

**RISK ASSESSMENT OF OCCUPATIONAL RADIATION DOSE AT THE  
TELE THERAPY FACILITY OF THE KORLE-BU TEACHING HOSPITAL  
GHANA**

**This thesis submitted to the:**

**UNIVERSITY OF GHANA, LEGON**

**By**

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In partial fulfilment of the requirement for the award of  
**MPHIL Radiation Protection Degree**

**INTEGRI PROCEDAMUS**

**JULY, 2016**

## DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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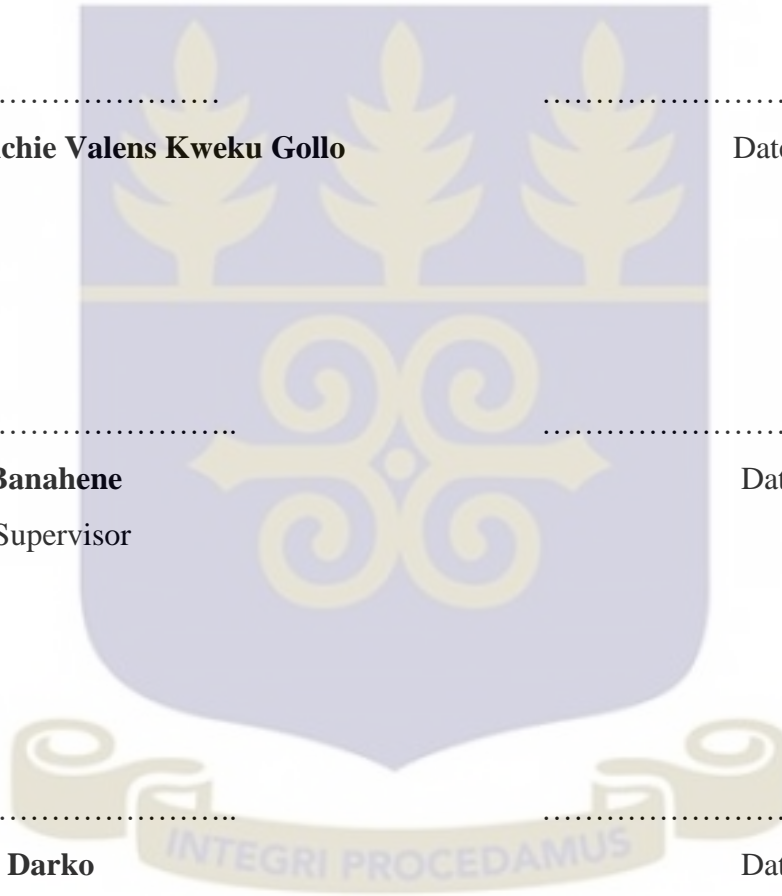
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## **DEDICATION**

I dedicate this work to the Almighty God and to my family especially to Miss Josephine Arku, Mr Joseph Adams, Mr Clement Gollo, Miss Stella Arku, Mr. Kingsley Bansah and his family, Mr George Klaus Hansen and his family, Mr and Mrs Senaha. Valentina Gollo and Francis Gollo



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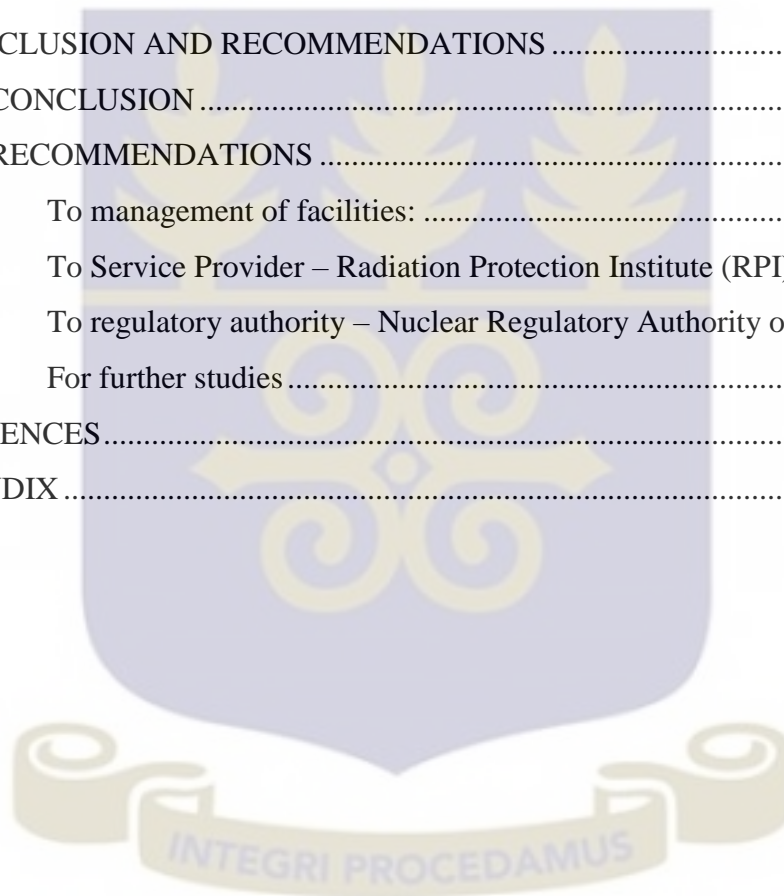
**TABLE OF CONTENTS**

