DEVELOPMENT OF PERSONNEL RADIATION MONITORING PROGRAM FOR OCCUPATIONALLY EXPOSED WORKERS IN MALAWIAN HOSPITALS: A CASE STUDY OF KAMUZU CENTRAL, BWAILA, AND MTENGO WA NTHENGA HOSPITALS

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DECLARATION

I, Getrude Chinangwa, hereby declare that this document is a result of my research work undertaken as a student under the Department of Medical Physics, Graduate School of Nuclear and Allied Sciences, University of Ghana, with the supervision of Dr. J.K. Amoako and Prof. J.J. Fletcher. This work has never been submitted in whole or in part anywhere else for any other award. In the case where other sources of information have been used, such sources have been cited in this work and acknowledged under references.

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DEDICATION

I dedicate this work to my beloved husband, Bickson, for his wonderful support throughout my study period.

ACKNOWLEDGEMENT

I am very grateful to my supervisors, Prof. J.J. Fletcher and Dr. J.K. Amoako for their guidance, constructive criticism and input in my work. Throughout my work, I also received support and assistance from a number of individuals and institutions to which I am very grateful. These include: The International Atomic Energy Agency (IAEA) which awarded me the scholarship for the whole program; The Dean, Administrators, Lectures and staff of the School of Nuclear and Allied Sciences (SNAS); The Director of Radiation Protection Institute (RPI) of Ghana Atomic Energy Commission (GAEC); Mr Michael Obeng, Mr Philip Owusu-Manteaw and all staff of the RPI Personnel Dosimetry Laboratory. I also wish to acknowledge the support I received in Malawi from The Ministry of Health officials, especially Mr B. Chipa; The Chairman and all members of the National Health Sciences Research Committee (NHSRC), The Management and staff of Kamuzu Central Hospital, Bwaila Hospital, and Mtengo wa Nthenga Hospital. I also received support from my bosses and colleagues at the Environmental Affairs Department, to whom I am very grateful. I also acknowledge the love, prayers, moral and social support from my family, friends and church. Above all, I honour God Almighty for His Grace and Wisdom which have always been sufficient in my times of need.

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ABBREVIATIONS

ADE	Ambient Dose Equivalent
AEC	Automatic Exposure Control
ALARA	As Low As Reasonably Achievable
ARS	Acute Radiation Syndrome
BSS	Basic Safety Standards
CR	Conventional Radiography
CT	Computed Tomography
DR	Diagnostic Radiology
ECC	Element Correction Coefficient
GAEC	Ghana Atomic Energy Commission
Gy	Gray
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
KCH	Kamuzu Central Hospital
keV	Kilo electron volt
kVp	Kilo voltage potential
LiF	Lithium Floride
mAs	Milli amps second
mA-min	Milli amps minute

MeV	Mega electron volt
Mg	Manganese
MoH	Ministry of Health
MRS	Multi Radiography System
NCRP	National Council on Radiation Protection and Measurement
OEWs	Occupationally Exposed Workers
OSL	Optically Stimulated Luminescent
PDE	Personal Dose Equivalent
PDS	Personnel Dosimetry Service
PMP	Personnel Monitoring Programme
QA	Quality Assurance
QC	Quality Control
RCF	Reader Correction Factor
RPI	Radiation Protection Institute
RPO	Radiation Protection Officer
SABS	South Africa Bureau of Standards
Sv	Sievert
TLD	Thermo luminescent Dosimeter
TTP	Time Temperature Profile
UV	Ultraviolet
WinREMS	Windows Radiation Evaluation and Management System

ABSTRACT

Malawi became an IAEA member state in 2006 and developed the Atomic Energy Act and Regulations in 2011 and 2012 respectively. However, regulatory authority and personnel monitoring services have not yet been established. As such, hospitals operating radiological services in Malawi do not have personnel monitoring programme. This study aimed at developing the personnel radiation monitoring program for three hospitals in Malawi namely; Kamuzu Central Hospital, Bwaila Hospital, and Mtengo wa Nthenga Hospital. A radiation protection questionnaire was administered to the X-ray Departments involved in the study to investigate radiation protection practices in the hospitals. Dose rate measurements in the facilities were taken using survey meters and doses to individuals were recorded using personal dosimeters. The results showed that the hospitals lack radiation protection program which covers the critical issues of quality assurance and control as well as the personnel dose monitoring. Average ambient dose rate values were 0.39 µSv/hr for Mtengo wa Nthenga Hospital, 5.03 µSv/hr for Bwaila Hospital and 4 µSv/hr for Kamuzu Central Hospital. Average monthly dose for workers was 0.247 mSv. The study recommends the establishment of a regulatory authority, consistent dose assessment, quality control tests and structural shielding assessment in these and probably all the diagnostic facilities in Malawi. The personnel monitoring programme developed from this study is intended to guide diagnostic facilities and personnel monitoring service providers in Malawi in tracking and reporting exposure record for their occupationally exposed workers.

CHAPTER ONE

INTRODUCTION

This chapter mainly presents the Background to the Study, Problem Statement, Justification and Objectives.

1.1 Background to the Study

Many hospitals offer diagnostic radiology (DR) services. DR is basically the use of x-rays to investigate the structure and function of the human body for clinical purposes [1]. X-rays, (just like gamma rays) are high frequency energy waves which are classified as ionizing radiation on the energy spectrum. [2]Ionizing radiation is defined as the form of energy which, during interaction with an atom, is strong enough to remove tightly bound electrons from the orbit of an atom, causing it to become charged or ionized.

Exposure to ionising radiation has two main effects to human beings, these are: deterministic effects and stochastic effects. Deterministic effects are those effects for which generally a threshold level of dose exists above which the severity of the effect is greater for a higher dose. Examples include: acute radiation syndrome (ARS), skin burns, sterility and cataract. These effects are mainly associated with exposure to high radiation doses for a short time (acute exposure). [3]On the other hand, stochastic effects are the effects, generally occurring without a threshold level of dose, but their probability of occurrence is proportional to the dose; and their severity is independent of the dose. Radiation induced cancer and some hereditary effects are main examples of stochastic effects. These effects are associated with exposure to low radiation doses for consistent long time (chronic exposure).

For every practice that involves the use of ionizing radiation, it is important for protection to be optimized. [4]Optimization simply means the process of making sure that the number of individuals subject to exposure, the likelihood of exposure and the magnitude of exposure are kept as low as reasonably achievable (ALARA). Optimization is key to achieving the aim of radiation protection which is to prevent deterministic effects and reduce the probability of stochastic effects. Dose assessment is crucial in achieving the dose limitation principle of radiation protection. In the process of achieving the objective of radiation protection, it is important to monitor the doses received by exposed individuals so as to make sure that they are within recommended limits. In this study, the practice of ALARA and dose limitation principles were assessed in some hospitals in Malawi.

1.1.1 Radiology Human Resource in Malawi

Radiology is the major practice involving ionizing radiation in Malawi. [5]According to the Ministry of Health (MoH), diagnostic radiology in Malawi is facing a lot of challenges, including shortage of human resources, inadequate supervision, and lack of appropriate infrastructure to comply with the minimum space requirements stipulated in International Radiology Standard Operation Guidelines. Other challenges include the donation of radiology equipment to hospitals without accompanying guidance on operating procedures and absence of radiation monitoring equipment.

[6]The Malawi College of Health Sciences is the only institution in Malawi which trains medical radiographers at certificate and diploma levels. Professionals have to go abroad to study for a degree in the field. Currently, the country has three radiologists and about one hundred and thirty four (134) radiographers in government hospitals. The mission and private hospitals have about sixty eight (68) radiographers. The Country Report for use in Radiology Outreach Initiatives, indicated that the fact that there is no higher level education beyond certificate and diploma for medical imaging in Malawi is a challenge which causes lots of radiographers to change profession or enter other allied health professions because the opportunity to advance in radiography is limited. The shortage of staff in Malawi implies that few available workers have much work to do which may lead to their over exposure to radiation. To address the human resource issue, MoH with support from International Atomic Energy Agency (IAEA) and other donors, has sent some staff for further studies in Medical Physics and other radiological disciplines.

In investigating the status of Quality Assurance (QA) and Quality Control (QC) measures in diagnostic x-ray facilities in Malawian government hospitals, Chinamale (2010), reported that there were no QA program and committees in all the X-ray Departments where the study was conducted (about 52% country wide). [7] And Results from QC tests which he performed on the X-ray equipment showed sub-optimal status of the equipment in most of the hospitals. This status may also lead to over exposure of patients and workers.

1.1.2 Regulatory Framework and Personnel Monitoring Service in Malawi

Malawi became an IAEA member state in 2006, and had its Atomic Energy Act and Regulations approved by Parliament in 2011 and 2012 respectively. [8] The Atomic Energy Regulations clearly stipulate the requirements of licensees and registrants regarding optimization of radiation protection and safety both in medical and industrial applications. However, the Regulatory Authority to enforce these requirements and monitor compliance by users has not yet been established.

[5] Many occupationally exposed workers (OEWs) in Malawi are not monitored. For some years, few radiographers and uranium mine workers have been monitored by personnel dosimetry service providers in South Africa and Australia. In 2012, IAEA provided the country with the Harshaw 4500 TLD Reader, to assist Malawi in establishing the Personnel Monitoring Service. The service is however, not yet fully in operation because infrastructural and operational arrangements have not yet been instituted.

1.2 Problem Statement

Literature review showed that many Malawian hospitals are operating Radiological Health Care Services without Radiation Protection Monitoring Program. Data from the Ministry of Health clearly shows that there is shortage of staff in X-ray Departments of most hospitals. This is evident with the prevailing one radiographer per hospital situation in many district hospitals. There is no data on the occupational exposure of radiology workers due to the absence of a monitoring program. [7] As already alluded to in

Chinamale's report, quality control tests are not conducted on X-ray equipment in most hospitals. There is also no recorded information on availability of radiation protection program in the hospitals. This situation therefore, brings uncertainty on workers' safety against ionising radiation. There is therefore, the need for the development of a monitoring program that will generate data on occupational exposure of workers and enable quality control tests on X-ray equipment in Malawian hospitals.

The following research questions came up, upon considering the above radiology situation in Malawi:

(i) Are there any radiation protection measures being practiced in Radiology Departments of hospitals in Malawi?

(ii) What mechanisms are hospitals employing to optimize radiation safety?

(iii) Are workers in X-ray Departments aware of radiation safety?

(iv) What are the estimated dose levels to workers in these hospitals?

1.3 Objectives

The overall objective of this study is to develop and recommend an effective and sustainable personnel radiation monitoring program to be used in the X-ray Departments of hospitals in Malawi.

Specific tasks to be addressed:

a. To investigate the radiation protection practices being undertaken in the hospitals;

b. To assess radiation exposure and dose levels through individual and workplace monitoring, and compare them against the internationally recommended limits;

c. To provide a systematic guide to radiological facilities that will facilitate the recording and reporting the radiation exposure of their workers.

1.4 Relevance and Justification

This study was relevant because its main output, thus the personnel monitoring program, will help to address the long-time need in the radiological facilities of Malawi. This program is not only a need but also a requirement for all users of ionizing radiation. The study will also contribute to useful baseline information for Malawi, particularly in the field of Radiation Protection which has not yet advanced. Hence it will be a basis for other follow-up research studies. The study will in addition help raise awareness on the importance of Radiation Safety in Radiology Departments; and the need for the establishment of a Regulatory Body in Malawi.

1.5 Scope of the Study

This study covers the personnel dosimetry concept within the broad area of occupational radiation protection.

1.6 Thesis Structure

This thesis has five chapters. Chapter one gives a brief introduction of the study. Chapter two is a review of some literature related to the study. Chapter three outlines the research methodology, Chapter four gives the research findings; and, Chapter five contains the conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

This chapter provides information about X-rays, occupational exposure in diagnostic radiology and personal dosimetry as stipulated in various texts.

2.1 Physics of X-rays

[9] X-rays were discovered in 1895 by the German physicist called Wilhelm Roentgen (1845-1923). X-rays have a very high frequency and a very short wavelength ranging between 0.001 to 10 nano meter (nm). X-rays and gamma rays are also referred to as photons. The difference between the two is that X-rays are emitted by electrons outside the nucleus while gamma rays are emitted by the nucleus. Photon energy (E) is given by:

$$E = hv \qquad \text{[Eq. 1]}$$

where the constant *h* is known as Planck's constant, and *v* is voltage.

[10] In diagnostic radiology, the photon energy is usually expressed in units of keV, where one electronvolt (eV) is the energy received by an electron when it is accelerated across of a potential difference of one volt. Energy levels used in DR normally range from 10 to 150 keV.

[11] X-rays are produced whenever electrons of high energy strike a heavy metal target, like tungsten or copper. As shown in Figure 2.1, the high voltage generator is always the source of energy to accelerate the electrons in the tube from the cathode to the anode where they strike the target element to produce X-rays.

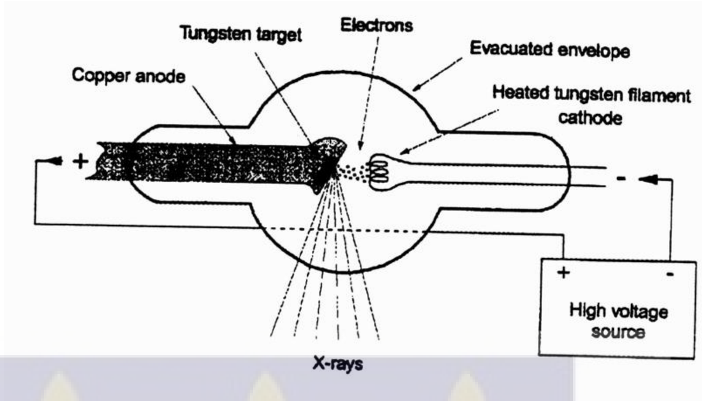

Figure 2.1: Production of X-rays

In clinical applications, X-rays are best suited to imaging bones and have a very high resolution. For imaging soft tissue however, the resolution is very low and so a contrast medium is needed. There are various types of X-ray machines used in DR depending on their functions. These include: conventional X-ray equipment for general static radiography, fluoroscopy equipment for dynamic radiography and computed tomography (CT) for tomographic or three or four dimensional slice imaging. There are also other machines for special applications such as mammography (for breast cancer screening); angiography (for screening blood veins); pediatric radiology (for new born babies and little children) as well as dental radiography (for screening teeth). Some machines are mobile but many are installed and fixed at one place. However, in all these machines, X-rays are produced under the same principle explained above.

When photons interact with matter, there are three possible effects depending on the incident photon energy, and these are: photoelectric effect, compton scattering and pair production. Photoelectric effect is associated with low energy photons which usually interact with inner shell electrons. As a result, the electron is ejected from the atom and is called photoelectron. [12] When the electron from outer shell moves to fill the vacancy created in the inner shell, the energy released is called characteristic radiation. Compton scattering is associated with medium energy photons. In this effect, the incident photon ejects an electron from the outer shell of the atom and then the photon is scattered with reduced energy. In pair production, high energy photon interacts with the nucleus resulting into electron-positron pair production. Finally the positron undergoes annihilation to form two 0.51 MeV photons. X-ray energies in diagnostic radiology are generally low such that photoelectric effect and compton scattering are commonly experienced.

2.2 Occupational Exposure Control

[13] Occupational exposure is defined as that exposure of workers incurred in the course of their work, and Occupationally Exposed Workers (OEWs) is the term referred to such workers. OEWs in diagnostic radiology mainly include: radiologists, medical physicists, radiographers and nurses.

As shown in Figure 2.2, there are three main sources of exposure involved in radiography; primary radiation, scattered radiation and leakage radiation. Primary radiation (or primary beam) is the useful radiation produced in the X-ray tube. [14] It is usually a spectrum of characteristic and bremsstrahlung radiation. When this radiation interacts with the human body, some rays transmit through the patient and decode the image on the receptor. But other rays go through Compton scattering effect causing the patient to emit scattered radiation. Leakage radiation is the radiation which escapes from the x-ray tube. Scatter and leakage radiation are also known as secondary radiation. This radiation is critical to the safety of workers, patients and the public.

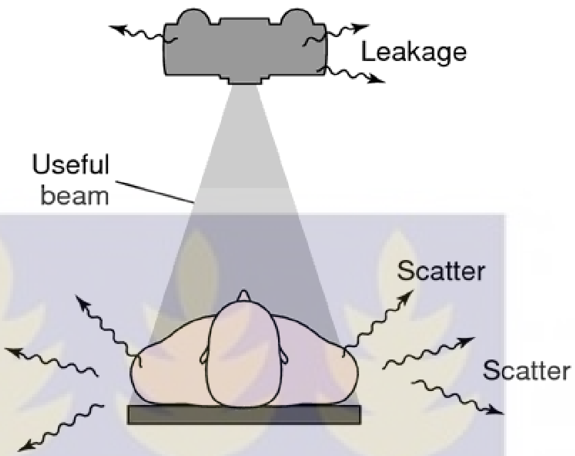

Figure 2.2: Three types of radiation: useful beam, scatter and leakage radiation

Justification, optimization and dose limitation are the three main principles of radiation protection. Justification is the process of determining that for a planned exposure situation, the expected benefits to individuals and to society from a new or existing practice, far outweigh the harm (including radiation risk) resulting from that practice. Optimization is the process of ensuring that the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures all are kept ALARA, taking into account economic and social factors. [15] Dose limitation is about observing that the recommended maximum annual dose value of the effective dose or the equivalent dose to individuals in planned exposure situations is not exceeded.

