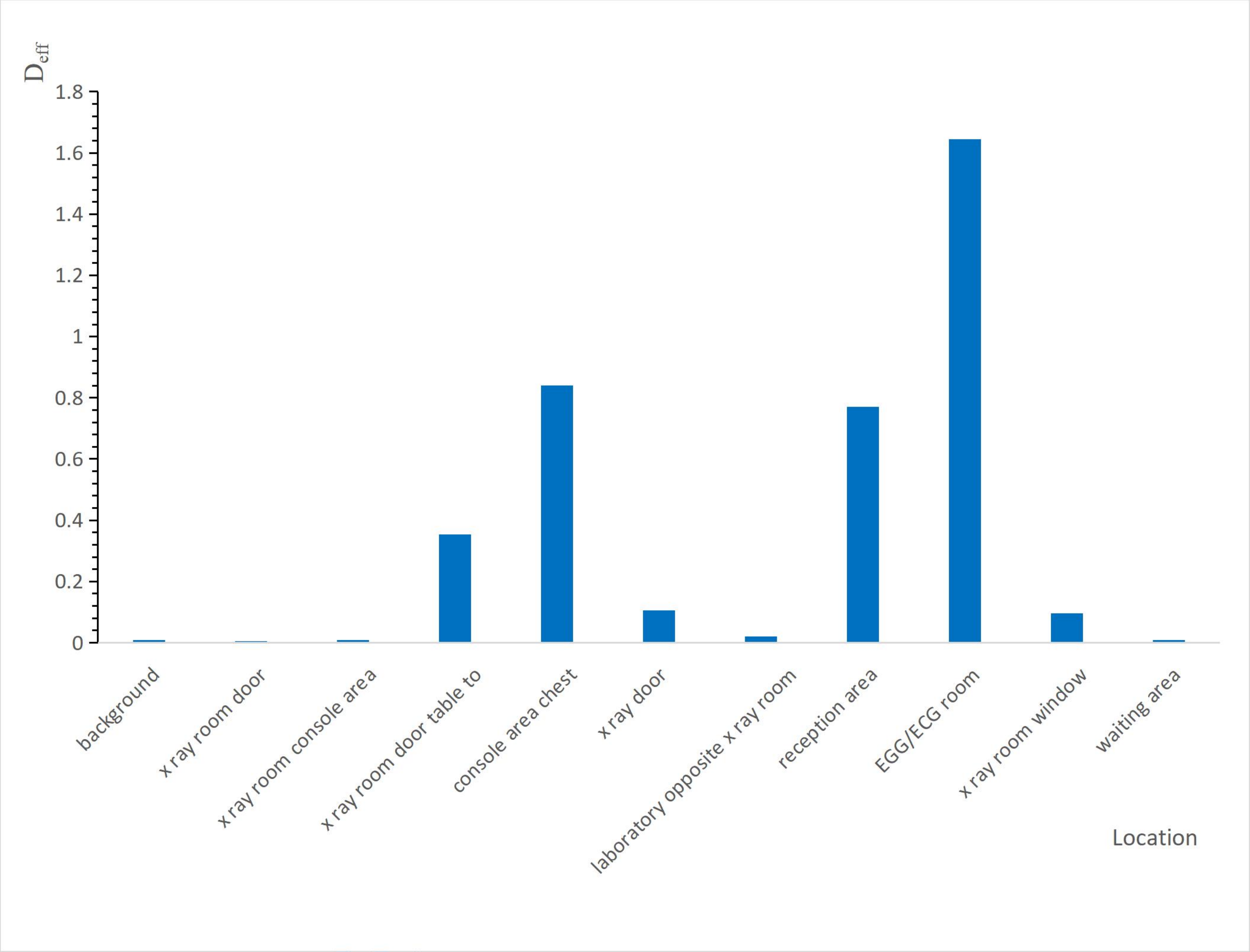

Figure 4.19: Annual effective dose at different locations in the study area J

Researcher: Okereke Chigbo 2022

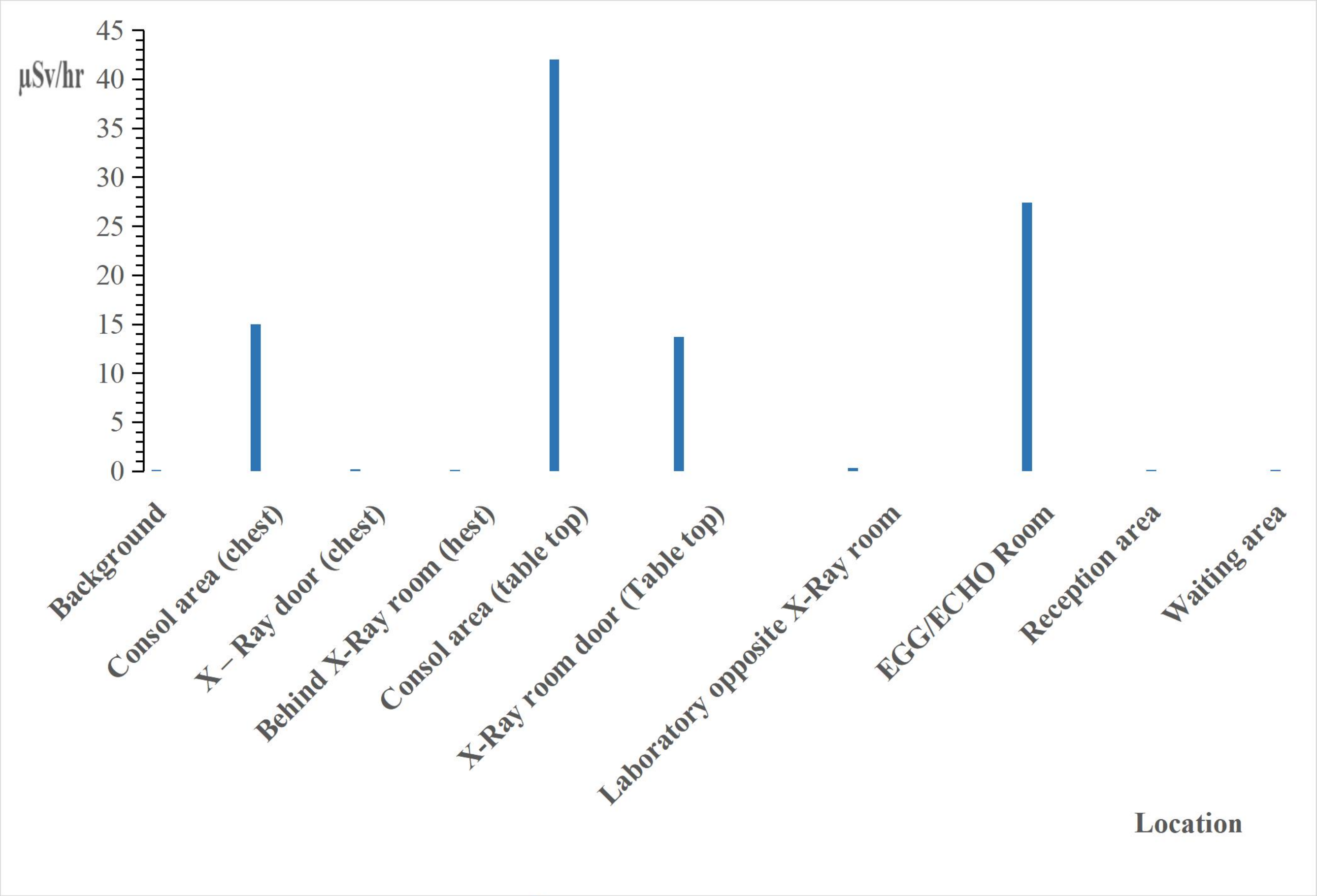