DECLARATION .....	ii
DEDICATION .....	iii
ACKNOWLEDGEMENT .....	iv
TABLE OF CONTENTS .....	v
LIST OF TABLES .....	ix
LIST OF FIGURES.....	x
ACRONYMS AND ABBREVIATIONS .....	xii
ABSTRACT .....	1
CHAPTER ONE .....	3
1 INTRODUCTION.....	3
1.1 BACKGROUND.....	3
1.2 STATEMENT OF PROBLEM .....	7
1.3 OBJECTIVES AND GOALS OF THE STUDY .....	7
1.3.1 The specific objectives of this research are to: .....	8
1.4 RELEVANCE AND JUSTIFICATION OF THE STUDY .....	8
1.5 SCOPE AND DELIMITATION.....	10
1.6 STRUCTURE OF THE THESIS .....	11
CHAPTER TWO.....	12
2 LITERATURE REVIEW .....	12
2.1 HISTORY OF RADIATION .....	12
2.1.1 Radiation sources .....	12
2.1.2 Radioactivity.....	13
2.1.2.1 Cobalt-60 decay scheme.....	13
2.1.2.2 Stochastic effects of radiation.....	14
2.1.2.3 Cancer.....	15
2.1.2.4 Deterministic effects of radiation .....	15
2.2 OCCUPATIONAL RADIATION EXPOSURE.....	18
2.2.1 Exposure .....	19
2.2.2 Linear energy transfer .....	19
2.2.3 Kerma.....	20

2.2.4	Particle Fluence.....	20
2.3	RADIATION MEASURING INSTRUMENT .....	20
2.3.1	Dose rate meters and Dosimeters.....	21
2.3.2	Thermoluminiscent Dosimeters .....	22
2.3.2.1	Basic radiation instrument components.....	23
2.4	RADIOTHERAPY.....	24
2.4.1	Radiation Protection and Work Practice:.....	25
2.4.1.1	Justification:.....	25
2.4.1.2	Optimization .....	26
2.4.1.3	Design and Operational Considerations .....	27
2.4.1.4	Dose Limitation .....	28
2.5	CLASSIFICATION OF AREAS:-.....	29
2.5.1	Controlled Area.....	29
2.5.2	Supervised Areas .....	30
2.5.3	Occupational Exposure .....	30
2.6	PERSONAL MONITORING .....	31
2.6.1	Pregnant Staff.....	31
2.6.2	Unintended Exposure.....	32
2.6.2.1	System of Recording and Reporting.....	32
2.6.2.2	The Workplace Radiation Monitoring Program.....	33
2.6.2.3	Occupationally Exposed Worker Records.....	33
2.6.2.4	Treatment records .....	33
	CHAPTER THREE.....	35
	3 MATERIALS AND METHOD.....	35
3.1	MATERIALS .....	35
3.1.1	Thermoluminiscent Dosimeter (TLD) badge.....	35
3.1.2	Operation principle of the Thermoluminescence detector .....	36
3.1.3	Automatic HARSHAW 6600 TLD reader.....	37
3.1.4	Dose rate meter .....	38
3.1.5	Theratron Equinox 100 Co-60 teletherapy machine.....	40
3.2	METHODS.....	40