ALARA principle is practically achieved by adhering to three techniques: time, distance and shielding. [16] These are the basic operational measures of reducing exposure to external radiation. The longer the time the worker spends with the radioactive source, the highly exposed he will be. The more the exposure, the greater the cumulative dose, and the higher the risk of biological harmful effects. The distance between the worker and the source also matters most. In this case, the source can be the switched on X-ray tube or the exposed patient. Distance factor is explained by the term known as *inverse square law*. The shorter the distance, the higher the exposure and the longer the distance, the lesser the exposure. The final principle is basically about provision of shielding materials for both the X-ray room and the workers. Materials of high density and high atomic number are most suitable for structural shielding. These include concrete, lead or steel. Lead aprons, lead gloves, thyroid shields, gonadal shields and googles are recommended shields for the body of workers.

2.3 Personal Dosimetry

Personal dosimetry is mainly about the measurement of the amount of radiation dose an individual receives. It is very important to monitor radiation doses that OEWs are receiving. [17] The main purpose is to assess whether or not the doses exceed the dose limits recommended by the International Commission of Radiological Protection (ICRP). This assessment helps to determine the effectiveness of protection measures being used in the facility. There are two categories of personal dosimetry namely external personal dosimetry and internal personal dosimetry. [18] External dosimetry is the measurement of dose due to sources outside the body while internal dosimetry is the dose measurement due to sources inside the body. This study deals with external dosimetry.

[15] External dosimetry is done using two methods, these are, active and passive monitoring. Active monitoring involves the use of an instrument or device which reacts to radiation immediately and gives an instant reading of either the whole body personal dose equivalent [Hp(10)] or the ambient dose equivalent [H*(10)]. In passive monitoring, the dose information is stored in the monitoring instrument and later on processed to obtain the individual dose results.

[19] Electronic pocket dosimeters and survey meters or dose rate meters are examples of instruments used in active monitoring. Electronic pocket dosimeters give immediate reading of Hp (10) while survey meters give immediate reading of H*(10). Film badges, Thermo luminescent Dosimeters (TLDs) and Optical Stimulated Luminescent dosimeters (OSLs) are examples of passive instruments used to measure the whole body personal dose equivalent. [19] The workers are given these devices to wear for a period of one to three months and thereafter recorded personal doses [Hp (10)] for a specified period are read and analysed in the laboratory.

2.3.1 Radiation Quantities

There are three categories of quantities used in radiation measurements, namely, radiometric quantities, dosimetric quantities and operational quantities. [20] Radiometric quantities are those which describe the radiation field and these include: energy, fluence (Φ), exposure (X) and kerma (K). Dosimetric quantities describe the effects produced by the radiation dose in the absorbing medium and these include: absorbed dose (D), equivalent dose (H), effective dose (E), collective dose and committed dose. Basically, the term *dose*, refers to the amount of energy deposited in a medium when radiation passes through it. Operational quantities include ambient dose equivalent [H*(d)], directional dose equivalent [H'(d, Ω)] and personal dose equivalent [Hp (d)]. [21] Ambient dose equivalent and directional dose equivalent are used in area (or workplace assessment) while personal dose equivalent is used in individual dose assessment.

For strongly penetrating radiation, a depth, d, of 10 mm is used; the ambient dose equivalent being H*(10) and the directional dose equivalent being H'(10,Ω) [18]. For weakly penetrating radiation, the ambient and directional dose equivalents in the skin at d = 0.07 mm are used but these are not likely to be encountered in the radiological environment. H_p (10) provides an approximation of whole body dose, H_p (0.07), the equivalent dose to the skin while H_p (3) is for the equivalent dose to the lens of the eye [19].

The ICRU recommends the use of operational quantities because the dosimetric quantities such as equivalent dose (which measure the radiation effect to specific organs) and effective dose (which measure the radiation effect to the whole body) are difficult to measure in practice. Below is a brief definition of these quantities:

Equivalent dose is defined as a summation of absorbed doses from different incident radiation types, each multiplied by appropriate radiation weighting factor. It is given by:

$$H_T = \sum D_{T.R} * W_R \qquad \text{(Eq.2)}$$

where $D_{T.R}$ = is the absorbed dose delivered by radiation type R averaged over a tissue or organ T and W_R = radiation weighting factor for radiation type R,

Effective dose, is defined as a summation of the tissue or organ equivalent doses, each multiplied by the appropriate tissue weighting factor. It is given by:

$$E = \sum H_T * W_T \qquad \text{(Eq. 3)}$$

where H_T = equivalent dose and W_T = tissue weighting factor.

In both cases, the results are in Sieverts (Sv).

As stated earlier, these cannot be measured in reality, thus, operational quantities are used to give a reasonable approximation to the same, and most radiation monitoring instruments are designed and calibrated accordingly in terms of the quantities intended to indicate [21].

2.3.2 Dose Limits and Constraints

Dose limitation is one of the principles of radiation protection. The purpose is to control the occupational and public exposures to avoid deterministic and stochastic effects of radiation. [17] ICRP came up with some values in terms of equivalent and effective dose to act as a guide in implementing this principle. ICRP recommends that in planned situations, occupational doses should not exceed the values shown in Table 2.1.

Table 2.1: Occupational exposure limits (ICRP 75, 1997)

Application	**Dose limits**
Effective dose (whole body)	50 mSv per year (or 1mSv per week) 20 mSv per year (or 0.4 mSv per week) averaged over defined periods of five years
Annual equivalent dose to lens of the eye	150 mSv
Annual equivalent dose to the skin	500 mSv
Annual equivalent dose to hands and feet	500 mSv

Many countries use these recommendations in their personnel monitoring programs. And many regulatory bodies also develop dose constraints. A dose constraint is the value of an individual dose not to be exceeded in the individual dose distribution considered in the optimization process. It is a source related quantity, that is, it refers to the source, practice or task to which the optimization process is applied. As a ceiling on the individual dose, the constraint is used to restrict the inequity of the distribution of dose [20]. Dose constraints are not dose limits and exceeding dose constraints does not imply non-compliance with regulatory requirements, but it could result in follow-up actions. Dose constraints are usually lower than dose limits and they may differ from one country to another. However, the intended outcome is that all exposures are controlled to levels that are as low as reasonably achievable, economic, societal and environmental factors being taken into account.

2.3.3 Radiation Monitoring Instruments

Radiation monitoring instruments are devices which detect and quantify external radiation exposure from radiation sources outside the body [21]. Dose rate or survey meters are usually the instruments used in workplace assessment while in individual assessment, the commonly used detectors are film badges, thermo luminescent dosimeters or optical stimulated luminescent dosimeters (OSLs).

2.3.3.1 Survey Meters

[22] A survey meter provides the dose records promptly or immediately during measurements, hence it is also called an *active* instrument. Survey meters (or dose rate meters) are capable of detecting strongly penetration radiation (i.e. gammas and X-rays) and also some beta particles. They do not detect alpha particles because they of their weak penetrating force. Neutrons are more difficult to monitor because they do not cause ionization directly. As such it is recommended to measure neutron dose rates with specially designed neutron monitors. [23] Two typical dose rate meters are Geiger-Muller tube dose rate meters and ion chamber dose rate meters. Dose rate meters usually give a direct reading of dose rate in units of microsieverts per hour (µSv/ hr). The old quantity for dose rate was mrem/hr, where 1 mrem/hr = 10 µSv/ hr.

Figure 2.3: Examples of survey meters/dose rate meters

It is important to note that survey meters are set to measure the ambient dose equivalent rate, which is the operational quantity in area monitoring as discussed above. This measurement gives a good approximation of the effective dose rate to the bodies. One way of determining the total dose from a dose rate meter is by multiplying the exposure time by the measured dose rate. [24] However, some dose rate meters are able to sum (or integrate) the dose received over a given time and give a read out in dose units (µSv) rather than dose rate units.

2.3.3.2 Thermo luminescent Dosimeters

A Thermo luminescent dosimeter (TLD) is the device which passively measures the effective dose [H_p (10)] of external radiation to the body [22]. It consists of small crystal chips or elements made of lithium fluoride and containing trace quantity of manganese, (LiF: Mg, Ti). It is placed in a holder and is worn on the chest by the worker when is working in the radiation field. Thermo luminescence refers to the emission of light by a semi-conducting material upon heating it. And thermo luminescent dosimeters (TLDs) operate basically by this principle.

A typical Whole Body TLD Card (as shown in Figure 2.4) consists of four LiF: Ti, Mg TL chips, 3 mm^2 (1/8 inch) square, encapsulated between two sheets of Teflon 0.0025 inches (10 mg/cm^2) thick and mounted on an aluminum substrate. Three of the chips are fabricated from TLD-700 in either of two thicknesses: 0.15 mm (0.006") or 0.38 mm (0.015"), and one from TLD-600, 0.38 mm (0.015") thick. Each chip/filter combination performs a specific function, as follows: One TLD-700 chip, 0.38 mm thick, covered with 242 mg/cm^2 ABS plastic and 91 mg/cm^2 copper filtration, is used for low energy photon discrimination and dose to the lens of the eye measurement. Another TLD-700 chip, 0.38 mm thick, with 1000 mg/cm^2 combined PTFE/ABS filtration (107 mg/cm^2 ABS + 893 mg/cm^2 PTFE filters) measures the deep dose. A thinner TLD-700 chip, 0.15 mm thick with 0.06 mm aluminized Mylar filtration determines the shallow dose. [25] The total filtration for this element, combining the PTFE card encapsulation and the aluminized Mylar filter, is 17 mg/cm^2. A TLD-600 chip, 0.38 mm thick, with 300 mg/cm^2 ABS plastic filtration, measures lens of the eye and neutron dose.

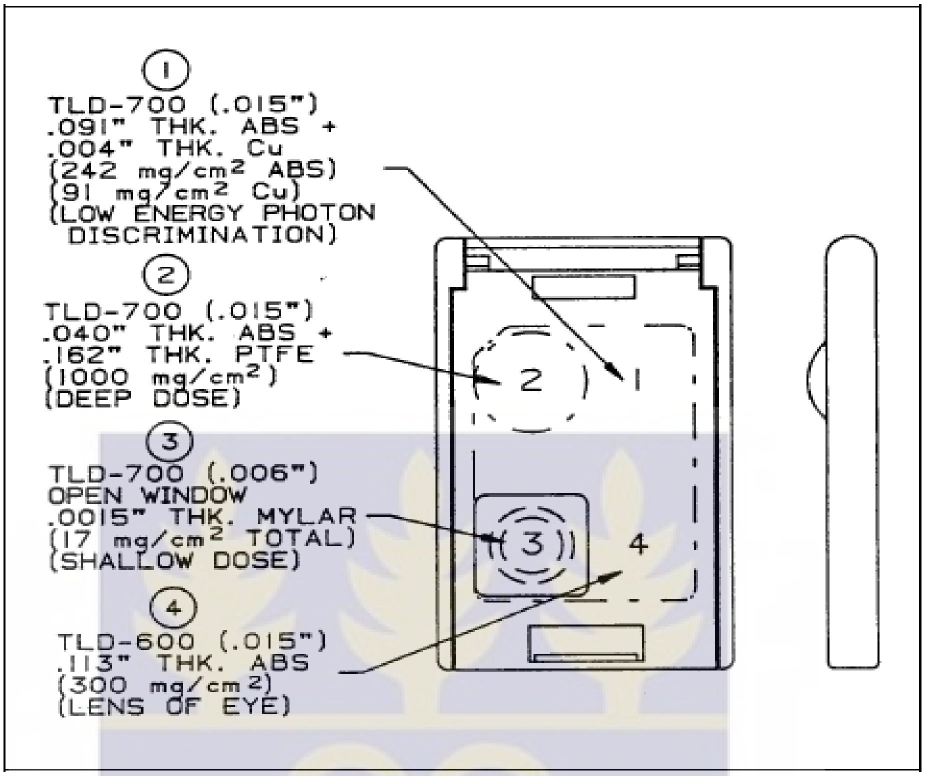

Figure 2.4: A typical personal dosimeter

The TLD Card Holder (Figure 2.5) is made of durable, tissue-equivalent, ABS plastic, and is casketed and sealed to retain the card in a light and moisture excluding environment. The Holder protects the card from environmental damage and retains the filtration media which attenuate the various radiation types to provide selective entrapment in the TL material. [25] This difference in radiation absorption allows determination of shallow, deep, and lens of the eye doses as well as some energy discrimination.

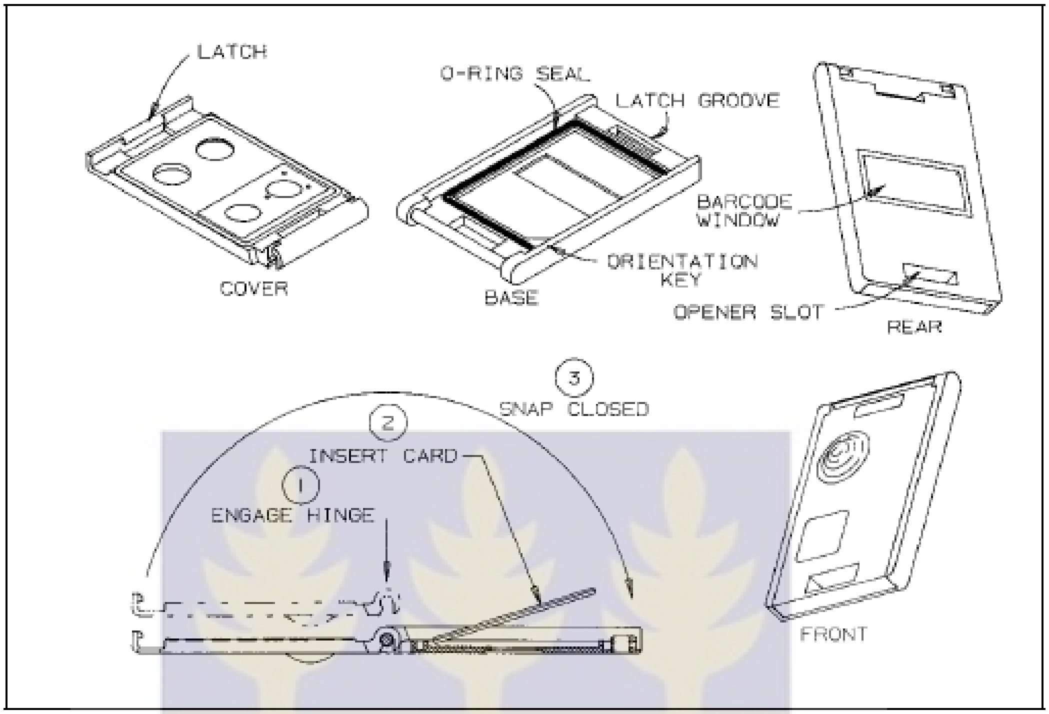

Figure 2.5: TLD holder

When exposed to external radiation, the TL material traps and stores the radiation energy which strikes it. [19] This absorbed energy per unit mass of the TL material (radiation dose) can be determined by thermally stimulating (heating) the material. Upon heating it under high temperatures, the absorbed energy is released in form of light (IR, visible or UV) which is converted into an electronic signal by the photomultiplier tube within the TLD Reader. The intensity of this emitted light represents the amount of the radiation dose and its signal is observed on the screen as a glow curve (Figure 2.7). [21] The area under the curve is directly proportional to the amount of the absorbed dose.

Figure 2.6: TLDs of multiple colours

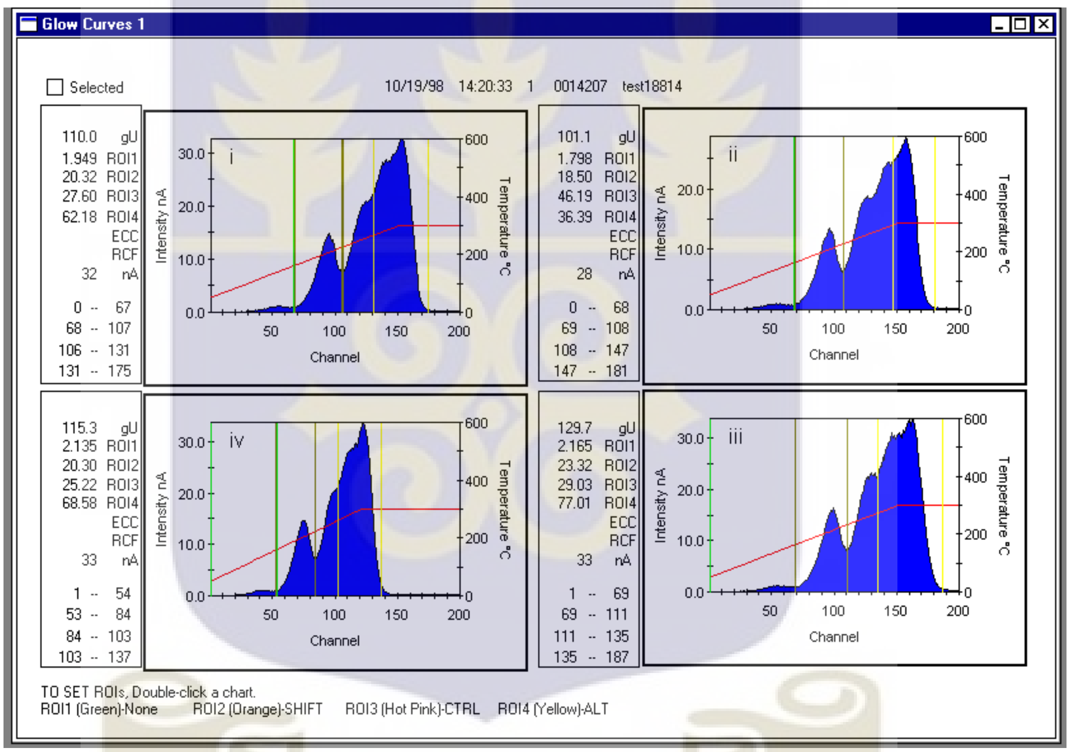

Figure 2.7: Glow curve view

TLDs are in different types depending on the purpose for which they are used. For example TLD-100 (Figure 2.6) is used for personal monitoring while TLD-200 is used in environmental monitoring. TLD material properties include sensitivity, tissue equivalence, energy response, fading, residual, linearity and reusability. Explanations for these properties are given in Table 2.2.