Figure 4.20: Radiological Facility J Radiation Dose Rate

Researcher: Okereke Chigbo 2022

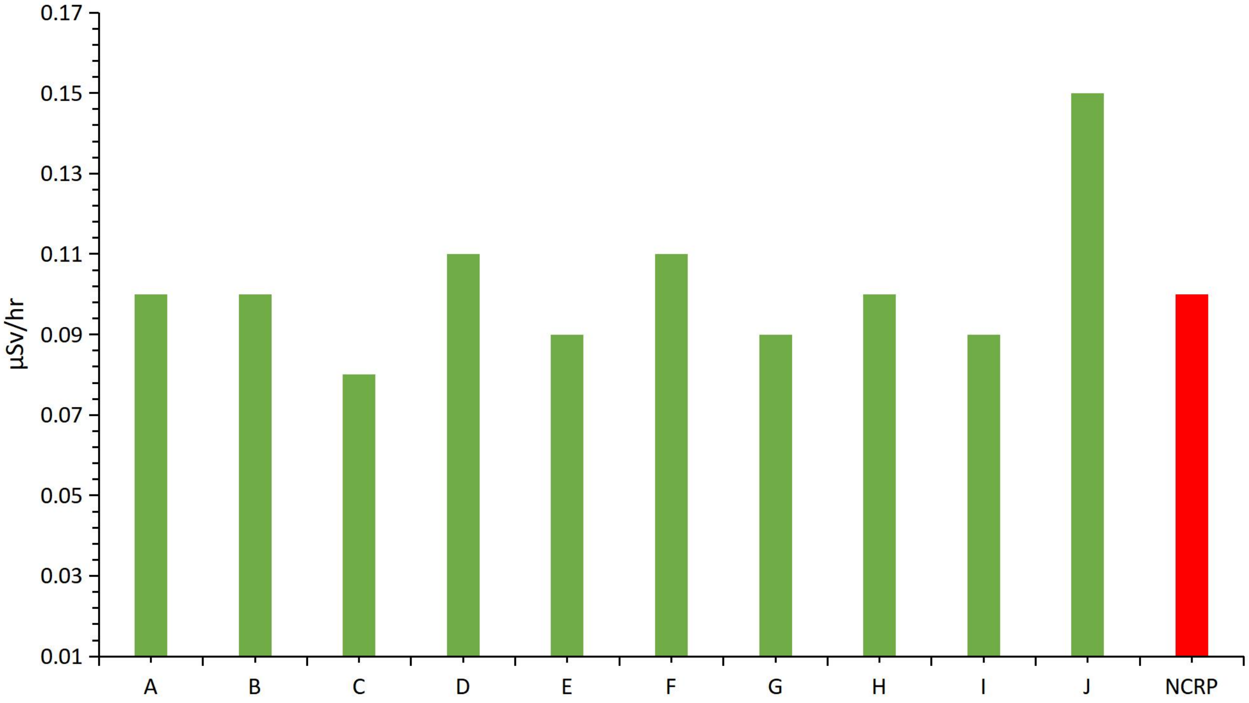

Figure 4.21: Comparison of this study background Dose rate of Facility A-J with NCRP background limit standard.