3.2.1	Occupational dose assessment .....	40
3.2.2	The mean annual effective dose(E).....	43
3.2.3	Estimation of annual Collective dose(S).....	44
3.2.4	Workplace monitoring .....	44
3.2.5	Dose rate measurement points .....	45
3.2.6	Treatment room.....	46
3.2.7	Control console room.....	46
3.3	RISK ESTIMATION .....	49
3.3.1	Nominal Risk Coefficients.....	49
3.3.2	Whole-Body Cancer Risk Estimation.....	50
3.3.3	Heritable Effects Risk Estimation.....	51
3.3.4	Total Detriment Risk Estimation .....	52
3.4	DETERMINATION OF AMBIENT DOSE EQUIVALENT .....	53
	CHAPTER FOUR.....	55
4	RESULTS AND DISCUSSION.....	55
4.1	MEAN EFFECTIVE DOSE DISTRIBUTION FROM TLDS .....	55
4.2	MEAN ANNUAL EFFECTIVE DOSE FROM DOSE RECORDS .....	56
4.3	RISK ASSESSMENT .....	62
4.3.1	Annual Cancer Risk Assessment (ICRP 1990 and 2007 Recommendations 62	
4.3.2	Annual Cancer Risk assessment for TLDs (ICRP 1990 and 2007).....	62
4.3.3	Annual Cancer Risk assessment from dose records (ICRP 1990 and 2007) 65	
4.4	ANNUAL LIFETIME CANCER RISK USING ICRP 1990 AND 2007 RECOMMENDATIONS .....	67
4.4.1	Annual lifetime risk assessment for TLD .....	67
4.4.2	Annual lifetime risk assessment from dose records (2010-2016).....	69
4.5	MEAN ANNUAL COLLECTIVE DOSE .....	70
4.6	AMBIENT DOSE RATE.....	72
4.6.1	Treatment Room .....	72
4.6.2	Controlled area.....	73
4.6.3	Control console room.....	74

4.7	INSTANTANEOUS DOSE RATES .....	75
4.7.1	Treatment room.....	76
4.7.2	Control console room.....	76
4.7.3	Controlled area.....	77
4.8	ANNUAL DOSE RATES.....	78
4.8.1	Annual dose rates (treatment room).....	79
4.8.2	Annual dose rate (control console room).....	80
CHAPTER FIVE.....		81
5	CONCLUSION AND RECOMMENDATIONS .....	81
5.1	CONCLUSION .....	81
5.2	RECOMMENDATIONS .....	82
5.2.1	To management of facilities: .....	82
5.2.2	To Service Provider – Radiation Protection Institute (RPI): .....	83
5.2.3	To regulatory authority – Nuclear Regulatory Authority of Ghana: .....	83
5.2.4	For further studies .....	84
REFERENCES.....		85
APPENDIX.....		88



**LIST OF TABLES**

Table 2.1: Annual Dose Limits (ARPANSA, 2008).....	29
Table 3.1 Technical specifications of the Rad-eye G10 survey meter .....	39
Table 3.2: Technical specifications of the Theratron Equinox 100 teletherapy equipment .....	40
Table 4.1: Exposure to workers from medical use of radiation.....	71
Table A. 1: Annual cancer risk assessment of occupationally exposed workers from 2010-2016 .....	88
Table A. 2: Lifetime risk estimation of occupationally exposed workers from 2010-2016 .....	88
Table A. 3: Risk estimate for TLDs using ICRP 1990 recommendations.....	89
Table A. 4: Risk estimate for TLDs using ICRP 2007 recommendations.....	90
Table A. 5: Estimated Lifetime risk for TLDs using ICRP 1990 recommendations.....	91
Table A. 6: Estimated lifetime risk using ICRP 2007 recommendations .....	92
Table A. 7: Comparative probability of cancer/year induced by low-LET radiation.....	93
Table A. 8: Estimated probability of cancer death/year (BEIR III, 1980).....	93
Table A. 9: Daily dose rate measurement in the controlled area .....	94
Table A. 10: Daily dose rate measurements in the control console room .....	94
Table A. 11: Daily dose rate readings in the treatment room .....	95
Table A. 12: Mean annual effective dose of occupationally exposed workers .....	95
Table A. 13: Effective Dose measurement of TLDs.....	96