Table 2.2: Properties of TLD material

Property	Definition/explanation
Sensitivity	Amount of light emitted from a given mass of TLD material exposed to a given amount of radiation. The small size of TLD makes it easy for it to be sensitive even to point dose exposure.
Tissue equivalence	Measure of how close a material's interaction properties mimic those of soft tissue when irradiated.
Energy response	Amount of light emitted from a TLD material when exposed to radiation of varying energies.
Fading	Loss of TL emission (light) over time for a given exposure.
Residual	Amount of signal remaining after initial read.
Linearity	TLD response to varying doses. A linear response over a large dose range is desired.
Reusability	Ability of the TLDs to be used over again and giving effective results. They can be read over 1000 times with minimal impact to signal intensity.

[22] Apart from chest TLD badges, there are also wrist badges which are used to estimate dose to hands and forearms when they are likely to be selectively exposed. They are worn around the wrist. [19] There are also finger ring TLDs made of durable low density polypropylene plastic and are adjustable to fit finger sizes from 16 to 28 mm in diameter.

2.3.4 Calibrating Survey Meters

Calibration is defined as the quantitative determination, under a controlled set of standard conditions, of the indication given by a radiation measuring instrument as a function of the value of the quantity the instrument is intended to measure [23]. For the purpose of quality assurance and control, it is recommended that radiation monitoring instruments used in radiation assessments should be calibrated in order to confirm that they are functioning correctly and that their performances are within standard requirements and specifications.

All radiation protection survey instruments must be calibrated against calibration sources representative of the sources the instrument will be used to measure. This ensures that the instruments are capable of responding within acceptable levels of accuracy [24]. To ensure the national and international uniformity of response, these calibration sources must be traceable to a primary or secondary standard, and these standards are usually held at a national or international standards laboratory. The primary standards used for the calibration of radiation protection monitoring equipment include exposure, dose rate, emission rate and activity. Secondary standards are calibrated against primary standards and it is a requirement that national standards laboratories compare their standards against each other at regular intervals to ensure international uniformity.

[23] Dose rate meter calibration is performed by determining the instrument response in a specific radiation field delivering a known dose rate at a particular set distance from the source. The instrument controls are then either adjusted to read the desired dose rate or a calibration factor is determined and included in a calibration report.

Prior to use, it is important to confirm that an instrument has been calibrated and that it is within its calibration dates. This information is usually given in the instrument manual or on a calibration certificate. The requirements for the frequency of calibration vary according to local regulations but usually one calibration per year is recommended for each instrument. [24] If an instrument is not within its calibration dates or it has been repaired for any reason, it should be recalibrated before it is used again.

2.3.5 Calibrating TLDs

The purpose for calibrating TLD Cards is to ensure that all cards will give the same response to a given radiation exposure [25]. The calibration process involves annealing the cards and determining their Element Correction Coefficients (ECCs). The ECC is simply the calibration factor of a TLD. It should be noted that for the new personnel dosimetry system, calibrating the cards to be dispatched to the field (field cards), is normally done after the generation of calibration cards (or golden cards) and the Reader calibration.

The following procedures are followed when calibrating the field cards [25]:

a) Annealing the cards to remove the residual dose by processing them in the Reader;
b) Exposing the cards to a known dose within two hours of annealing them;
c) Storing the dosimeters in a subdued UV environment with a temperature not higher than 30 ^{0}C for at least thirty minutes;
d) Reading the dosimeters by processing them in the Reader;

e) Setting calibration parameters. The acceptable range is 0.77 (as Lower Detection Limit), and 1.43 (as Upper Detection Limit);

f) Initiating calculations in the WinREMS. The ECC is computed in the WinREMS installed on the computer connected to the Reader by entering an acceptable ECC range for each chip position. This value will determine the deviation from the mean (1.0) that will be considered acceptable for the field dosimeters. Dosimeters which fall outside of this range are considered in the software as dosimeters with bad ECCs and are not used as field dosimeters;

g) Accepting the calculated values to apply the data to the ECC database.

2.4 Personnel Monitoring Program

The IAEA Basic Safety Standards (BSS) state that the facility management has the principal responsibility for setting up a Personnel Monitoring Program. Personnel Monitoring Program is basically a systematic process for monitoring, recording, evaluating, and reporting the radiation doses received by occupationally exposed individuals in the facility. Its main purpose is to ensure compliance with established dose limits and to keep radiation doses ALARA [26]. The Radiation Protection Officer (RPO) within the facility ensures that the Personnel Monitoring Program exists and is being implemented. He or she can advise management on the modification or review of the program.

Basically the program is the stipulation of procedures which all OEWs should follow in ensuring personnel radiation safety and dose limitation. [27] The following are some of the main issues which are included in the program (among others):

i. Requirements for the usage and storage of individual monitoring devices.
ii. Dose record keeping procedures
iii. Dose reporting procedures
iv. Instructions for pregnant workers

It is a good practice for the facility to have a Personnel Monitoring Program because it helps to provide information for workers to understand how, when and where they are exposed and to motivate them to reduce their exposure [27]. As stated earlier, the main objective of this study is to develop the personnel monitoring program for X-ray Departments of Malawian hospitals. Documents relating to permission for access to the health facilities; and Ethical Clearance for the Study are presented in appendix 1.

CHAPTER THREE

MATERIALS AND METHODS

This chapter describes the study area, sample size, materials and methods used for data collection and analysis.

3.1 Study Area

The study was conducted in three hospitals within the Central Region of Malawi. Malawi is a small landlocked country located in the south-eastern part of Africa. It is bordered by Zambia to the northwest, Tanzania to the northeast, and Mozambique on the east, south and west. The country is separated from Tanzania and Mozambique by Lake Malawi, the third largest lake in Africa. It covers an area of 118,484 km^2 with an estimated population of 16,777,547 [37]. The land covers 94,080 km^2 and 24,404 km^2 of the country is covered with water. Its capital city is Lilongwe. The country is divided into twenty eight (28) districts within three main geographic regions: Northern Region, Central Region and Southern Region.

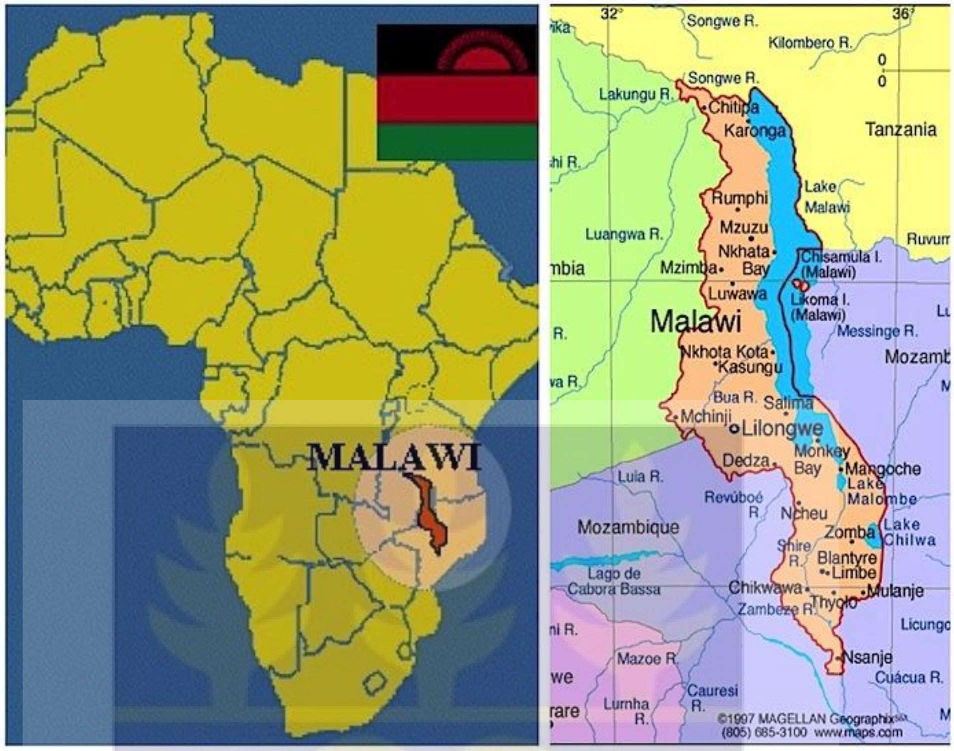

Figure 3.1: Map of Malawi and its location in Africa

The three hospitals studied were, Kamuzu Central Hospital (KCH), Bwaila Hospital, and Mtengo wa Nthenga Hospital. These hospitals were chosen for the study according to the three-tier health care delivery system which exists in Malawi based on the three levels of health care. [5] The three levels of health care in Malawi are primary level, secondary level and tertiary level. Primary health care or community care is basically organized to meet the primary health services. This consists of community initiatives, dispensaries, maternity units, health centres and community and rural hospitals. District hospitals constitute the secondary level of health care and provide specialized services to patients referred from the primary health care level, through outpatient and inpatient services and community health services. These services are enhanced by provision of adequate specialized supportive services, such as laboratory, diagnostic, blood bank, rehabilitation and physiotherapy services. [6] Tertiary health care, which consists of highly specialized services, is provided by central hospitals and other specialist hospitals providing care for specific disease conditions or specific groups of patients.

Mtengo wa Nthenga Mission Hospital is one of the community hospitals in Dowa and according to health care levels explained above, it is at primary level. Bwaila is the district hospital in Lilongwe, thus at secondary level, and Kamuzu Central Hospital is at tertiary level. The purpose was to have an idea of radiation protection status at all the levels of health care.

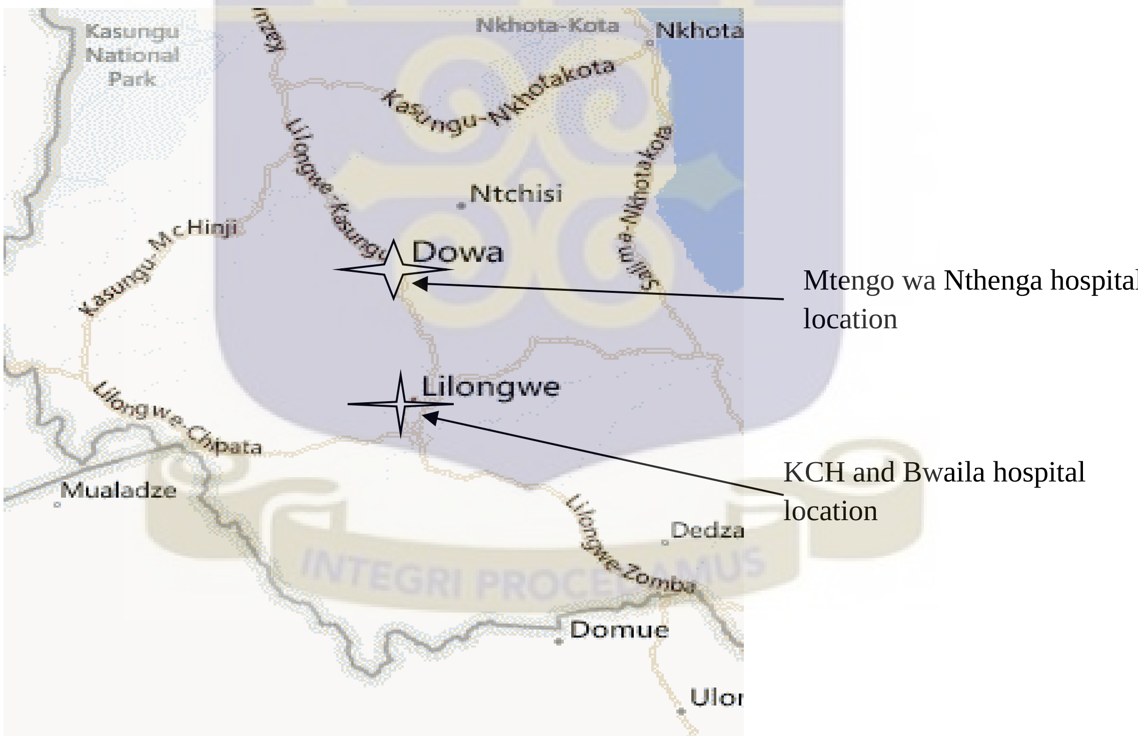

Figure 3.2: Map of Malawi Central Region showing hospitals' locations

The functionality of X-ray machines and the number of radiographers in their x-ray departments, were also contributing factors to the hospital selection. The Ministry of Health reported that most X-ray machines in the country had technical fault as such they were not functional. This was confirmed with the observation that the X-ray department of Bwaila hospital was serving not only Lilongwe district residents but also residents from other districts where machines are not working. Therefore the choice of these hospitals was also based on the assumption that their x-ray machines have high workload which may have an effect on occupational exposure.

3.2 Sample Size

Fifteen (15) radiographers were sampled for the study. This number represented about thirty percent (30%) of the radiographers within the Central Region. Twelve radiographers were from KCH, two from Bwaila Hospital and one from Mtengo wa Nthenga hospital.

3.3 Materials

A questionnaire was used for general assessment of radiation protection practices in the x-ray departments. Survey meters were used for workplace monitoring and Themoluminescent Dosimeters were used for individual monitoring.

3.3.1 Questionnaire Administration

A questionnaire was administered to the three X-ray Departments of the respective three hospitals studied. The purpose of the questionnaire was to obtain information about radiation protection of workers in these departments. Specifically it was meant to assess the knowledge and practice of safety measures against ionising radiation (X-rays in this case).

The questionnaire had three main parts. The first part sought the general information of the responder and the hospital. The second part was to seek information about quality assurance and control practices in the departments, and the final part assessed the personnel protection measures (Appendix 2).

3.3.2 Survey Meters

Two Rados Multi-Purpose Survey Meters with serial numbers: 2200588 and 2200589 respectively and manufactured by Mirion Technologies (Figure 3.3) were used to measure the ambient dose rate [H*(10)] in the x-ray rooms. The survey meters are owned by the Malawi Environmental Affairs Department. These are portable and lightweight instruments normally used for workplace assessments.

Figure 3.3: Two Rados survey meters used in the study

Table 3.1 shows the radiological characteristics of these instruments as stipulated in the user manual [24].

Table 3.1: Radiological characteristics of RDS-31 Multi-purpose survey meters

Component	**Details**
Radiation detected	Gamma and X-rays, 48keV-3MeV, alpha and beta radiation with external probes.
Measured quantity	Ambient dose equivalent H*(10)
Dose rate measurement range	0.01μSv/h-0.1Sv/h or 1μrem/h-10rem/h
Dose measurement range	0.01μSv-10Sv or 1μrem-1000rem
Configurable units	Sv/h, R/h, Gy/h, cps, cpm, dpm and Bq
Others	Real time clock function, Audible alarm, visual alarm and configurable vibration alarm as an option.

3.3.3 Thermo luminescent Dosimeters

Nineteen (19) TLDs from the Personnel Dosimetry Laboratory of the Radiation Protection Institute, Ghana Atomic Energy Commission (RPI, GAEC) were used for the Study. Personnel Dosimetry Laboratory were used for the study. Fifteen (15) TLDs were issued to the workers, three (3) was used as control cards for each hospital and one (1) was the control card for all the cards to determine the background dose outside the hospitals as well as other potential dose encountered in transportation.

The dosimeters were of LiF: Mg, Cu, P material type, with two chips or elements (2 and 3) for measuring personal dose equivalent Hp (10) and Hp (0.07). Chip (2) is normally for the deep dose, i.e. the external whole body exposure dose equivalent at a tissue depth of 10 mm while chip (3) is normally for shallow dose, that is, the external exposure dose equivalent to the skin at a tissue depth of 0.07 mm. The lower detection limit (LLD) of these dosimeters is 0.01 mSv. This means that the cards are sensitive such that they can detect radiation exposure as low quantity as 0.01 mSv. TLDs normally have varying intrinsic material sensitivity which is corrected during calibration by applying the element correction coefficient (ECC).

3.4 Description of Facilities

3.4.1 Overview of Mtengo wa Nthenga Hospital X-ray Facility

This facility has one radiographer who holds a bachelor's degree in diagnostic radiography and has eleven (11) years working experience. The facility also has one Conventional Radiography machine which was installed in 2010. The machine uses screen films with manual processor (i.e. darkroom).

3.4.1.1 X-ray Room

a) The room size measures 4.5 m x 6.5 m (29.25 m^2). Usually the minimum standard room should measure 25 m^2. The room is well spacious (Figure 3.4).

b) Its wall is made up of concrete, 26 cm thick. The standard wall thickness is 20 cm.

c) The entrance door to the room is made up of wood with a lead lining sheet of 3 mm.

d) The room has a functional air conditioner.