Researcher: Okereke Chigbo 2022

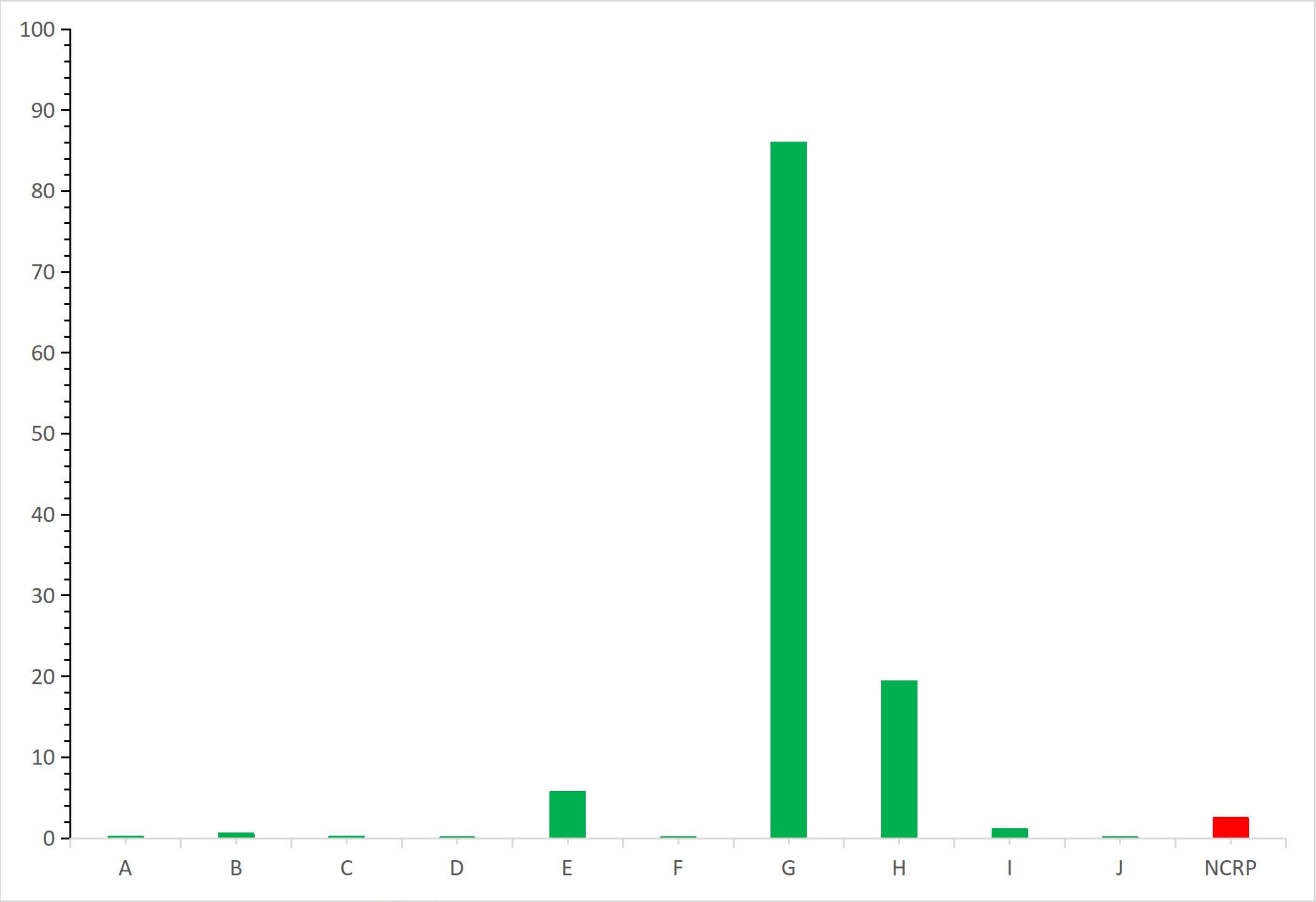

Figure 4.22: Comparison of this study reception area dose rate of Facility A-J with NCRP limit standard.

Researcher: Okereke Chigbo 2022

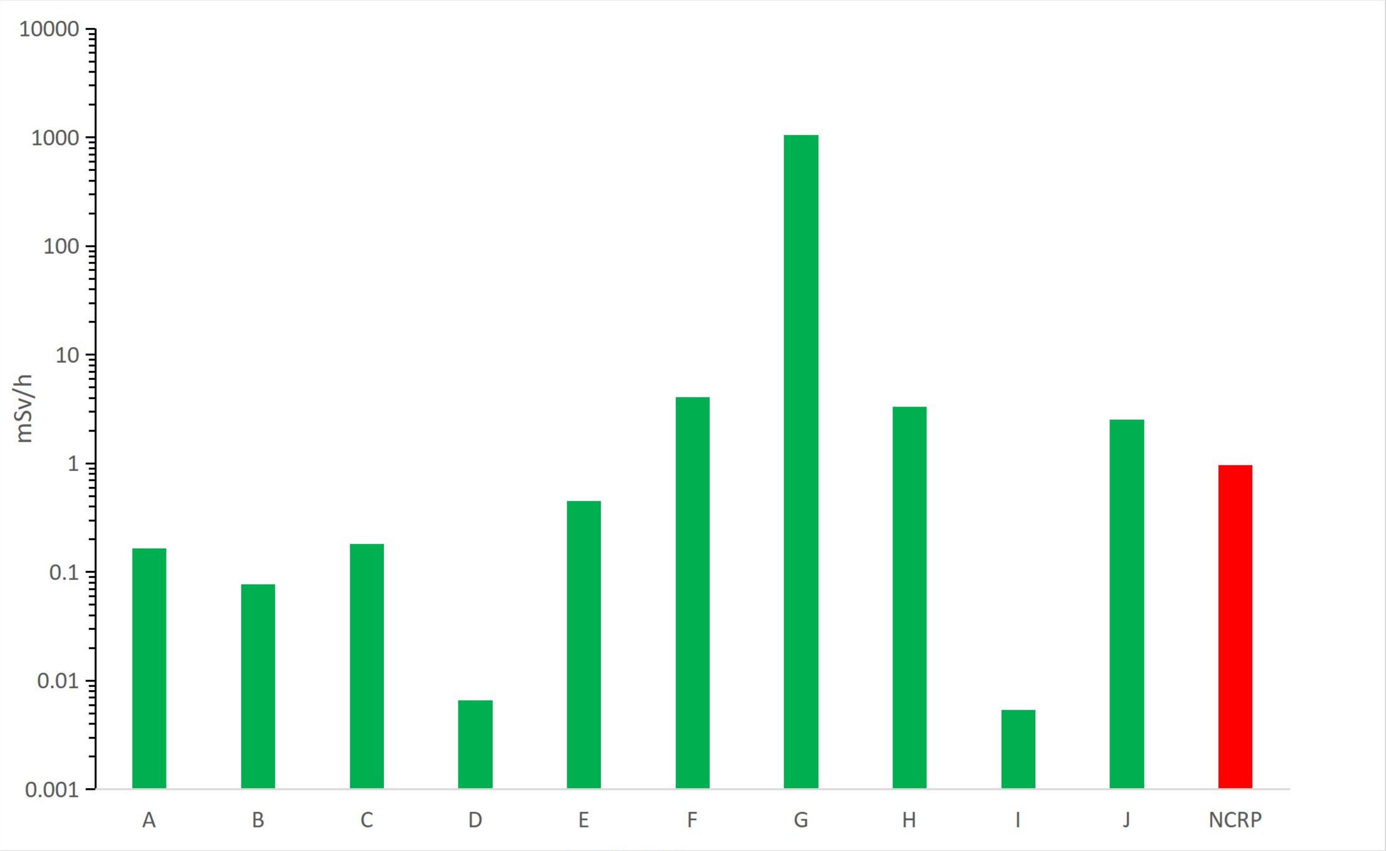

Figure 4.23: Comparison of this study ADR of Facility A-J with NCRP safety limit.

Researcher: Okereke Chigbo 2022

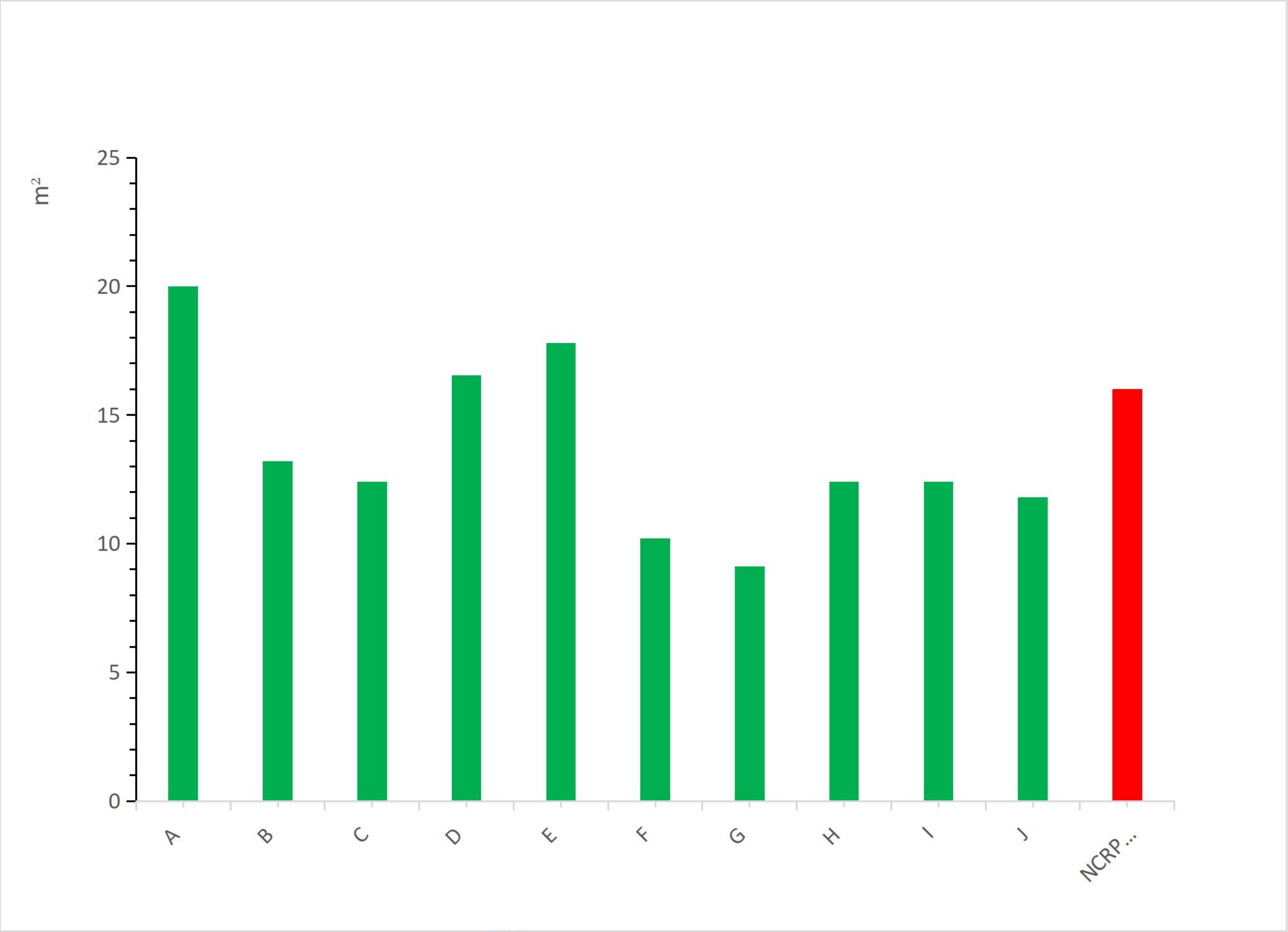

Figure 4.24: Comparison of this study room dimension of Facility A-J with NCRP & NNRA standard.