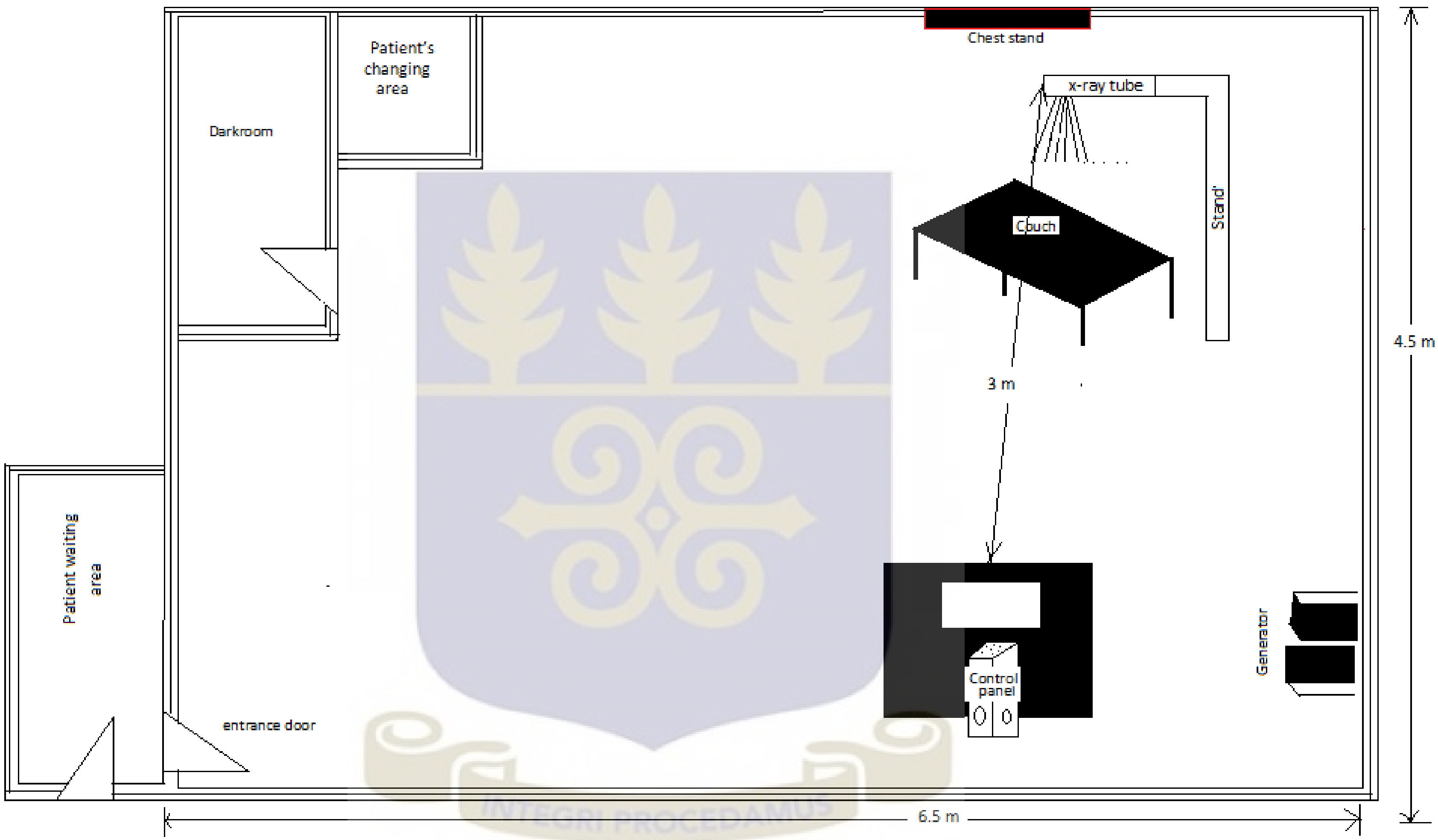

Figure 3.4: Mtengo wa Nthenga Hospital X-ray Room Layout

3.4.1.2 X-ray Machine

i. The x-ray machine installed in the room (Figure 3.5) is **Philips MRS (multi radiography system)** with tube serial number 07E 464 and two generators of serial numbers B 50537 and G 26745.

ii. The machine was manufactured in Germany in October 2007 and was installed at the hospital in 2010.

iii. The x-ray machine is used for general radiography (with manual film processing).

iv. The maximum operating parameters for the machine are: 100kVp, and 80mAs.

Figure 3.5: X-ray Machine for Mtengo wa Nthenga Hospital

3.4.1.3 Control Panel

a) The distance between the X-ray tube and the control panel is 3 m.

b) The control cubicle (Figure 3.6) is mobile and measures 1m by 2 m .

c) The viewing window measures 30 cm by 30 cm. The standard window should be 40 cm by 40 cm.

d) The window glass is 1cm thick but it is not labelled whether it is lead or not.

Figure 3.6: A Mobile Control Panel Shield

3.4.2 Overview of Bwaila Hospital X-ray Facility

3.4.2.1 X-ray Room

a) The room size was 4.2 m x 6.3 m (26.46 m^2) as sketched in Figure 3.7.

b) The wall is 15.2 cm thick made up of concrete.

c) The entrance door to the room is made up of wood without a lead lining sheet.

d) The room has a functional air conditioner.

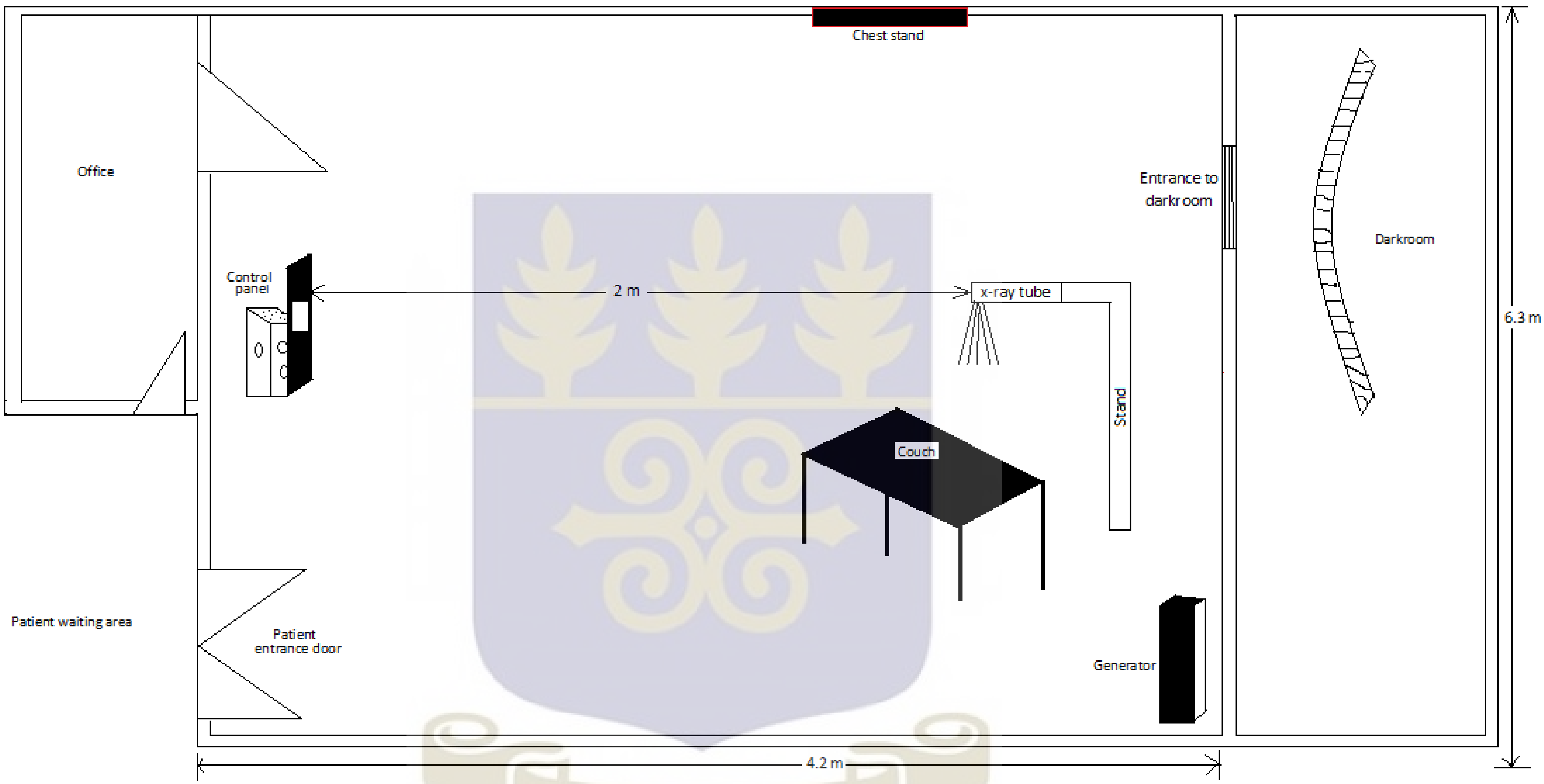

Figure 3.7: Bwaila Hospital X-ray Room Layout

3.4.2.2 X-ray Machine

a) The room has a Philips general radiography machine installed in it (Figure 3.8).

b) Date of installation and other specifications of the machine were missing.

c) The x-ray machine uses the Automatic Exposure Control (AEC) as well as manual film processing.

d) The maximum operating parameters for the machine are: 117 kVp, and 60 mAs.

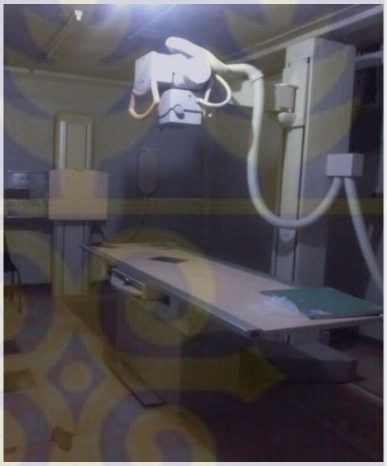

Figure 3.8: Bwaila Hospital X-ray Machine

3.4.2.3 Control Panel

i. The distance between the x-ray tube and the control panel is 2 m.

ii. The control cubicle is mobile and measures 1 m by 2 m and is 3 cm thick.

iii. The viewing window measures 30 cm x 40 cm (0.12 m^2).

iv. The lead glass specification is: A_DIN/0320/2.2mm Pb/110 kV/s.

3.4.3 Overview of Kamuzu Central Hospital CT Scanner Facility

3.4.3.1 CT Room

a) As shown in Figure 3.9, the CT room measures 7 m x 5.6 m (39.2 m^2). The standard minimum room size should measure about 30 m^2.

b) The wall concrete thickness is 40 cm. The minimum standard wall thickness is 35 cm.

c) Both patients' and staff's entrance doors are made up of steel 4 cm thick.

d) The room has a functional air conditioner.

3.4.3.2 CT Machine

i. The type of the machine is **Philips Brilliance 64 slice CT scanner** (Figure 3.10).

ii. The machine was installed at the hospital in 2013.

iii. It is used for various examinations such as head, abdomen, brain, cervical spine and others.

iv. The maximum operating parameters for the machine are: 140 kVp, and 600 mAs.

3.4.3.3 Control Panel

i. The distance between the CT scanner centre and the control panel is 4.1 m.

ii. The control cubicle measures 7 m by 2 m.

iii. The viewing window measures 1.35 m x 0.68 m (0.92 m^2). The standard window in Ghana should be 1 m^2.

iv. The viewing window glass specifications were missing both on the glass and on paper as such radiation assessment was the only way to identify whether the glass is lead or not.

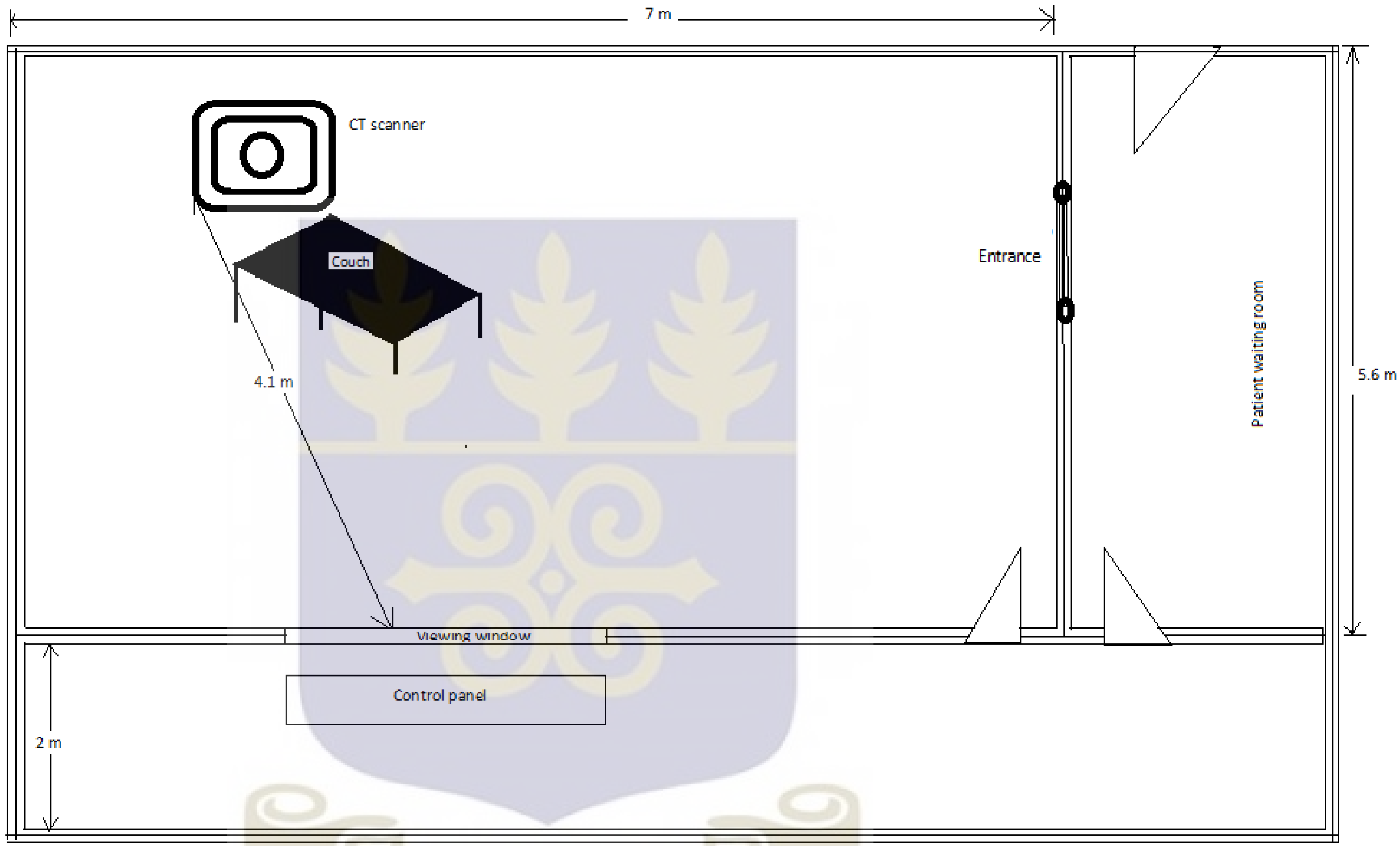

Figure 3.9: KCH CT Scanner Room Layout

Figure 3.10: KCH CT Machine

3.5 Methods

Ethical clearance procedures was observed before collecting data. Permission was sought from the three hospitals and the field work started after approval from Malawi National Health Sciences Research Committee (see Appendix 1).

3.5.1 Workplace Monitoring

Response check was done to ensure that the survey meters were operating correctly before taking measurements. These checks included: visual check, battery check, calibration check, light sensitivity and source checks. The survey meters used, were within calibration period according to manufacturer's specification. However, for quality control purposes, a calibration check was conducted prior to the assessment. This was done at Malawi Bureau of Standards Instrumentation Unit on 12th January 2016 (see Appendix 3).

A workplace monitoring survey form was used in radiation safety assessment of the workplace. The form was in three parts namely; general information, X-ray room details and dose measurements at the control panel (see Appendix 4).

Each hospital was visited for four times in one month and each assessment was for four hours between 8 am to 12 noon. This time duration was the peak period of work in all the hospitals involved in the Study. Dose readings were taken at the control panel as the operator was exposing patients. Other relevant information such as workload, x-ray room size, wall thickness, viewing window size and glass thickness were assessed. Tape measure was used to determine the room sizes and wall thickness. The workload assessed was to measure the radiation output of the x-ray unit in a week [37].

3.5.2 Individual Monitoring

The calibrated cards were issued to the workers to detect and record their doses. The monitoring period was one month from 25th January to 25th February 2016. Each hospital was also provided with one control card to measure background radiation outside the controlled room. Apart from these control cards, there was another control card which was not sent to any hospital, this was intended to account for other potential encountered exposures especially in transit. The values for these cards were subtracted from the recorded personnel dose to obtain the true dose.

3.6 Data Analysis

Microsoft Excel and Windows Radiation Evaluation and Management System (WinREMS) were used to analyse the collected data. Reading of the cards was done using the Harshaw 6600 Automated TLD Reader (Figure 3.11) located at the Personnel Dosimetry Laboratory of the Radiation Protection Institute, GAEC. The Reader is connected to the external computer through a serial port. Windows Radiation Evaluation and Management System (WinREMS) was installed on the computer. This software controls the operations of the Reader, including storing the operating parameters: Time Temperature Profiles (TTPs), Reader Calibration Factors (RCFs), and Element Correction Coefficients (ECCs) [25].

Figure 3.11: Harshaw 6600 Automated TLD Card Reader

3.6.1 Dose Calculation

1. The following formula was used within WinREMS to calculate the dose to individual workers:

$$D(\text{in microsievert}) = \frac{Q \times ECC}{RCF} \quad \text{(Eq. 4)}$$

where Q is the charge or the TLD reading (in nanocoulombs), ECC (dimensionless) is the Element Correction Coefficient, and RCF is the Reader Calibration Factor (in nanocoulombs/microSievert).