Researcher: Okereke Chigbo 2022

4.2 Discussion of Findings

The international Atomic Energy Agency (IAEA) recommended a dose-rate of not more than 2.5µSv/h at any accessible location to the public. Any location with dose rate more than 7.5µSv/h is considered a controlled area and access to such location must be restricted[1]. The survey meter readings as seen in Table 4.1 gives the dose rates measured at various units of Diagnostic Centre A, the investigated diagnostic center model of machine, year of purchase and year of manufacture. This table shows that the X-ray machines located in Diagnostic Centre was manufactured 16years ago (close to two decades), purchased 13 years ago. It has kVp rage of 125 - 40 and mAs of 500 – 0.1. 80kVp and 40mAs was used for the study. The distance of the X-ray tube to the dummy object is 1.5m. The building was purposed built which was clearly seen in the radiation dose rate data as presented in figure 4.2. The receptionist's area, behind X-ray room door and the laboratory room were found to have satisfactory levels <0.5µSv/h of radiation dose rate as recommended by NCRP. The radiation dose rates measured in the consol area and X-ray room door read 2.75µSv/h and 1.05µSv/h respectively. As clearly shown in figure 4.1 the technician has an estimated annual dose (D_{eff}) of 0.165 mSv which is the highest in the facility but seen to be < 0.96mSv as recommended by National Council on Radiation Protection and Measurements (NCRP) Report 147 and International Commission on Radiological Protection (ICRP). The radiation dose rate of diagnostic facility A were found satisfactory, and reads (0.14 – 2.75 µSv/hr).

The X-ray machine in diagnostic Centre B was manufactured about fifteen (15) years and purchased seven (7) years ago. The X-ray Machine model is 300Ma Medical Diagnostic X-Ray Machine and have a maximum kVp of 120 and 300 mAs. 100kVp and 50mAs was used for the study. The distance of the X-ray tube to the dummy object is 1.5m. From figure 4.3, the consol area which is a small caved out space inside the X-ray room, with a radiation dose rate of 1.28µSv/h has an estimated annual dose of 0.0768 mSv/week for the technician is < 0.96mSv/week as recommended by NCPR. However, the X-ray room door, general lab, reception area and corridor has dose rate (< 0.5µSv/hr) which is the satisfactory level. The radiation dose rate in facility B is (0.57 – 1.28µSv/hr). Facility B is purposed built facility and has a total of 18 staff who spend 10 hours daily.

The machine in Diagnostic Centre C, is 300Ma Medical Diagnostic X-Ray Machine manufactured in October,2012. 50kVp and 0.5mAs was used for the study while the machine has a maximum of 120kVp and 300 mAs. This diagnostic Facility, is not a purposed built facility for diagnostic activities. The background radiation dose is within acceptable limit. The radiation dose rate is 0.08µSv/hr - 3.8mSv/hr. The technician takes procedures with his lead apron behind a small wood which he uses as console area. Diagnostic Centre C does not have any personal dosimetry service provider as recommended by the ICRP and NNRA. The estimated annual doses were calculated based on the dose rate at various location in the Diagnostic Centre. The technician had the highest value in this center with an annual estimated dose of 0.1806mSv.

Facility Diagnostic Centre D is one of the puposed built facility the study was carried out in, with a total of 23 staff. From figure 4.7 as shown the radiation dose rate is (0.09µSv/hr - 0.19 µSv/hr) which is within the satisfactory level (<0.5µSv/hr) this means that the X-ray room is well shielded thereby the persons and public are in save based on my study. The effective dose is 0.0066 which is < 0.96 mSv/ week as recommended by NCRP. The machine model is Allengers High Voltage Double Tank manufactured October 2015.

Radiological Diagnostic Centre E as presented in Table 4.5. the wall of the CT room is shielded with lead sheets and the survey meter measurements showed very low dose rates. This is in compliance with regulatory standards. The estimated annual dose to workers as presented in Table 4.5. showed that the dose rates are within the recommended values. The highest estimated annual effective dose is 0.81mSv/week which is within the recommended dose limits for occupational radiation workers of 50mSv/a by International Commission on Radiological Protection (ICRP).

From figure 4.9. Diagnostic facility E, the background radiation dose is normal, the radiation dose rate in the facility is (0.27 µSv/hr – 7.51 µSv/hr). Machine use for the study in the particular facility is a computed tomography machine and no dummy object was used as the exposures were all done with real human but with different kVp and mAs as different procedures (Lumbosacral, Chest, Neck etc) were taking place. From figure 4.9 the CT door has the highest dose rate 13.5 µSv/h and the door is very close to the waiting area. This is hazardous to the public and personnel who have activity to do within there. The public limit is 0.019mSv/week. The consol has a radiation dose rate of 7.51 µSv/h and estimated annual dose rate of 0.4506 mSv/h.

The machine investigated in Diagnostic Centre F was manufactured about twenty years ago.

This center has eight (8) workers. The X-ray machine model is PX-20N and was manufactured April 1990, over thirty years ago. The kVp (80) and mAs (20) of the machine have been fixed constant for any type of exposure. Though it has range of (50 – 80 kVp) and 2-20 mAs respectively. The distance of the X-ray tube to the dummy object used is 1.5m. From the table, the estimated annual doses of technician 0.77mSv/h is slightly higher than that of the manager 0.5376mSv/h and the receptionist 0.6912mSv/h which are all within the recommended limit. As well shown in figure 5.1, the receptionist's area, general waiting area and the laboratory room were found to have satisfactory levels <0.5µSv/h of radiation. However, the radiation dose rates measured in the X-ray room door is 67.57µSv/h with D_{eff} of 4.05mSv/h where the technician stands when taking exposures and corridor opposite the X-ray room door 35µSv/h are very high there by personnel and public within the facility who will be present within this point while exposure is been taken will be at a very high risk. X-ray room outside window which is also very close to where people are living have a very high dose rates, this means that everybody who stays in that particular building will always receiver a very high effective does rate of 5.94mSv/h each time exposure is taken even without going to radiological facility. The radiation dose rate of diagnostic facility F were found very high at this three point and reads (29 - 99 µSv/h).

Diagnostic Centre G has the result is presented in Table 4.8. The facility has nine workers; it is very clear that there is a danger. The technician stays in the same room were the X-ray machine is while taking exposure without any standing barrier (consol). The background dose rate is normal but while espousing, every other location measured was very high. Where the technician stands with only his lead apron reads 18.45mSv/h (18,450µSv/h), X-ray room door (86µSv/hr) and the outside window (1.36mSv/hr) which very hazardous to X-ray technicians and the public living very close to the X-ray window as was sighted. The radiation dose rates in this facility G is (46µSv/hr – 18.45mSv/hr) with D_{eff} (2.46mSv/h - 1054.8mSv/h) which is more than the NCRP recommended dose of 0.96mSv/h The X-ray machine model is AMX 4Plus and was manufactured July2003. Have a maximum kVp of 125 and maximum mAs 200. 120 KVP and 64mAs was used during this assessment. The distance of the X-ray tube to the dummy object is 1.5m.

Diagnostic Centre H as shown in figure 4.15, the background radiation dose is normal. The radiation dose rate in this facility is 0.25µSv/hr – 3,560µSv/h which is hazardous to the personnel and the public. The technician takes exposure with only her lead apron, she stays in the same room while exposing no consol area was noticed. The does rate is extremely high as seen in the estimated annual dose (0.015mSv/h – 213.6mSv/h). The X-ray machine model is F100 surgicare, installed 2020 and Manufactured August 2007. Maximum/Minimum rang of kVp and mAs **(**40 – 80 kVp and 15 – 60 mAs). 80 kVp and 60 mAs was used for the assessment.

Diagnostic Centre 1 is a diagnostic center with an average of 60 examinations per week, Annual dosimeter readings showed values lower than the recommended regulatory limits. The mean dosimeters report is 0.16mSv/h. The radiation levels immediately outside the X-ray room (by the door) and the H/R area, laundry room (when imaging is done using the table top), reception area and the upstairs above the X-ray room were found to be minimal (0.08 -1.76µSv/h) and satisfactory. However, instantaneous dose rates obtained at the console area 11.9 – 19.75µSv/hr depending on whether the table top or chest stand is used in the laundry room using chest support (12.85µSv/h) and behind the X-ray room window (34.3 – 45.2µSv/hr) are not minimal. The X-ray model is MARS 6R Allengers, manufactured November 2016 and installed July 2020. The machine has a kVp range of (40 -125kVp) and mAs rage of (1 – 200mAs). 120kAp and 80 mAs were used respectively for the assessment. The distance was 1.01m.

From table 4.10 facility J, the receptionist's area, general waiting area and the laboratory room opposite the X-ray room were found to have a minimal level (<0.5µSv/hr) of radiation. However, the EEG/ECHO room and the console area were found to have radiation dose rates (27 -42µSv/hr) higher than the required normal rage. The model of the X-ray machine is Siemens Mobile ETT plus Hp manufactured 2003 and installed 2017. Distance of 1.5m was used during the assessment. The machine has kVp range of 40 – 133 and mAs rage of 0.50 – 32kVp. However, kVp of 81 and mAs of 28 was used.

From the ten diagnostic facilities, 60% of the workers are not aware of NNRA regulations and practices. No shielding of any kind was found in center G and H but there are few lead aprons in the examination room.

The Nigeria Nuclear Regulatory Authority (NNRA) recommends a minimum radiographic room area of at least $16m^2$. A study jointly sponsored by the international Labor Organization (ILO), International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) recommend a radiographic room dimension of not less than 6 x 4 x 3 in length, breath and height. Therefore, this gives a room area of at least $24m^2$. The Atomic Energy Regulatory Board (AERB)[3] recommended a minimum room dimension ranging from $16m^2$ to $20m^2$. Figure 1 to 5 shows the room area of the five (5) radiographic rooms with Diagnostic Centre A ($20m^2$), Diagnostic Centre D ($16.54m^2$), and Diagnostic Centre E ($17.8m^2$), respectively met all recommended standards. Diagnostic Centre B, C, F, G, H, I and J which read $13.2m^2, 12.4m^2$, $10.21m^2, 9.11m^2, 14.01m^2, 12.4m^2,$ *and* $11.8m^2$ respectively did not meet any of the standards. The implication of the above measurements is that the rooms designated as X-ray rooms in the studied centers largely suggest poor radiation protection to the operator and perhaps, other people within the controlled area during operation[3]. The inverse proportional to the square of the distance from the radiation source. From radiation protection perspective, the larger the room dimension; the more distance would be between the X-ray tube and the control room (operator's booth), therefore the lesser the radiation that will reach the operator and the wall of the radiographic room. It is recommended that the X-ray tube is not closer than 1m to the operator's booth Thus, doubling the distance reduces the dose by a factor of four[4].

Furthermore, the distance between the operator to the radiation source and operator's consol to the chest stand should be at least 3m as recommended. According to Atomic Energy Authority of Sri Lanka, the minimum distance between the operator[5] and source should be 2m. The findings from this study showed a distance less than recommended value in Diagnostic Centres B, C, F, G, H, I and J. This implies that more radiation would be reaching the operator of the X-ray machine in these facilities. This is undesirable in the face of the likelihood of the operator exceeding the maximum permissible occupational dose. Some corrective measures are recommended. Eight (8) out of the ten (10) centers studied has walls of their radiographic rooms lined with 2mm lead equivalent which satisfied the recommendations of NNRA and the Radiological Protection Institute of Ireland. Two (2) center was found not to have any shielding at all, Structural shielding which should be calculated by qualified physicist in order to ensure adequate radiation protection was done. There was adequate use of lead aprons in all the X-ray rooms. The use of radiation monitoring devices (thermos-luminescent dosimeter) by the staff in Diagnostic Centre D and E were very impressive while there were no personnel monitoring devices of the staff in Diagnostic Centre A, B, C, F, G, H, I and J. More so, warning lights and warning signs were used at the entrances of five X-ray room doors while three had the indication with white chalk.