2. **Workload**

Workload is simply the radiation output of the machine per week. It is expressed in mA-minutes per week. It gives an indication of the radiation quantity being produced by the X-ray machine in a week which will ultimately have an effect on the exposure of patients as well as workers. High workload entails increased exposure. Workload of the X-ray machines was evaluated using the formula below:

$$W = R \times D \times E \qquad \text{(Eq. 5)}$$

where: W = workload (in mA minutes per week), R = number of radiographs per day, D = number of days of operation per week, E = exposure (in mA minutes)

3. **Ambient Dose Equivalent (ADE)**

Ambient dose equivalent [**H*(d)**] at a point in a radiation field is defined as the dose equivalent that would be produced by the corresponding field in the ICRU sphere at a depth *d* mm [40]. This quantity is mostly used to assess doses from strongly penetrating radiations such as gamma and X-rays at the recommended depth of 10 mm of the ICRU sphere. It gives a reasonable approximation to the effective dose. From the dose rate measurements taken at control panels of the X-ray units, the ADE values were calculated using the formula:

$$D = DR \times T \qquad \text{(Eq. 6)}$$

where: D is the dose, DR is the dose rate recorded by the instrument and T is the exposure time.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the research findings from the assessment done. It also gives some comparisons made between workplace and individual monitoring results. The comparison with results from other studies has also been presented. Due to the absence of local radiation protection guidelines on the safe use of X-rays in Malawi, the researcher has compared the findings against the recommendations by the International Commission on Radiological Protection (ICRP), International Atomic Energy Agency (IAEA), the American National Council on Radiation Protection and Measurements (NCRP, 147), and the Ghana Nuclear Regulatory Authority.

4.1 Implementation of Basic Elements of Occupational Radiation Protection

Table 4.1 presents the status-quo in the facilities in regards to some basic indicators of effective radiation protection programme.

Table 4.1: Implementation status of occupational radiation protection measures in hospitals

Element	**Mtengo wa Nthenga**	**Bwaila**	**KCH**	**Remarks**
Number of X-ray machines	1	1	6*	*with 1 CT
Number of workers	1	3	17*	*Including one radiologist
Average number of patients per day	10	150	15*	*For CT scanning
Presence of qualified and experienced personnel	Yes	Yes	Yes	
Presence of RPO	Yes*	No	Yes*	*But not formally trained in radiation protection
Number of personnel trained in Radiation Protection	0	0	2	
Presence of radiation safety committee	No	No	No	
Presence of quality assurance program	No	No	No	
Presence of personnel monitoring program	No	No	No	
Routine workplace radiation surveys	No	No	No	
Presence of protective wear (lead aprons)	Yes	Yes	Yes	But rarely used
Presence of warning lights	No	No	Yes*	*One functional
Presence of radiation symbols	No	No	Yes	
Display of operating procedures	Yes	No	Yes	
Consultation with external experts in radiation protection	No	No	No	

As shown in Table 4.1, it was discovered that crucial aspects of an effective radiation protection program are not being implemented in these facilities. Workers in these facilities require training in radiation protection, more especially, the Radiation Protection Officers (RPOs). The absence of quality assurance program is in agreement with the findings in Chinamale's study in 2010 [7]. Due to lack of quality control equipment, the operators are unable to perform the quality control tests which help to ensure that the machines are operating properly according to the image quality and radiation protection requirements. This is the common scenario even in other African countries [36]. In other countries where the regulatory authorities are functional, the quality control tests are performed by regulatory authority officials during their regular inspections to the facilities. In that way, the regulatory authorities act as both watchdogs as well as backup in making sure that the operational and protection standards are not compromised. However, this is a big challenge in Malawi, where the regulatory authority has not yet been established. As such the quality control tests are not being performed at all.

It was also discovered that safety assessments are not conducted at the installation stage of the machines, during operation, maintenance and also at decommissioning. The radiation surveys around the workplace are not performed, and there is no program for monitoring the exposure of individual workers. One facility (KCH) reported to have engaged South Africa Bureau of Standards (SABS) as a personnel monitoring service provider at one time using TLDs. Dose records were reviewed and showed that dose values were always 0.0 mSv for all the workers. However, SABS stopped providing the service due to the client's failure to pay the bills for some time. This study has been useful to these facilities in the way that it has developed the personnel monitoring program for these facilities, hence contributing to the implementation of sustainable radiation protection of workers in the hospitals.

4.2 Calculation of Workload

Table 4.2 shows the weekly workload of machines in mA.min based on the given factors for the study facilities. According to workload formula given in the methodology section, the parameters were multiplied together to get total workload.

$$W = R \times D \times E \quad \text{(Eq. 5)}$$

where: W = workload (in mA minutes per week), R = number of radiographs per day, D = number of days of operation per week, E = exposure (in mA minutes)

Table 4.2: Workload of the Facilities

Parameters	**Mtengo wa Nthenga Hospital**	**Bwaila Hospital**	**KCH**
Average mAs/day	15	15	478
Average # of films/patients	3	3	1
Average # of slices/patients*	-	-	278
Average # of patients/day	10	150	15
# of working days/week	5	5	5
Time conversion factor	0.01667	0.01667	0.01667
Total Workload (mA.min/week)	**38**	**563**	**166, 138**

*Applicable to CT Scanners only

The weekly machine output for Mtengo wa Nthenga Hospital was 38mA.min. This is an indication of the radiation amount produced by the machine in a week. The monthly workload will thus be: 38 mA.min/week x 4 weeks = 152 mA.min. Multiplying this figure by the number of months in a year (12) will give us the approximate annual workload which is 1824 mA.min. In comparison with the general values given in NCRP 147, this workload is lower. NCRP 147 shows that for X-ray machines with maximum kV of 100, maximum weekly workload values do not exceed 1000 mA.min. During the study, it was discovered that the kV mostly used for examinations at this facility ranged from 50 to 90 kV, and mAs from 5 to 40 depending on the type of examination and the patient size. High kV and mAs were used mainly for abdomen examination and for big sized patients unlike for chest examinations and less body sized patients. The average number of patients examined per day at this facility is relatively low, and it also contributes to the low workload value. The X-ray service at this facility is not free therefore might be a factor for the low turn up for patients.

For Bwaila Hospital;

The calculation shown on Table 4.2 shows that the machine radiation output is high. It was observed that the machine collimation bulb was not working. Exposures were being conducted without beam collimation. This fault can obviously contribute to the high workload recorded. The number of patients per day is also another factor contributing to this high workload. It was reported that X-ray units in some government hospitals within the central region were not functional and this resulted in many patients being referred to this hospital for their examinations hence increasing the workload.

For KCH;

Normally CT machines operate using high mAs and kVp as such they have higher workload values than general X-ray machines [39].

4.3 Ambient Dose Estimation

The essence of a radiation survey around the workplace is to determine the ambient radiation dose reaching the machine operator especially at the control panel. The radiation survey helps to determine whether the radiation doses received by the workers are within recommended dose limits. Equation (6) was used to estimate the ambient dose [H*(10)] in the facilities under Study:

$$\text{Dose} = \text{Dose Rate} \times \text{Exposure Time} \qquad \text{(Eq. 6)}$$

The dose rate values recorded in data collection were summed up and the average dose rate per day was calculated. The exposure time was also summed up and average 'radiation-on' time per day was determined. It should be noted that this is the total time when X-ray tube is switched on because the X-ray equipment does not emit radiation when it is switched off. The average dose rate was multiplied by the average exposure time and the average dose per day was determined in μSv and then converted into mSv by dividing by one thousand (1000). The total dose in the month was estimated by multiplying the resultant dose by the number of working days in the month, that is, twenty days (20). In all the facilities, it was reported that they have five working days per week. Multiplying five days by the number of weeks in the month (usually four) gives us twenty working days in the month. The annual dose was further projected by multiplying the dose rate (μSv/hr) by the number of working hours per year (thus 2000). This was to conservatively estimate the annual dose based on the current status of affairs in these facilities.

The type A uncertainty of measurement (or the standard deviation) was also considered during the dose estimation. The uncertainty of measurement is simply a parameter, associated with the result of a measurement that characterizes the dispersion of values that could be reasonably attributed to the measurand [23]. Below is the formula which was used to calculate Type A uncertainty (u_A):

$$U_A = s(\bar{a}) \quad \text{and}$$

$$s(\bar{a}) = \frac{s(a_i)}{\sqrt{n}} \qquad \text{(Eq. 7)}$$

where $s(\bar{a})$ is the standard deviation of the mean value of statistically independent observations, $s(a_i)$ is the standard deviation of the individual results and n is the number of observations. Table 4.3 presents the estimated ambient dose for each facility plus or minus the uncertainty value.

Table 4.3: Ambient Dose Readings

PARAMETER	**Mtengo wa Nthenga**	**Bwaila**	**KCH**
Average dose rate per day (µSv/hr)	0.39 ± 0.1	5.03 ± 2.05	4.0 ± 2.0
Average dose per day (mSv)	3.77×10^{-8}	1.19×10^{-6}	1.39×10^{-5}
Average dose per month (mSv)	7.53×10^{-7}	2.38×10^{-5}	2.78×10^{-4}
*Projected annual dose (mSv)	0.78	10.06	8.0

*Estimated by multiplying the average dose rate by the 2000 working hours in a year.

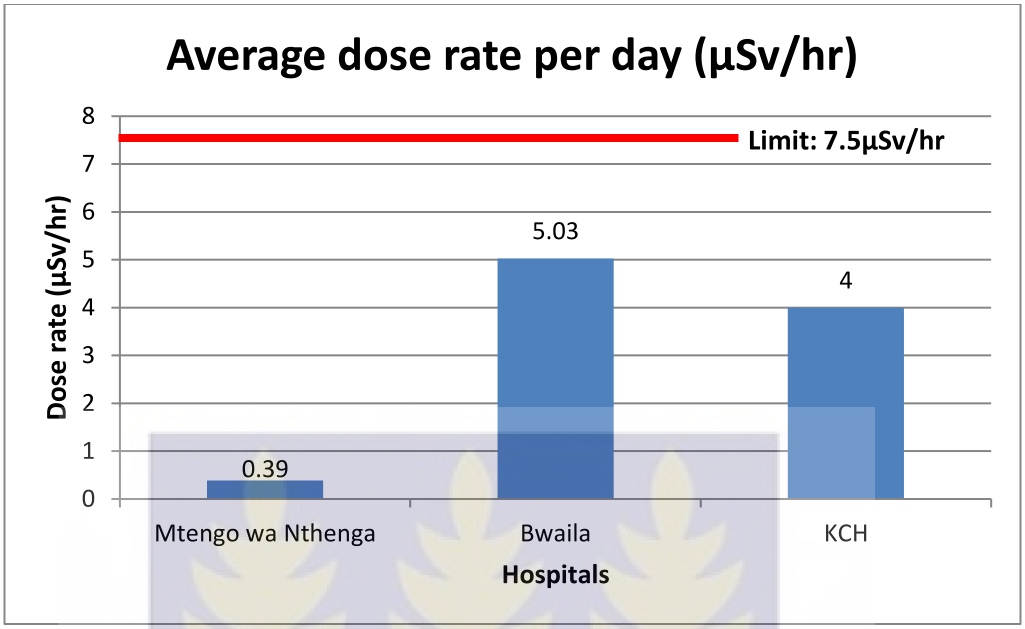

Figure 4.1: Chart of average ambient dose rate per day

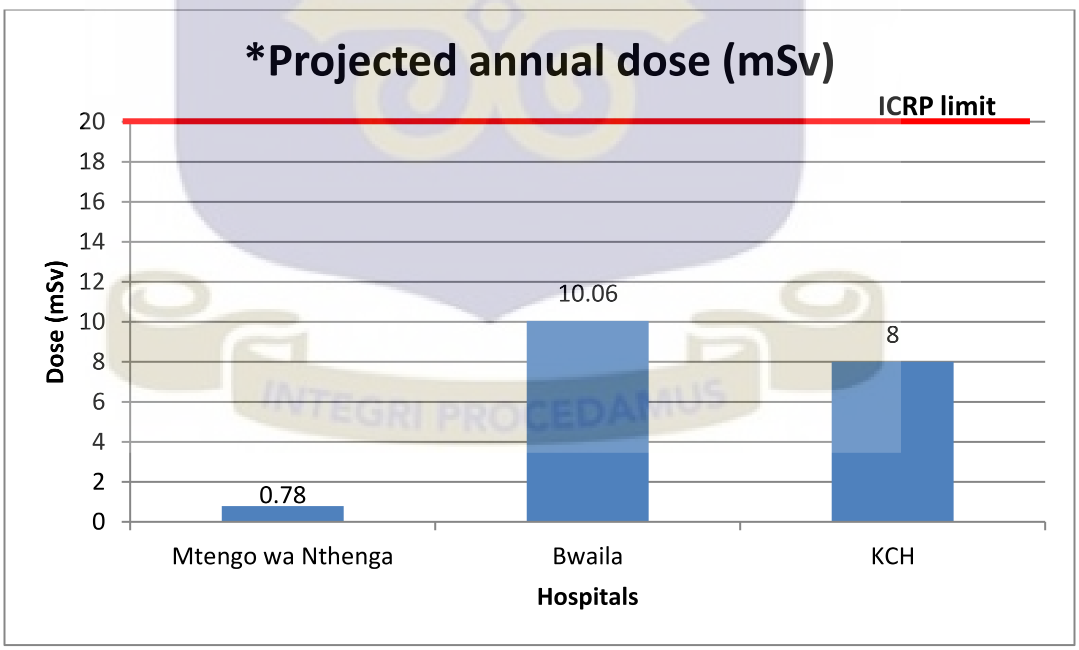

Figure 4.2: Chart showing projected annual dose

From Table 4.3 and Figure 4.1, it was observed on the average that, all facilities had ambient dose which was below the ICRP recommended limits. The recommended limit for the dose rate in the workplace is 7.5 µSv/hr. The effective dose limit per year for the worker is 20 mSv which translates into 1.67 mSv per month.

Bwaila registered high dose rate per day (5.03 µSv/hr), followed by KCH (4 µSv/hr) and finally Mtengo wa Nthenga (0.39 µSv/hr). However, in terms of cumulative ambient dose [H*(10)] per day and per month, the values for KCH were relatively higher, followed by Bwaila and finally Mtengo wa Nthenga. The reason behind this is the exposure time. The scanning duration for the CT scanner is always longer (in seconds) than for general X-ray machines (in milli seconds). Bwaila general X-ray facility had high dose rate because of high workload. The number of patients exposed at this facility per day was higher than in the other two facilities. The other contributing factor is that the machine at Bwaila did not have the light used for beam collimation. This meant that exposures were taking place without adjusting the field size; and it is the collimation light which helps very much in achieving this. As a result there was a lot of scattered radiation reaching the worker. Mtengo wa Nthenga registered lower values mainly because of low workload. The number of patients at this facility was small resulting into short exposure time and thereby low scattered radiation reaching the worker. Bwaila shows high cumulative annual projected dose followed by KCH and finally Mtengo wa Nthenga (Figure 4.2). Apart from the factors mentioned earlier own, this case might be so, due to inadequacy of other optimization technicalities such as shielding design at the facility which can further be assessed.

4.4 Individual Monitoring

The TLD cards used, had two chips for recording personal dose equivalent Hp (0.07) for skin dose and Hp (10) for the whole body. Personal dose equivalent (PDE), Hp (d), is defined as the dose equivalent in soft tissue below a specified point on the body at a depth *d* mm. The background dose was subtracted from the direct reading of the individual card (monthly dose, Appendix 5) to give the true dose received by the individual in that month.

True dose = Card Reading – Background (Eq.8)

Figures 4.3 and Table 4.4 present the dose trends for the fifteen workers who were involved in the study.

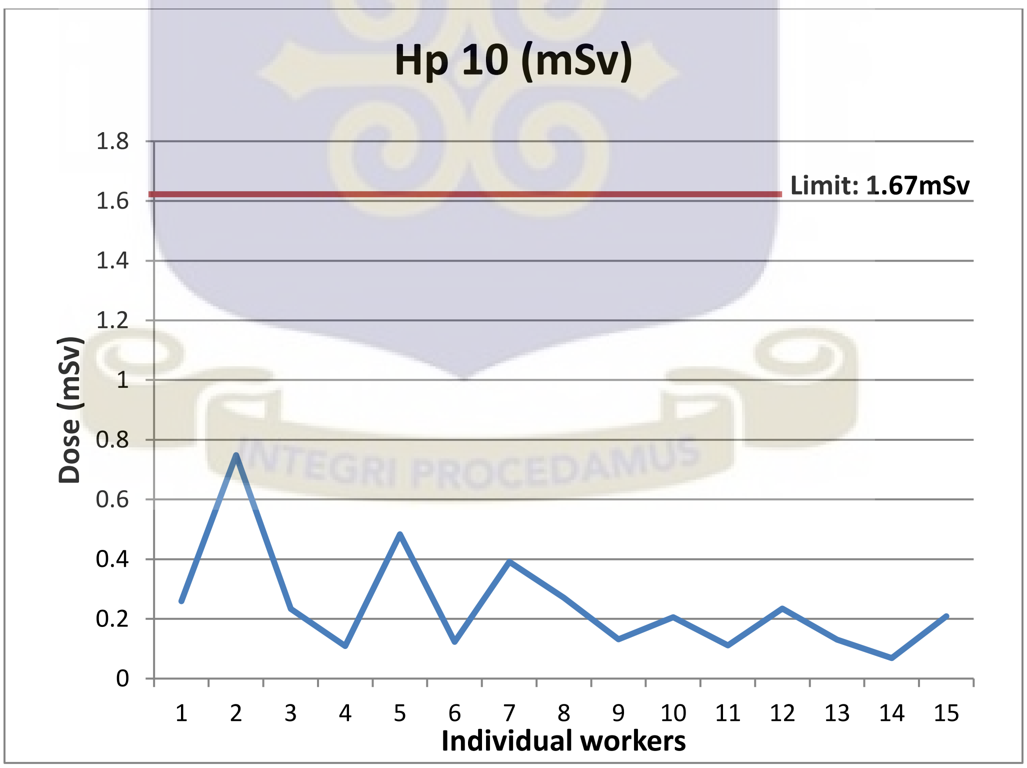

Figure 4.3: Individual dose trends [Hp (10)]

Table 4.4: Statistics of staff deep radiation dose

Statistics	Minimum	Maximum	Mean	Standard Deviation
Hp (10) mSv/month	0.069	0.749	0.247	0.178

Comparing the results (Table 4.4) with ICRP dose limits for workers, it was observed that all doses were below the limit (1.67mSv/month). However, one worker registered the dose of 0.75mSv which is close to an investigation level. For the sake of observing the ALARA principle, an investigation can be conducted for this worker. Some countries such as Ghana, have put their monthly limit at 1mSv which is used as the investigation level [41]. This means that for any dose close to, equal to or above 1mSv in a month, an investigation has to be done to check the conditions that might have led to such a value. The idea is to limit the exposure levels to as low as reasonably achievable (ALARA).