Endnotes

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Chapter Five

Conclusion

5.1 Summary of Findings

These findings provide a picture of the progress to be made in limited-resource settings in meeting the Basic Safety Standard (BSS) for radiation protection. From the ten (10) Diagnostic Centres studied. My findings with respect to room sizes and layouts, relative distances from the X-ray tube to the nearest shielded Walls, and locations of the control consoles and the darkrooms, showed that Diagnostic Centres B, C, F, G, H, I and J do not have the recommended room sizes of at least $16m^2$. Relatives distances from the X -ray tube to the nearest shielded walls were not fully optimized in six of the centers. However, the location of the control console and the measured distances from the X-ray were appropriate in Centres H and J.

In Centre J, the instantaneous dose rates obtained at the console area (11.9 – 19.75µSv/hr), in the laundry (12.85 µSv/hr using chest support) and behind the X-ray room window (34.3 - 45.2µSv/hr) are unsatisfactory. Center J, the EEG/ECHO room and the console area were found to have dose rate (27 - 42µSv/hr) higher than the safe range. Centers G and H were the worst when it comes to radiation safety guidelines. In both centers, the technician stays within the X-ray room without any standing protective barrier. The radiation dose rates for center G were found extremely high (46µSv/hr – 18.45mSv/hr). The current use of lead apron is insufficient. Center H radiation dose rates were also high (0.25µSv/hr – 3.56 mSv/hr) and wall was not laid with lead sheet. 3.56mSv/h was reading at outside window (no building were found in the location).

Center F, radiation dose rate was found very high (28 -99µSv/hr) in some areas (X-ray room door where the technician stands when taking exposure) the corridor opposite X-ray room door, toilet area and behind the X-ray room.

The radiation dose rate of diagnostic facility A, recorded (0.063 – 0.165mSv/h) at X-ray room door and consol area respectively but < 0.96mSv/h. Diagnostics radiation dose rate in facility B is recorded (0.57 – 1.28µSv/hr) with the highest dose recoded at the consol area. The radiation dose for facility C is 0.08µSv/hr - 3.8mSv/hr. Diagnostic Centre D which is one of the puposed built facility the study was carried out in, had radiation dose rate of 0.09µSv/hr - 0.19 µSv/hr and the radiation dose rate in the facility is 0.27 µSv/hr – 7.51 µSv/hr.

5.2 Conclusion

The foregoing revealed that while facilities developed from existing buildings may not be adequate in room size, shielding of the radiographic room walls and doors, provision of warning, lights and signs. Optimization of radiation protection could be achieved through careful consideration of the radiographic room design and layout by adherence to room specifications by regulatory bodies. Each X-ray installation should be provided adequate shielding facilities as per national and international Standards. Introduction of shielding in diagnostic radiological facilities plays vital role in order to ensure radiation safety workers and the public working in and around the facilities. However, the assumptions or approximations are utilized in shielding calculations in different approach may overestimate or underestimated the barrier thickness of the facility. The overestimation of the barrier thickness may increase the cost of the shielding and influence the user to loose commitment about radiation safety. Even though the dose rate measured around the facilities are found within the regulatory limit in most of the cases, but it is also evident that doses in Diagnostic Centre F, G and H are not optimized. However, the dose rate is measured utilizing many other techniques such as using TLD could give a more precise results basically for the effective dose. The ten radio-diagnostic Centres covered in this study have given us ten different structural designs of diagnostic X-ray rooms, types of shielding materials used and radiation transmission through barriers.

5.3 Recommendations

i. The evaluation of personnel radiation monitoring in the selected diagnostic centres shows that personnel radiation monitoring (dosimeter badge) is available in two of the Diagnostic Centers, though not all of the staff are monitored. All staff who work in the X-ray facility are excepted to always wear one.

ii. The absence of staff dose history needs to be visited to enable the monitoring of radiation risk to staff. There is a need for Nigeria Nuclear Regulatory Authority to enforce the standards of radiation protection as published in their various safety reports.

iii. The concluded research showed that a lot of radio-diagnostic centers are not regulated, as some do not even know about the practices of NNRA. These findings call for standardization in radiology room designs and regular radiation safety assessment as recommended by regulatory bodies.

iv. Specifically, replacement of the ordinary wooden door to the X-ray room with one suitable for radiation protection for center F.

v. Use of radiation warning stickers on the door around the X-ray room (Centre F, G and H). Suspension of the use of the X-ray equipment till some reasonable safety measures are put in place (Centre F, G and H); this includes proper lead-lining of the X-ray room and use of other shielding barriers.

5.4 Contribution to Knowledge

i. This study has demonstrated the level of radiation protection practice in the selected radiological facility.

ii. It has also helped to establish best practices and the feedback (given the participating centres) from the study would assist each radiological facility to improve its radiation protection practice (dose optimization), ensuring that both personnel and the public are protected from unnecessary radiation exposure.

5.5 Suggested Area for Further Study

The results of this work show that dose rate in most of the facilities are relatively higher than the recommended NCRP safety standard. Therefore, further research work should be directed towards health risk of radiation exposure from diagnostic facilities in Ibadan. With the proliferation of X-ray facilities in Ibadan and the increase in the number of X-ray examinations carried out, it is needful for NNRA to design and sponsor an extensive Shielding and dose monitoring through the use of research students.

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Appendix

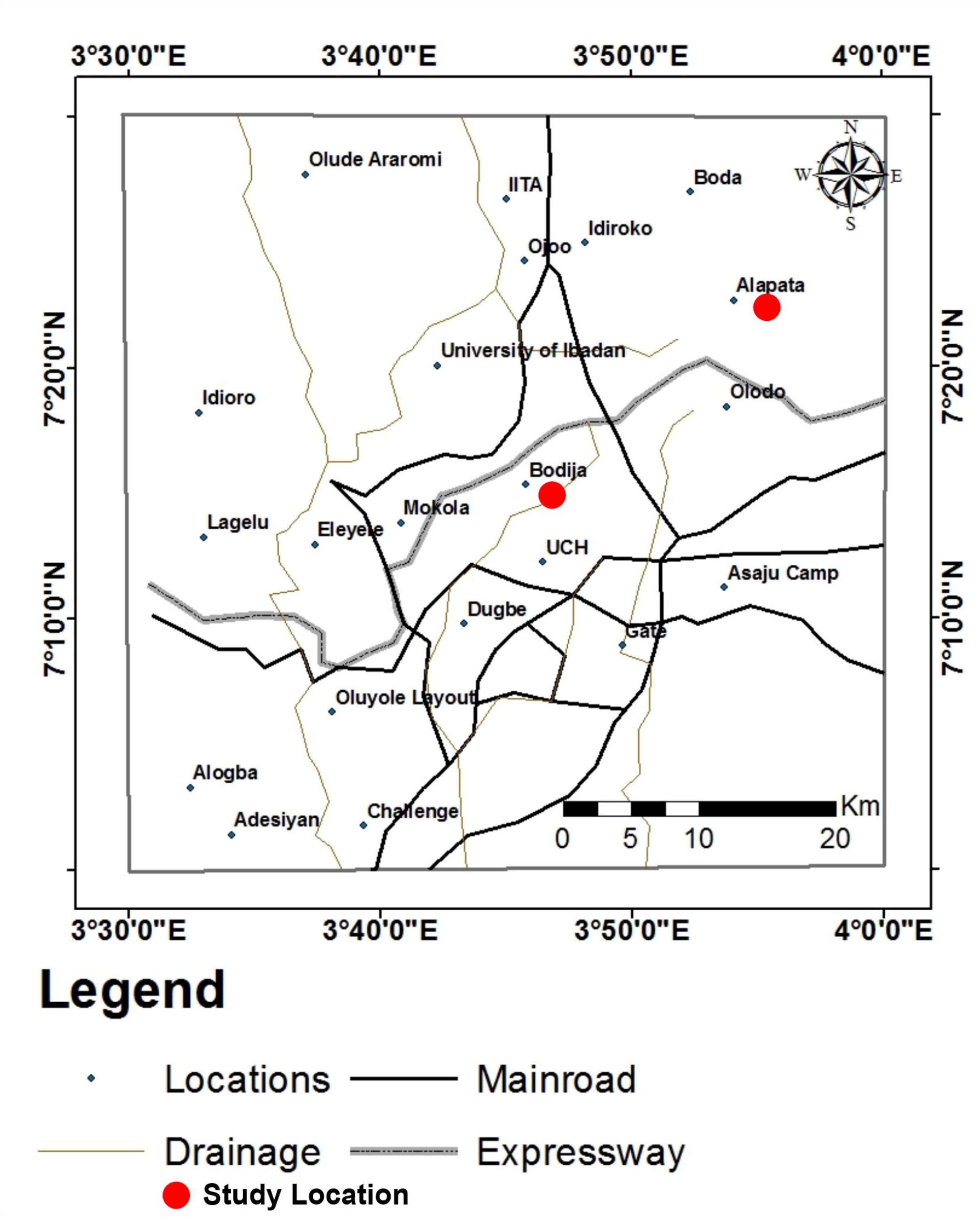

Figure 4.21 Map showing the Study Location

Researcher: Okereke Chigbo 2022

Bio-data

A. Personal Data

Name:	Chigbo Igwe OKEREKE
Address:	52, Bolarinwa street, college crescent Ibadan.
Email Address:	igwechigbo@gmail.com
Phone Number:	+234 70-3744-2145
Date and Place of Birth:	September 15, 1985/ Jos
Nationality:	Nigeria
Name and Address of next of Kin:	Maryann E. IGWE 52, Bolarinwa street, college crescent, Ring Road, Ibadan.

B. Educational Background

Educational Institutions attended with Dates and Qualifications Obtained

Akanu Ibiam Fed. Poly. Staff School Unwana	Primary School Leaving Certificate (1997)
Federal Government College Okposi	West African Examination Council (2003)
University of Maiduguri	Bachelor of Science (2011)
Lead City University	Post Graduate Diploma in Physics (2021)
Lead City University	Masters of Science in Physics (In view)

C. Working Experience with Dates

Work Place	Date
1. Odukpani Primary Health Center, Calabar	2011 - 2012
2. Search for common ground (SFCG)	2012 - 2012
3. Mercy Corp	2013 - 2015
4. Mission to Save the Helpless (MITOSATH)	2015 - 2018
5. Federal College of Animal health & Prod. Tech. Ibadan	2018 - till date.

D. Publications:

Title:	Natural Radioactivity Levels of Some Herbal Plants with Antimalarial Potency in Ibadan South-West Local Government Area of Oyo State, Nigeria
Year of publication	January, 2020
Volume	13, Issue 1, pp 01-07
Journal	IOSR Journal of Applied Chemistry (IOSR-JAC)

Title:	Investigation of Physico- Chemical Properties of Some Herbal Plants Used to Treat Malaria in Ibadan South- East Local Government Area, Oyo State, Nigeria.
Year of publication	October, 2021
Volume	1, Issue 1, pp 206-212
Journal	Annals of Research Journal

E. Academic/Professional Membership

Nigeria Institute of Physics (NIP) – Member

F. Award

Non

G. Major Conferences attended with Dates.

1. 3rd International Conference on Medical Health Sciences.

   Venue: Bingol, Turkey.

   Date: 24th – 26th December, 2021.

2. 43rd Nigerian Institute of Physics (NIP)

   Venue: Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

   Date: 21st -26th September, 2021.

3. 42nd Nigerian Institute of Physics (NIP)

   Venue: Federal University of Technology, Owerri, Imo State, Nigeria

   Date: 18th - 20th, November, 2019.

4. Basics of Networking using Routers workshop

Venue: Ajayi Crowther University Oyo, Nigeria.
Date: 15th - 16th December, 2020.

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The University Compliance Certification

This is to certify that the thesis by Chigbo Igwe OKEREKE in the Department of Physics, Faculty of Natural and Applied Science, Lead City University, Ibadan, Oyo State, Nigeria is full compliance with the approved University Format and style.

Signature

Date