For the skin dose [Hp (0.07)], the readings were also below the monthly limit of 25 mSv [38] and 42 mSv for ICRP (that is, dividing the annual limit of 500 mSv by 12 months), as shown in Figure 4.4 and Table 4.5.

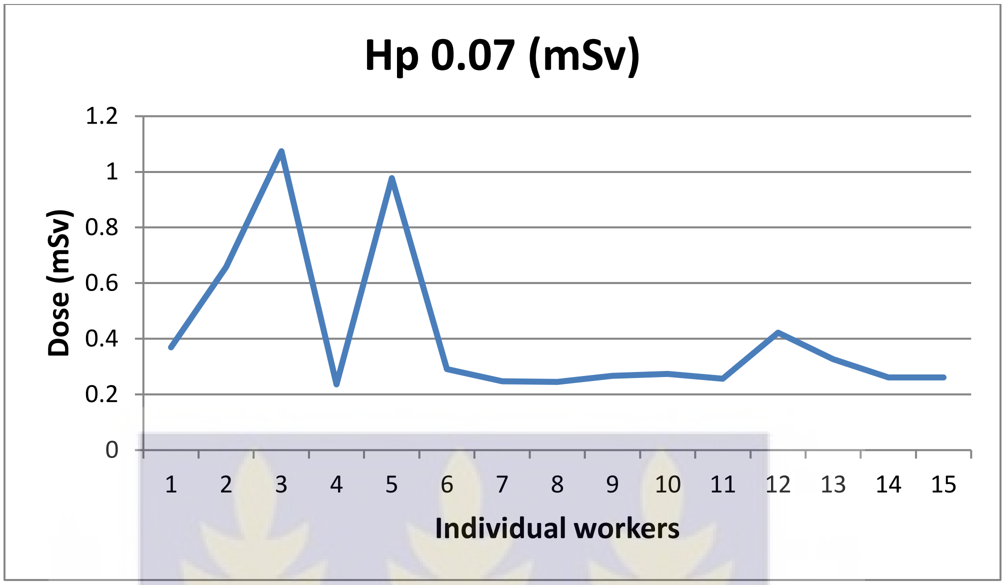

Figure 4.4: Individual dose trends [Hp (0.07)]

Table 4.5: Statistics of staff skin radiation dose

Statistics	Minimum	Maximum	Mean	Standard Deviation
Hp (0.07) mSv/month	0.236	1.074	0.411	0.272

4.5 Dose Assessment Comparison

From the previous sections, it was observed that dose values for individual and workplace monitoring are not exactly the same. However, their pattern or trend is similar. For example, Bwaila hospital had highest values both in ambient dose rate as well as the individual dose. On the other hand, Mtengo wa Nthenga had low values in both monitoring methods. Another observation was that KCH had low individual dose values despite the high workload and long exposure time associated with the CT scanner. The reason is that in this facility, workers are not constantly in the radiation field (CT control room) at the same time. It was observed that in their work schedule, there is staff rotation which implies that the radiation field is shared to different individuals. The operator at the CT machine is not the same individual all the time. On other days, the radiographers operate ultrasound machines (without radiation), conventional x-ray machines or mobile x-ray machines (C-arms) which generally have low exposure rates. Unlike at Bwaila where only two workers were constantly working with one general x-ray machine and where the number of patients per day is always high. As such, the two workers are in the radiation field for a longer time than those at KCH.

A similar study was conducted in Montenegro in 2007. Montenegro is a small, developing and “non-nuclear” country in Europe. At a time of the study, there was neither a regulatory authority for radiation protection in the country nor a source register. The application of radiation sources was limited mostly to medicine. The study was also performed in medical institutions and the aim was to compare the results against internationally recommended limits. It was found that the average equivalent dose for one month period was 0.0703 mSv for physicians and 0.0827 mSv for technicians. The highest dose recorded in one month was 1.1 mSv for a technician in Niksic Hospital. The study concluded that the doses were well below internationally recommended limits (that is, 20 mSv per year) for all subjects monitored [28].

Nepal, is a country located in South Asia whose situation somehow relates to that of Malawi. It became a member of the IAEA in 2007. Nepal has a long history of medical radiology since 1923 but unfortunately, by 2012 the country still did not have any

Radiation Protection Infrastructure to control the use of ionizing radiation in the various fields. In 2012, a study, whose objective was to assess the radiation protection in medical uses of ionizing radiation, was conducted. Twenty-eight hospitals with diagnostic radiology facilities were chosen for the study and radiation surveys were also done at five different radiotherapy centres. A questionnaire was administered to occupationally exposed workers, radiation dose levels were measured and an inventory of radiation equipment was made. The study also aimed at creating awareness among workers on possible radiation health hazard and risk. It was also deemed important to know the level of understanding of the radiation workers in order to initiate steps towards the establishment of Nepalese laws, regulation and code of radiological practice in this field. It was found that radiation dose levels at the reference points for all the five radiotherapy centres were within safe limits. Around 65% of the radiation workers had never been monitored for radiation. The study found out also that there was no quality control program in any of the surveyed hospitals except in radiotherapy facilities [29].

Other similar studies were conducted in Kenya, Mexico, Kuwait and Ghana [30, 31, 32, and 33] with the purpose of comparing the individual doses against the recommended limits. Table 4.6 presents the individual monitoring findings from such studies in comparison with the findings from this study.

Table 4.6: Comparison of Present Study with Other International Studies

Country	Year of Study	Average Monthly Dose (mSv)	Average Annual Dose (mSv)
Kenya	2002-2005	0.24	2.94
Mexico	2004	0.24	2.9
Kuwait	2008-2009	0.0875	1.05
Ghana	2000-2009	0.0875	1.05
Malawi (this study)	2016	0.247	2.946*

*Projected

The results from individual monitoring carried out in this study for Malawi are not much different from the findings from the other studies. However, a potential increase in dose values for Malawi can be assumed if the sample size and the study monitoring period is increased to match with those of some of the countries listed here.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions drawn from the results of the study as well as the recommended actions to be undertaken.

5.1 Conclusion

Generally, the study achieved its objectives. The study has shown that there is lack of implementation of basic elements of occupational radiation protection which is mainly as a result of inadequate knowledge. Many workers do not know about harmful effects of ionizing radiation and measures of protection. This is the reason behind the lack of safety culture observed in some facilities.

Secondly, the study showed that individual doses were below the ICRP recommended limits. Average monthly dose for workers was 0.247 mSv against the 1.67 mSv for ICRP limit. Although the cumulative ambient dose rate values in all the three hospitals in the Study did not exceed the recommended limit of 7.5 µSv/hr, ambient dose rate was high at Bwaila Hospital (5.03 µSv/hr) and Kamuzu Central Hospital (4 µSv/hr) mainly due to high workload of the X-ray machine and CT scanner respectively.

Thirdly, guidelines were developed for the three hospitals involved in the study to facilitate the establishment and implementation of sustainable personnel monitoring programme in their respective X-ray departments. These guidelines (stipulated in Appendix 6) can also be adopted for use in other radiological facilities in Malawi.

5.2 Recommendations

5.2.1 Establishment of Regulatory Body

The absence of a regulatory body in Malawi is the underlying cause of lack of implementation of radiation protection measures in Malawian hospitals. X-ray departments are operating without observing radiation safety standards which in ideal situation are set by the regulatory body which also ensures that radiation users are sensitized accordingly. It is the body that ensures the presence of such programmes in every facility that deals with ionising radiation, and law enforcement is undertaken where there is non-compliance.

This study therefore recommends that the government of Malawi should consider putting in place a regulatory body as soon as possible. This will help to make a difference in the institutions in as far as radiation protection is concerned. For example, apart from the 'Atomic Energy Act and Regulations' which Malawi has, the regulatory body will have to develop the radiation protection and safety guides for safe use of X-rays, occupational radiation protection, dose limits, inspection and enforcement among other guides. These documents will offer practical guidance for all concerned stakeholders. The body will also ensure that radiation safety training is provided to all users of radiation sources and devices in the country.

5.2.2 Operational Parameters affect scattered radiation

In diagnostic radiology, exposure techniques and parameters also have an effect on the scattered radiation. Crucial factors include the tube voltage (kV), current-exposure time product (mAs), field size, exposure time and collimation. High kV, mAs, field size and exposure time lead to high dose to the patient which in turn results to high scattered radiation reaching the worker. Therefore, the machine operator needs to choose these parameters so carefully that the image will be of good quality at the minimum dose to reduce the unnecessary exposure to as low as reasonably achievable. The CT scanner is always using high kV, mAs and long time and therefore leads to high scattered radiation. Therefore, the facility needs to have sufficient shielding to attenuate the scattered radiation. Absence of collimation light on the X-ray machine at Bwaila hospital also contributed to high scattered radiation. The collimated radiation beam reduces the scattered radiation. It is therefore, being recommended that the hospital management should consider fixing this problem on the machine so that unnecessary exposures to both patients and workers are reduced.

5.2.3 Exposure Assessment

The study also revealed that currently, exposure assessment for occupationally exposed workers in the hospitals is absent. The hospitals do not have survey meters for their own routine workplace assessment. It was also discovered that in all the hospitals, no pre-commissioning safety assessment was done upon the installation of the machines. This can be attributed to lack of both human and technical resources for the effective carry-out of the task.

However, as the use of radiation technology is advancing in Malawian hospitals, the situation requires a change. It is unacceptable to continue using ionising radiation technology without having a consistent dose assessment program for the exposed workers. It is high time the Personnel Dosimetry Service (PDS) in Malawi became fully operational. It is the PDS which will ensure consistent dose monitoring of exposed workers as well as compliance with ICRP dose limits.

Since there are currently no personnel monitoring service providers in Malawi, the government through the regulatory body should be responsible for this service using the Harshaw Model 4500 TLD Reader which was supplied to the country by the IAEA. The Ministry of Health (which is currently keeping the TLD Reader) and the Environmental Affairs Department (the interim regulatory authority) need to put in place the operational infrastructure of the dosimetry service. In this study, the dose assessment was undertaken for just one month, but when the PDS is operational, it will have to ensure that the doses for all occupationally exposed workers in both medical and industrial fields, are consistently monitored in every three months.

5.2.4. X-ray Equipment Quality Control Tests

Another recommendation from this study is that quality control tests need to be periodically performed on X-ray machines in the hospitals. Quality Control (QC) basically refers to the routine assessment and monitoring of the performance of the x-ray machine to determine its compliance to the radiological operating standards [39]. The main objective of these tests is to ensure that the machine operators are able to obtain good quality images that give adequate clinical information and also unnecessary radiation exposures to patients and workers are reduced.

When the X-ray machine passes the QC tests, it means that it is operating within standards; and its exposure levels are within recommended limits. If the machine fails the

QC tests, it means that its performance is sub-optimal and that the optimization principle of radiation protection is not being adhered to. Machine operators and the regulatory body are responsible for performing these tests. Some QC tests need to be carried out daily, weekly, monthly or annually.

During the study, it was generally observed that QC tests are not undertaken on the machines and some machines still operate even though some of their technical aspects are below the requirements. For example, at Bwaila hospital, the machine was operating without the collimation light. This is unacceptable and compromises the safety of patients, the public and the workers.

5.2.5 Structural Shielding Assessment

As pointed out earlier, the study revealed the need to conduct a shielding assessment in these and other diagnostic facilities in Malawi. During workplace monitoring, KCH and Bwaila hospital registered high ambient dose rate values at the control panels on some days. The values were higher than the recommended maximum rate of 7.5μSv/hr. This may indicate insufficient structural shielding. Hence, it is important to investigate the integrity and thickness of the secondary barriers, in order to ensure that the exposure rate outside the X-ray area is as low as reasonably achievable (ALARA).

Shielding is one of the three practical basic techniques of radiation protection [16]. The other two are time and distance. Shielding is basically the placing of a barrier between the radiation source and the people subjected to exposure. Occupationally exposed workers can shield themselves by wearing personal protective equipment (PPE). However, shielding is also provided by the building materials of the examination room (thus, structural shielding).

There are two kinds of structural shielding materials, namely, primary barriers and secondary barriers. Primary protective barriers, such as a lead-lined wall, are meant to reduce the exposure rate outside the x-ray room in the direction of the primary beam. While secondary protective barriers are meant to reduce the exposure rate from both leakage and scattered radiation outside the x-ray room. Sometimes existing structures, such as concrete walls, provide sufficient secondary barriers, otherwise, where these are insufficient, additional shielding, such as lead sheets, must be added [40].

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APPENDIX 1: ETHICAL CLEARANCE LETTERS

SCHOOL OF NUCLEAR AND ALLIED SCIENCES
University of Ghana – Atomic
Phone: +233 (0) 302 400723,400310
Fax: +233 (0) 302 400807
Office of the Director
P. O. Box AE1
Atomic - Accra
GHANA

Our Ref: SNAS/ACA/AFRA/15/24/20

Your Ref:

Date: 26th October, 2015

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

MS. GETRUDE CHINANGWA

I wish to introduce to you Ms. Getrude Chinangwa, M.Phil Part II student in Nuclear Sciences and Technology programme of the School of Nuclear and Allied Sciences, University of Ghana, Atomic, Ghana

In partial fulfillment of the requirement for the degree she is seeking, she is to complete a research programme in an area of Nuclear Science and Technology. She has expressed interest to take data from Malawian Hospitals to enable her assess the occupational doses of staff in the hospitals.

Her research topic is "**ASSESSMENT AND DEVELOPMENT OF PERSONAL MONITORING PROGRAM FOR OCCUPATIONALLY EXPOSED WORKERS IN MALAWIAN HOSPITALS**".

I am kindly requesting that you offer her the necessary assistance.

Thank you.

Yours faithfully,

Prof. Yaw Serfor-Armah
Dean

GRADUATE SCHOOL OF NUCLEAR
& ALLIED SCIENCES
UNIVERSITY OF GHANA
ATOMIC
DIRECTOR/DEAN

Preserving, maintaining and enhancing nuclear knowledge in Ghana and Africa

University of Ghana

School of Nuclear and Allied Sciences

P.O. Box AE 1, Atomic Energy

Accra, Ghana

December 28, 2015

The Chairperson,

National Health Sciences Research Committee

Ministry of Health

P.O. Box 30377

Lilongwe 3

Malawi

Dear Sir,

REQUEST FOR PERMISSION TO CONDUCT RESEARCH

I humbly write to kindly request for permission to use Kamuzu Central Hospital, Bwaila Hospital and Mtengowanthenga Mission Hospital to conduct a research leading to the award of a Master of Philosophy (MPhil) degree.

I am a Malawian lady pursuing a Masters Degree in Nuclear Science and Technology (Radiation Protection option) at the University of Ghana School of Nuclear and Allied Sciences, under an International Atomic Energy Agency Fellowship. My University of Ghana student Identification Number is **10509464.** My MPhil Thesis research is titled "DOSE ASSESSMENT AND DEVELOPMENT OF PERSONNEL MONITORING

PROGRAMME FOR OCCUPATIONALLY EXPOSED WORKERS IN MALAWIAN HOSPITALS."

The research work involves the assessment of the safety of Radiographers against Ionising Radiation (X-rays). The main objective of the research is to propose Radiation Monitoring Program in the hospitals. The work will involve monitoring the radiation doses received by the Radiographers for a one-month period (in January 2016). In addition, a Questionnaire will be administered to the Heads of the X-ray Department of the Hospitals. Prior to my studies in Ghana, I worked as an Environmental District Officer in the Environmental Affairs Department of Malawi.

Attached to this cover letter are: the **Summary** of my research work, an **Introductory Letter** from the School of Nuclear and Allied Sciences, University of Ghana (my school), the **Full Research Proposal Document**, the **letters of no objection** from the afore-mentioned hospitals, the **Consent Form**, my **Curriculum Vitae,** and the **Data Collection Tools**. For any information I may be required to provide, my contacts are as follows:

Cell: +265 (0) 999 679 015 Email: chinangwag@gmail.com

I will appreciate your kind consideration of my request.

Yours faithfully,

Getrude Chinangwa (Ms)

Telephone: + 265 789 400
Facsimile: + 265 789 431
e-mail mohdoccentre@gmail.com
All Communications should be addressed to:
The Secretary for Health

In reply please quote No. MED/4/36c

MINISTRY OF HEALTH
P.O. BOX 30377
LILONGWE 3
MALAWI

21st January 2016

Getrude Chinangwa
University of Ghana

Dear Sir/Madam,

RE: Protocol #16/1/1521: Dose assessment and development of personnel monitoring program for occupationally exposed workers in Malawian Hospitals

Thank you for the above titled proposal that you submitted to the National Health Sciences Research Committee (NHSRC) for review. Please be advised that the NHSRC has **reviewed** and **approved** your application to conduct the above titled study.

- **APPROVAL NUMBER** : **NHSRC #1488**
  The above details should be used on all correspondence, consent forms and documents as appropriate.
- **APPROVAL DATE** : **21/01/2016**
- **EXPIRATION DATE** :This approval expires on **21/01/2017**
  After this date, this project may only continue upon renewal. For purposes of renewal, a progress report on a standard form obtainable from the NHSRC secretariat should be submitted one month before the expiration date for continuing review.
- **SERIOUS ADVERSE EVENT REPORTING** :All serious problems having to do with subject safety must be reported to the National Health Sciences Research Committee within 10 working days using standard forms obtainable from the NHSRC Secretariat.
- **MODIFICATIONS**: Prior NHSRC approval using standard forms obtainable from the NHSRC Secretariat is required before implementing any changes in the Protocol (including changes in the consent documents). You may not use any other consent documents besides those approved by the NHSRC.
- **TERMINATION OF STUDY**: On termination of a study, a report has to be submitted to the NHSRC using standard forms obtainable from the NHSRC Secretariat.
- **QUESTIONS**: Please contact the NHSRC on Telephone No. (01) 789314, 0888344443 or by e-mail on mohdoccentre@gmail.com
- **Other:**
  Please be reminded to send in copies of your final research results for our records as well as for the Health Research Database.

Kind regards from the NHSRC Secretariat.

....

FOR CHAIRMAN, NATIONAL HEALTH SCIENCES RESEARCH COMMITTEE

SECRETARY FOR HEALTH
2016 -01- 21
P.O. BOX 30377, CAPITAL CITY, LILONGWE 3

PROMOTING THE ETHICAL CONDUCT OF RESEARCH
Executive Committee: *Dr.B. Chilima (Chairman), Dr B. Ngwira (Vice Chairperson)*
Registered with the USA Office for Human Research Protections (OHRP) as an International IRB
(IRB Number IRB00003905 FWA00005976)

TELEPHONE NO.: (265) 753 555
TELE FAX NO.: (265) 756 380

PLEASE ADDRESS ALL COMMUNICATIONS TO: THE HOSPITAL DIRECTOR
E-MAIL: Kch@sdnp.org.mw

MINISTRY OF HEALTH
KAMUZU CENTRAL HOSPITAL
P. O. Box 149
LILONGWE
MALAWI

5TH JANUARY 2016

Ref : nhsrc 2016

The Chairman,
National Health Sciences research Committee,
Ministry of Health,
P.O. Box 30377,
Lilongwe 3.

Dear Sir,

Re:LETTER OF SUPPORT FOR A RESEARCH TITLED – DOSE ASSESSMENT AND DEVELOPMENT OF PERSONNEL MONITORING PROGRAMME FOR OCCUPATIONALLY EXPOSED WORKERS IN MALAWIAN HOSPITALS

I am writing to express my support in the willingness by the researcher to conduct the above named research at Kamuzu Central hospital.

The research will address gaps in the assessment and monitoring radiation exposure among health personnel in the hospitals.

Thanks in advance for the support you are going to give the researcher.

Yours Sincerely,

KAMUZU CENTRAL HOSPITAL DIRECTOR
05 JAN 2016
P.O. BOX 149
LILONGWE

Dr. Jonathan Ngoma
Hospital Director

Ref. No.:
Telephone No.: 265 726 466/464
Telefax No.: 265 727817
Telex No.:
E-Mail. lilongwedho@malawi.

COMMUNICATIONS TO BE ADDRESSED TO:

In reply please quote NO DZH/MALAWI,
Lilongwe District Health Office
P.O. Box 1274
Lilongwe
Malawi

6th January, 2016

TO : The In-charge, Bwaila Hospital

Dear Sir/Madam

PERMISSION TO CONDUCT RESEARCH STUDY IN LILONGWE DISTRICT

Permission has been granted to the bearer of this letter

Getrude Chinangwa, to conduct research study

" The Assessment and Development of personnel monitoring programme for occupationally exposed workers in Malawi Hospitals".

Any assistance rendered would be appreciated.

LILONGWE DISTRICT HEALTH OFFICE
- 6 JAN 2016
DISTRICT HEALTH OFFICER

Dr. A. Chauma
FOR:DISTRICT HEALTH OFFICER

FRANCISCO PALAU COMMUNITY HOSPITAL
Mtengo wa Nthenga

Private Bag 63
Lumbadzi
Malawi, Africa

Tel No. 01973715
Cel No. (265) 999 964161
E-mail: fpalaumw@yahoo.com.

Ms. Getrude Chinangwa
University of Ghana - Atomic
School of Nuclear and Allied Sciences
Ghana

7th Jan. 2016

Dear Madam,

Re: Permission of Research

This is to grant you the permission on the research program in an area of your studies.

As stated of your research topic *"Assessment and development of personal monitoring program for occupationally exposed workers in Malawian hospitals"* in agreement with the radiographer of the said hospital you are free to do your research within your necessary time limit.

I wish you the best of your studies.

Yours sincerely,

FRANCISCO PALAU MTENGO WA NTHENGA C. HOSPITAL P/BAG 63, LUMBADZI

T. Cheong

Sr. Teresita Cheong
Hospital In-charge

APPENDIX 2: QUESTIONNAIRE

UNIVERSITY OF GHANA

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

MPHIL IN NUCLEAR SCIENCE AND TECHNOLOGY (RADIATION PROTECTION OPTION)

PROJECT TITLE: DEVELOPMENT OF PERSONNEL MONITORING PROGRAM FOR OCCUPATIONALLY EXPOSED WORKERS IN MALAWIAN HOSPITALS

QUESTIONNAIRE

Introduction

The purpose of this questionnaire is to obtain information about radiation protection of workers in some hospitals of Malawi. It is intended to be administered to Heads of X-ray department or whosoever in charge of radiation protection in the facility. The information to be obtained will ***NOT*** *be used for any purpose other than academic research for which it is intended. For more information, call 0999 679 015 or email: chinangwag@mail.com.*

PART A: GENERAL INFORMATION

1. Name of Hospital: _______________
2. Responsibility of respondent:________________________
   b. For how long have you worked in radiology service?

      ____

   c. Academic qualification:
3. Are you aware of radiation protection of workers in radiology?
4. What practices of staff protection do you know?
5. What practices does your department undertake?

PART B: FACILITY INFORMATION

6. How many x-ray machines are in this facility?__________________
7. Type of X-ray system:
   a. Conventional Radiography
   b. Computed Radiography (CR)
   c. Direct Digital Radiography (DDR)
   d. Computed Tomography (CT)
   e. Fluoroscopy
   f. Others:
8. Date of installation_____________________________
9. Is there a Quality Assurance Program or Committee in the facility?
   b. What Quality Control tests do you perform on the machine/s?

c. How frequent are QC tests done?

10. Is there a radiation safety committee or a radiation protection officer (RPO) in your facility?

    Number of committee members:______________________________

    Academic qualification for RPO:_____________________________

    His/her responsibilities:

11. Is there any external expert who offer advice on radiation protection to this facility?

12. Are areas in your facility designated as controlled and supervised areas?

13. Are there local rules in the department?

14. Are they displayed on the operator's control panel?

15. Are there radiation warning signs in the facility?

16. Are there warning lights at the entrance door to the X-ray room?

    b. Are they functional?

PART C: PERSONNEL PROTECTION

17. How many workers are in this department?

    Radiologists: ________________

    Radiographers:_______________

    Medical Physicists_____________

    Nurses:_______________________

Support staff__________________

Others________________________

18. How many female workers are in the department?

19. Any rules for pregnant workers?

20. What protective wear are workers given?

    a. Lead aprons

    b. Lead gloves

    c. Googles

21. Number of working days per week:_____________________________

22. Average working hours (in the x-ray room) per day.

23. Are occupational doses monitored?

    b. How are occupational doses monitored?

    c. How frequent are they monitored?

24. Does the facility have a program of monitoring workers?

    b. Do you think the personnel monitoring program is important and necessary in your facility?

25. How many workers have ever attended a radiation protection training?

26. Are there staff exposure and health surveillance records?

27. Do you conduct radiation surveys or assessments around the working area?

    b. How frequent?

28. Any emergency response mechanisms in place at the facility?

APPENDIX 3: CALIBRATION DOCUMENTS

MALAWI BUREAU OF STANDARDS

Promoting Standardization and Quality Assurance in Malawi

INSTRUMENT SUPPORT SERVICES UNIT

CERTIFICATE OF CALIBRATION
Certificate Number: GK201601013001

NAME OF APPLICANT: Environmental Affairs Dept. **Address:** P/Bag 394, Lilongwe 3

Calibration Date: 2016-01-12 **Issue Date:** 2016-01-13 **Expiry Date:** 2017-01-11

Description of Equipment: Survey Meter **Manufacturer:** Mirion Technologies (RADOS) OY

Model/Type No: RDS-31 **Serial No:** 2200588

Location of the calibration: MBS Instrumentation Unit

Calibrated By:	Godwin Khundi Metrologist (Technical Signatory)	Signature
Checked by:	Stephen Kuyeli Director Testing Services	Signature
Certified By:	D. M.D Chokazinga Director General	Signature

This certificate is issued in accordance with chapter 48:04 (Weights and Measures Act) of the laws of Malawi and under such terms and conditions as set by the MBS and amended from time to time as may be necessary. The certificate may not be published other than in full except with the prior written approval of the Director General, Malawi Bureau of Standards.

(Official Stamp)

MALAWI BUREAU OF STANDARDS

Promoting Standardization and Quality Assurance in Malawi

INSTRUMENT SUPPORT SERVICES UNIT

CERTIFICATE OF CALIBRATION
Certificate Number: GK201601013002

NAME OF APPLICANT: Environmental Affairs Dept. **Address:** P/Bag 394, Lilongwe 3

Calibration Date: 2016-01-12 **Issue Date:** 2016-01-13 **Expiry Date:** 2017-01-11

Description of Equipment: Survey Meter **Manufacturer:** Mirion Technologies (RADOS) OY

Model/Type No: RDS-31 **Serial No:** 2200589

Location of the calibration: MBS Instrumentation Unit

Calibrated By: Godwin Khundi, Metrologist (Technical Signatory) — Signature

Checked by: Stephen Kuyeli, Director Testing Services — Signature

Certified By: D. M.D Chokazinga, Director General — Signature

This certificate is issued in accordance with chapter 48:04 (Weights and Measures Act) of the laws of Malawi and under such terms and conditions as set by the MBS and amended from time to time as may be necessary. The certificate may not be published other than in full except with the prior written approval of the Director General, Malawi Bureau of Standards.

(Official Stamp)

MALAWI BUREAU OF STANDARDS
Promoting Standardization and Quality Assurance in Malawi

SURVEY METER CALIBRATION REPORT

NAME OF APPLICANT: Environmental Affairs Dept. **ADDRESS:** P/Bag 394, Lilongwe 3

EQUIPMENT/INSTRUMENT TYPE: Radiation Survey Meter

MANUFACTURER : Mirion Technologies (RADOS) OY

LOCATION : Lilongwe

MBS No : AS9848

REPORT No. : ISS/15/AS93

1. Service required

Calibration

2. Service Method

Calibrated using Cs-137 nuclide standard source

3. Results

Standard Used				Survey Meter	Total uncertainty
Source Type : Cs-137 Serial No.:1476-24-5 Manufacturer: Eckert & Ziegler Country of Origin: USA				Model No: RDS-31S Serial No.: 2200588	
Exposure Time	Distance(Height)	Dose rate	Source Energy	Dose	Deviation Tolerance
60seconds	10mm	3μSv/H	661.7KeV	0.05μSv	0.4%

NB: The instrument performance is within specifications and complies with standard requirements

- Dose rate is ±0.04 μSv/H

Calibrated By...G. Khundi......Signed.......Date...2016-01-12

Checked By...D. Mhlalwanga......Signed.......Date...2016-01-14

Authorized By...S. M. Kuyeli......Signed.......Date...2016-01-14

MALAWI BUREAU OF STANDARDS
Promoting Standardization and Quality Assurance in Malawi

SURVEY METER CALIBRATION REPORT

NAME OF APPLICANT: Environmental Affairs Dept. ADDRESS: P/Bag 394, Lilongwe 3

EQUIPMENT/INSTRUMENT TYPE: Radiation Survey Meter

MANUFACTURER : Mirion Technologies (RADOS) OY

LOCATION : Lilongwe

MBS No : AS9848

REPORT No. : ISS/15/AS93

1. Service required

Calibration

2. Service Method

Calibrated using Cs-137 nuclide standard source

3. Results

Standard Used				Survey Meter	Total uncertainty
Source Type : Cs-137 Serial No.:1476-24-5 Manufacturer: Eckert & Ziegler Country of Origin: USA				Model No: RDS-31S Serial No.: 2200589	
Exposure Time	Distance(Height)	Dose rate	Source Energy	Dose	
60seconds	10mm	3µSv/H	661.7KeV	0.05µSv	0.4%

NB: The instrument performance is within specifications and complies with standard requirements

- Dose rate is ±0.04 µSv/H

Calibrated By: G. Vikumbi Signed: [signature] Date: 2016-01-12

Checked By: D.Mhlanga Signed: [signature] Date: 2016-01-14

Authorized By: S.M. Kuyeli Signed: [signature] Date: 2016-01-14

CONDITIONS UNDER WHICH THE MBS INSTRUMENT SUPPORT SERVICES UNIT (MBS-ISSU) WILL PERFORM CALIBRATION WORK

1. Calibrations are carried out at the discretion of MBS-ISSU, which reserves the right to decline any request for calibration.
2. All instruments compliance are tested or checked against specific standards or particular specifications. These standards may be appropriate Malawi, British, IEC standards, or otherwise manufacturer's original specifications.
3. All instruments / equipment sent by the applicants for calibration to the MBS-ISSU shall be collected and delivered at the applicant's cost and risk.
4. If a calibration is not completed because of defects or deficiencies in items submitted by the applicant, an appropriate reduction in the fee may be allowed, depending on the amount of work already performed.
5. The performance of the instrument was determined by comparison with manufacturer's specification as found in the instrument handbook or any other technical documentation. Any significant uncertainty of the measuring system will also be included.
6. Standard Instruments used to carry out calibration are included in the report.

VALIDITY OF CALIBRATION

The values portrayed by the calibration report are correct at the time of calibration. Subsequently, the accuracy will depend on such factors as the care exercised in handling and use of the instrument.

Recalibration should be performed after a period which has been chosen by the applicant to ensure that the instrument's accuracy remains within the desired limits.

Mirion Technologies (RADOS) Oy
Mustionkatu 2, P.O.Box 506
FI-20101 Turku

RDS-31 CALIBRATION CERTIFICATE

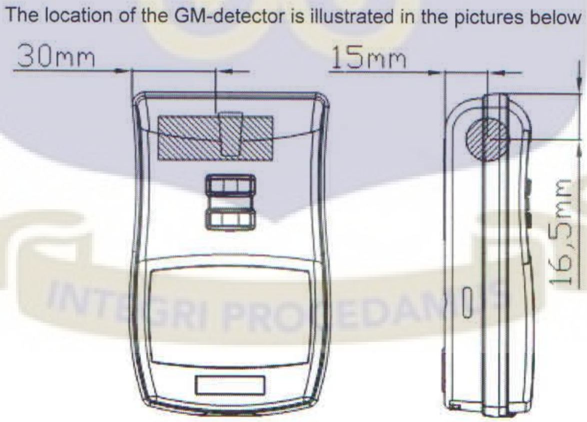
Serial number:	2200588
Calibrated by:	128
Dose H*(10) of 60 s at ref. field / µSv:	50,2
Dose H*(10) of 60 s at ref. field / mrem:	5,0
Inspected by:	10
Date:	14.6.2012

Reference condition:

Ambient temperature 22 C, Battery voltage 3 V

The units were calibrated as per the recommendations of the Radiation and Nuclear Safety Authority of Finland, document No. VAL 1.3.
The source used for the calibrations has the following specifications:
Source Cs-137, energy 662 keV, Calibration Dose Rate Field 3mSv/h.
The calibration is traceable to the standards of Radiation and Nuclear Authority of Finland

The location of the GM-detector is illustrated in the pictures below



CE

Mirion Technologies (RADOS) Oy
Mustionkatu 2, P.O.Box 506
FI-20101 Turku

RDS-31 CALIBRATION CERTIFICATE

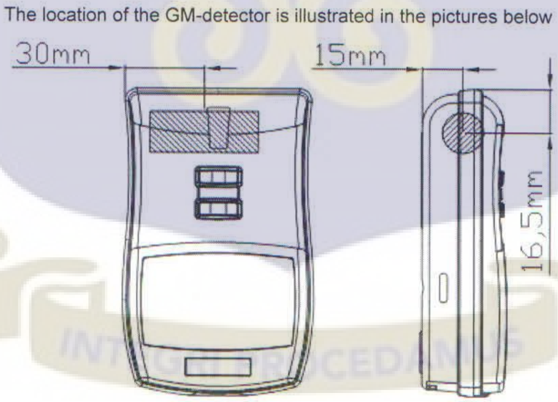
Serial number:	2200589
Calibrated by:	128
Dose H*(10) of 60 s at ref. field / μSv:	49,5
Dose H*(10) of 60 s at ref. field / mrem:	5,0
Inspected by:	10
Date:	14.6.2012

Reference condition:

Ambient temperature 22 C, Battery voltage 3 V

The units were calibrated as per the recommendations of the Radiation and Nuclear Safety Authority of Finland, document No. VAL 1.3.
The source used for the calibrations has the following specifications:
Source Cs-137, energy 662 keV, Calibration Dose Rate Field 3mSv/h.
The calibration is traceable to the standards of Radiation and Nuclear Authority of Finland

The location of the GM-detector is illustrated in the pictures below



CE

APPENDIX 4: WORKPLACE MONITORING SURVEY FORM

UNIVERSITY OF GHANA

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

MPHIL IN NUCLEAR SCIENCE AND TECHNOLOGY (RADIATION PROTECTION OPTION)

PROJECT TITLE: DEVELOPMENT OF PERSONNEL MONITORING PROGRAM FOR OCCUPATIONALLY EXPOSED WORKERS IN MALAWIAN HOSPITALS

WORKPLACE MONITORING SURVEY FORM

A. General information

Hospital name:	Assessor's name:
Measuring instrument:	Manufacturer:
Instrument model or serial #:-	Date of last calibration:

B. X-ray room details

Room size_______________________________________

Wall thickness____________________________________

Distance between the x-ray machine and the control panel

____

Control panel lead-glass window size and thickness:

____

X-ray tube model and serial number

Generator model and serial number

____

C. DOSE MEASUREMENTS AT THE CONTROL PANEL

Date				
Type of x-ray machine				
Number of radiographs per day				
Exposure				

parameters used Kv: mAs:								
Dose rate values (sv/h)								

APPENDIX 5: COMPUTED EXPOSURE REPORT FOR TLDs READINGS

COMPUTED EXPOSURE REPORT Page 1

Date	Time	Dosimeter ID	(i)	(ii)	(iii)	(iv)	units
03/03/16	13:33:35	PMT Noise	0.0155	0.01	0.01875	0.016125	nC
03/03/16	13:34:19	Reference Light	80.285	80.227	106.37	106.46	nC
03/03/16	13:35:05	700771		420.04	496.56		uSv
		ECC:		1.1378	1.3461		
		RCF:		0.037338	0.056701		
03/03/16	13:35:51	700465		576.96	321.67		uSv
		ECC:		1.0362	1.038		
		RCF:		0.037338	0.056701		
03/03/16	13:36:39	700919		254.63	335.06		uSv
		ECC:		1.2021	1.3144		
		RCF:		0.037338	0.056701		
03/03/16	13:37:28	701074		413.22	1141.7		uSv
		ECC:		1.1432	1.2072		
		RCF:		0.037338	0.056701		
03/03/16	13:38:17	700239		669.26	1051.6		uSv
		ECC:		1.193	1.3723		
		RCF:		0.037338	0.056701		
03/03/16	13:39:07	700482		456.83	319.21		uSv
		ECC:		1.3039	1.0254		
		RCF:		0.037338	0.056701		
03/03/16	13:39:58	700901		316.06	400.18		uSv
		ECC:		1.1459	1.3176		
		RCF:		0.037338	0.056701		
03/03/16	13:40:49	701130		423.7	426.16		uSv
		ECC:		1.2982	1.3309		
		RCF:		0.037338	0.056701		
03/03/16	13:41:40	700927		927.91	725.42		uSv
		ECC:		1.1902	1.2701		
		RCF:		0.037338	0.056701		
03/03/16	13:42:31	700926		394.56	334.89		uSv
		ECC:		1.2819	1.3945		
		RCF:		0.037338	0.056701		
03/03/16	13:43:21	PMT Noise	0.012625	0.010625	0.016125	0.022625	nC

OMPUTED EXPOSURE REPORT Page 2

Date	Time	Dosimeter ID		(i)	(ii)	(iii)	(iv)	units
3/03/16	13:45:40	700734			297.04	330.95		uSv
			ECC:		1.0325	1.2339		
			RCF:		0.037338	0.056701		
3/03/16	13:46:31	700612			317.5	340.83		uSv
			ECC:		1.0187	1.1507		
			RCF:		0.037338	0.056701		
3/03/16	13:47:22	700228			294.53	310.14		uSv
			ECC:		1.0279	1.0969		
			RCF:		0.037338	0.056701		
3/03/16	13:48:13	700250			308.78	364.73		uSv
			ECC:		1.231	1.1945		
			RCF:		0.037338	0.056701		
3/03/16	13:49:41	701202			525.01	343.15		uSv
			ECC:		1.0683	1.2514		
			RCF:		0.037338	0.056701		
3/03/16	13:50:31	701126			367.88	312.17		uSv
			ECC:		1.128	1.3801		
			RCF:		0.037338	0.056701		
3/03/16	13:51:23	700048			339.06	417.12		uSv
			ECC:		1.1638	1.1563		
			RCF:		0.037338	0.056701		
3/03/16	13:52:15	700834			318.68	410.52		uSv
			ECC:		1.1346	1.3453		
			RCF:		0.037338	0.056701		
3/03/16	13:53:07	701133			340.28	338.4		uSv
			ECC:		1.2091	1.3549		
			RCF:		0.037338	0.056701		
3/03/16	13:53:57	PMT Noise		0.013875	0.012	0.015375	0.014875	nC
3/03/16	13:54:41	Reference Light		78.308	79.424	105.59	105.56	nC
		700070			391.1	347.9		uSv
			ECC		0.9982	1.152		
			RCF		0.0373	0.0567		

APPENDIX 6:

PERSONNEL RADIATION MONITORING PROGRAM FOR OCCUPATIONALLY EXPOSED WORKERS IN RADIOLOGY DEPARTMENTS OF HOSPITALS IN MALAWI

1.0 INTRODUCTION

This programme is the main objective and output of the academic research work titled "*Development of Personnel Monitoring Programme for Occupationally Exposed Workers in Malawian Hospitals: A Case Study of Kamuzu Central, Bwaila and Mtengo wa Nthenga Hospitals*". This work was carried out by *Ms. Getrude Chinangwa* in 2016 in partial fulfilment of the requirements for the award of her Master of Philosophy in Nuclear Science and Technology at the Graduate School of Nuclear and Allied Sciences, University of Ghana.

The purpose of this programme is to help and guide occupationally exposed workers in X-ray departments in:

- monitoring and controlling individual doses regularly in order to ensure compliance with the recommended dose limits;
- reporting and investigating overexposures for taking necessary remedial measures urgently;
- maintaining lifetime cumulative dose records of the occupationally exposed workers.

By definition, the personnel monitoring programme is the systematic process for monitoring, recording, evaluating, and reporting the radiation doses received by occupationally exposed individuals in the facility. And it is important in ensuring compliance with regulatory authority established dose limits so as to keep radiation doses As Low As Reasonably Achievable (ALARA).

This programme is just one of the basic elements of the radiation protection programme (RPP) which every facility dealing with ionising radiation is required to have. As such, it only addresses issues to do with radiation assessments. The RPP is a comprehensive programme covering many critical areas of radiation protection including radiation monitoring, and it is one of the safety requirements stipulated by the International Atomic Energy Agency (IAEA) as well as the Malawi Atomic Energy Act, 2011.

Target users of this document include hospital management, radiologists, radiation protection officers (RPO), radiographers, personnel monitoring service providers and professionals interested in occupational radiation protection in diagnostic radiology. This programme is not restricted to the hospitals which were involved in the study. Other hospitals in Malawi can also adopt it for their use.

2.0 RESPONSIBILITIES

The hospital management has primarily the overall responsibility for occupational radiation safety in the facility. Management should ensure that all mechanisms to ensure safety are in place. Management can delegate some of its tasks to some individuals e.g. the RPO or head of X-ray department. Individual workers are also responsible for their own safety; as such they need to embrace safety culture in all their undertakings.

3.0 SOURCES OF OCCUPATIONAL EXPOSURE IN DIAGNOSTIC RADIOLOGY

In diagnostic radiology the main source of occupational exposure is scattered radiation from the patient. The leakage radiation from the X-ray tube also contributes to occupational exposure.

4.0 DOSIMETRIC QUANTITIES

The dosimetric quantities recommended for radiological protection purposes, and in which the dose limits are expressed in the BSS, are the effective dose E and the equivalent dose H_T in tissue or organ T. The basic physical quantities include the particle fluence φ, the kerma K and the absorbed dose D. The ICRU introduced operational quantities for practical use in radiological protection where exposure to external sources is concerned. These quantities were later defined in ICRU Report 51. The operational quantities for area monitoring are the ambient dose equivalent $H^*(d)$ and the directional dose equivalent $H'(d,\Omega)$, and the quantity for individual monitoring is the personal dose equivalent $Hp(d)$.

5.0 DOSE LIMITS

Below are the dose limits or workers as given by the International Commission on Radiological Protection (ICRP).

Table 5.1: Occupational exposure limits (ICRP 75, 1997)

Application	Dose limits
Effective dose (whole body)	50 mSv per year (or 1mSv per week) 20 mSv per year (or 0.4 mSv per week) averaged over defined periods of five years
Annual equivalent dose to lens of the eye	150 mSv
Annual equivalent dose to the skin	500 mSv
Annual equivalent dose to hands and feet	500 mSv

6.0 INDIVIDUAL MONITORING

6.1 Who should be monitored

Individual monitoring is normally required for persons who routinely work in areas that are designated as controlled areas because of the external radiation hazard. An individual monitoring service approved by the regulatory authority should be used. The dosimeters should be capable of measuring Hp(10) and Hp(0.07) with adequate accuracy for all relevant radiation types (beta, gamma, X-rays).

6.2 Thermoluminescent Dosimeters (TLDs)

TLDs are personnel monitoring badges that contain small crystals capable of storing some of the energy from radiation. If the crystals are then heated to a specific temperature, they release the stored energy as light. The amount of light released is proportional to the amount of radiation the TLD badge received, which can be measured to determine the wearer's dose. TLDs should be protected from extreme environmental conditions which may affect their ability to accurately record radiation. They must be exchanged on a quarterly basis.

6.3 Usage and storage of TLDs

Dosimeters should be worn at chest level (between the shoulders and the waist), outside of any clothing with the window (or detector) facing outward. Be consistent in wearing the badges on the same area of the body especially at the point where it is most likely to receive maximum exposure. Every worker must wear the dosimeter that is assigned to them. If the worker is wearing a lead apron, the badge must be worn on the collar, outside of the apron. When undergoing a medical exam or therapy which involves radiation exposure, the worker should not wear the TLD (because this is not part of occupational exposure).

When not in use the dosimeters should be stored with the control card to ensure accurate dosimetry records. The control TLD card must be stored in a low background radiation location and must be returned with the other badges each monitoring period. Never leave dosimeters in close proximity to a radiographic device or other radiation source. Store dosimeters where they will not inadvertently be exposed to radiation, excessive heat, light, moisture or chemicals. Badges should only be kept at work, never taken home. In routine operations, each monitored worker should have two dosimeters; the worker wears one while the other (which was worn previously) is being processed and evaluated. In situations where individual doses have greatly exceeded those expected under normal working conditions there must be a follow up investigation to determine the reason behind.

6.4 Lost or damaged badges

The RPO must immediately report to the regulatory authority or the monitoring service provider of any lost or damaged TLD badge. Spare badge may be used to replace the lost or damaged one before the end of the monitoring period, provided the spare badge is imprinted with the individual's name or another form of identification. Radiographic personnel assigned a spare badge will have the dose recorded by the dosimeter added to their occupational dose record.

6.5 Female Pregnant Workers

Occupationally exposed female staff should notify the RPO of pregnancy as soon as possible. Those that have declared themselves pregnant should be instructed to always wear their assigned dosimeters at waist level to estimate the dose to the embryo/fetus. The radiation dose to the surface of the abdomen of a pregnant worker should be restricted to approximately 2 mSv for the remainder of the pregnancy. This should ensure that the fetal dose will be less than 1 mSv and provide an appropriate measure of protection. The 2 mSv dose constraint should be readily achievable provided management and staff maintain appropriate protection standards and have a sound safety culture. Notification of pregnancy should not be a reason to exclude a female worker from her normal duties.

6.5 Records of individual monitoring results

Records should be consolidated for each monitored individual. They should indicate the monitoring purpose, period, individual name, and the workplace. Consideration should be given to any applicable national requirements or international agreements concerning the privacy of individual data records. The records should include the results of individual monitoring for both external radiation and intakes of radioactive material (where necessary). Every worker must have access to their exposure records. Exposure records for every worker should be kept for a maximum period of thirty (30) years. If the worker resigns from his work and joins another occupationally exposed profession, his dose records from the previous work must be carried over to the new workplace so that the cumulative dose can easily be tracked.

7.0 WORKPLACE MONITORING

Workplace monitoring should be carried out before operation of a new installation; when there is a change in the structural (or other) shielding that may affect radiation levels in surrounding areas; and following maintenance or repair of x-ray equipment that may impact on the x ray tube output by increasing radiation levels. The goals of monitoring are:

- To identify any unexpected changes that may have occurred due to changes in workload, procedures, shielding or the location of the x ray equipment;
- To provide a record of the assessment of existing radiation protection and safety conditions in all controlled and uncontrolled areas; and
- To estimate the exposures to workers in compliance with regulatory requirements.

7.1 Factors to consider

The following factors should be considered when carrying out area monitoring:

- The position of the tube and the direction of the primary beam
- The position of the patient
- Adjacent rooms that bound the controlled area
- Locations at which measurements might be taken

7.2 Locations to take measurements

Measurements should be taken in the control room/panel, in the dark room, at the waiting area, in the corridor, and in the adjacent rooms. The dose rate should not exceed 7.5µSv per hour.

7.3 Measuring Devices

Survey meters which detect all types of radiation are suitable to be used in workplace monitoring. Survey meters should be calibrated at least once every year. Calibration ensures accuracy of measurements. The operational quantity used in workplace monitoring is ambient equivalent dose, H*(10). It is important for facilities to have their own survey meter (s) so that RPOs can regularly assess the workplace.

7.4 Workplace Monitoring Records

The following survey data should be recorded:

- name of the person performing the survey
- date of the survey
- the measuring device used (manufacturer, model and serial number, date of last calibration)
- sketch of the room showing the measured values
- measurements of scattered radiation during irradiation of a phantom in the patient's position with standard exposure factors and field size.

Records of the calibration of monitoring equipment should also be kept, which include identification of the equipment, the calibration accuracy over its range of operation for the type(s) of radiation that it is intended to monitor, the date of the test, identification of the calibration standards used, the frequency of calibration, and the name and signature of the qualified person under whose direction the test was carried out. Records should be easily retrievable and be protected against loss. Such protection is usually attained by maintaining duplicate sets of records in well separated locations, so that both copies cannot be destroyed in a single incident.

8.0 TLD READING MACHINE

The individual monitoring service provider should be staffed with adequately qualified and trained personnel, and should have suitable processing equipment and other relevant facilities. Malawi has the Harshaw 4500 TLD Reader. This section provides the brief description and the basic operation of this machine.

8.1 Functional overview

The 4500 Reader contains the necessary firmware and hardware to read: 1, 2, 3 or 4-chip cards, chipstrates, chips, rods, disks or powder. An off-the-shelf personal computer provides the platform for running WinREMS software and displaying profiles.

The basic external components of the Reader include:

1. a front control panel consisting of a start button, three status lights (Ready, Cycle, and Fault), a power indicator light, the two-position sample drawer, and a lens cleanout drawer;
2. a rear connection panel for 100/120/220/240 vac power (power connection, fuse, and voltage switch), the Nitrogen gas connection and the RS-232-C connection;
3. a right-side panel for the Power switch.

The position of the PMT selection lever (located behind the access door) determines the reading mode: either card/chipstrate (hot gas) or unmounted material (planchet).

8.2 Operational Overview

The following are the main operations which are carried out on the Harshaw machine.

1. Generating Calibration Cards
2. Calibrating the Reader
3. Calibrating field cards
4. Reading field cards

Detailed procedures for these tasks are described in the Harshaw 4500 user manual.

8.3 Purpose of Calibrating the Reader and Cards

Full calibration requires calibrating both the Reader and all the cards in the system. The purpose for calibrating TLD Cards is to ensure that all cards in a system will give virtually the same response to a given radiation exposure. Because of natural variations in TL material responsiveness and in the physical mass of manufactured TL chips, there is a variation in response of as much as 30% from the mean in a population of dosimeters. The calibration factor for dosimeters is called the Element Correction Coefficient, or ECC. The ECC is used as a multiplier with the Reader output (in nanocoulombs) to make the response of each dosimeter comparable to the average response of a designated group of dosimeters maintained as calibration dosimeters.

The purpose for Reader calibration is to maintain a consistent output from the Reader over a period of time based on a convenient local source. Such a source might be a Sr-90 source built into the Reader or a Cs-137 source in a Harshaw Model 6610 Irradiator. By using a set of Calibration Dosimeters and a consistent local source, the Reader's performance may be kept at a constant level in spite of high voltage changes, repairs, dirt accumulation, or long term drift. The calibration factor for Readers is known as the Reader Calibration Factor, or RCF. This factor converts the raw charge data from the Photomultiplier Tubes (in nanocoulombs) to dosimetric units (rems, for example) or to generic units (gU) for input to an algorithm. The two factors are applied according to the following formula:

$$Exposure = \frac{Charge\ x\ ECC}{RCF}$$

8.4 Reader Performance Testing

It is important to periodically check the performance of the dosimetry system as an integral part of quality assurance. It is another way of evaluating Type B uncertainties associated with measurements. Type B uncertainties are those which cannot be reduced by repeated measurements. The most recommended performance tests to be conducted on the dosimetry system include: linearity test, energy dependence test and angular dependence test.

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