**LIST OF FIGURES**

Figure 2.1: Cobalt-60 decay scheme..... 14

Figure 3.1: TLD badge for personal monitoring at the facility..... 36

Figure 3.2: TLD 6600 workstation ..... 38

Figure 3.3: Rad eye G-10 gamma survey meter ..... 39

Figure 3.4: TLD badge positions in the control console room ..... 41

Figure 3.5: TLD badge positions in the simulation room..... 42

Figure 3.6: Measurement points in the treatment room..... 46

Figure 3.7: Measurement points in the controlled area ..... 47

Figure 3.8: Measurement points in the control console room ..... 48

Figure 4.1: Mean annual effective doses from TLD cards ..... 56

Figure 4.2: Mean annual effective dose of workers at the teletherapy department in 2010  
..... 57

Figure 4.3: Mean annual effective dose of workers at the teletherapy department in 2011  
..... 58

Figure 4.4: Mean annual effective dose of workers at the teletherapy department in 2012  
..... 58

Figure 4.5: Mean annual effective dose of workers at the teletherapy department in 2013  
..... 59

Figure 4.6: Mean annual effective dose of workers at the teletherapy department in 2014  
..... 59

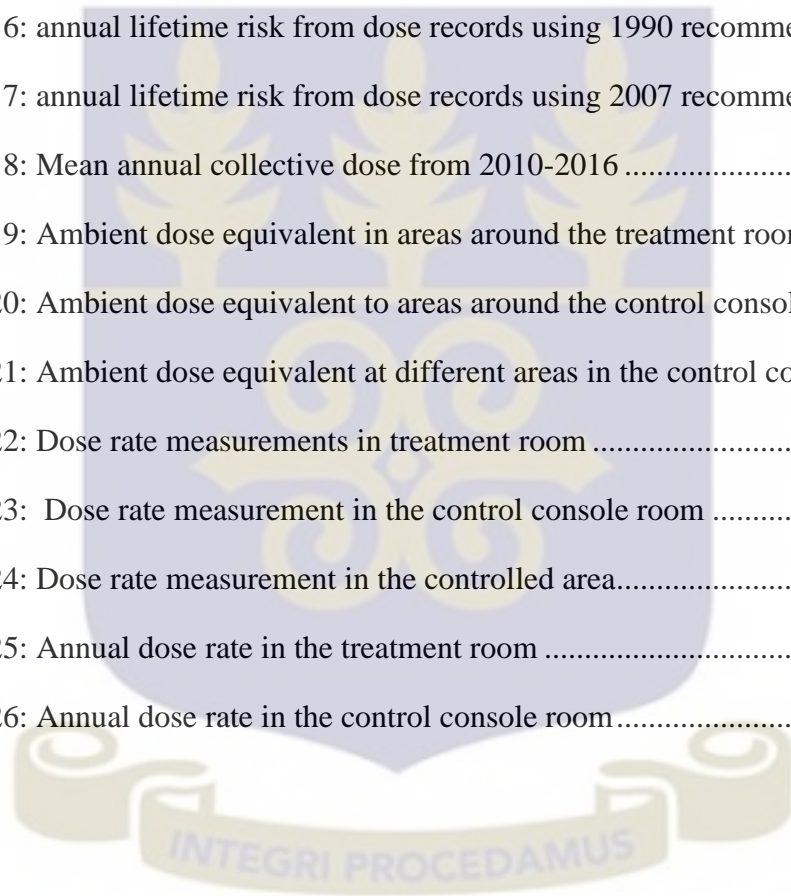
Figure 4.7: Mean annual effective dose of workers at the teletherapy department in 2015  
..... 60

Figure 4.8: Mean annual effective dose of workers at the teletherapy department in 2016  
..... 60

Figure 4.9: A graph showing the trend of effective doses received by occupationally  
exposed workers at the teletherapy facility at Korle-bu teaching hospital ..... 61

Figure 4.10: TLD cards annual risk using 1990 recommendations ..... 63

Figure 4.11: TLD cards annual risk using 2007 recommendations .....	64
Figure 4.12: Mean annual cancer risk for workers (2010-2016) using ICRP 1990 recommendations .....	65
Figure 4.13: Mean annual cancer risk for workers (2010-2016) using ICRP 2007 recommendations .....	66
Figure 4.14: Mean annual lifetime risk for TLDs using ICRP 1990 Model.....	67
Figure 4.15: Mean annual lifetime risk for TLDs using ICRP 2007 Model.....	68
Figure 4.16: annual lifetime risk from dose records using 1990 recommendations.....	69
Figure 4.17: annual lifetime risk from dose records using 2007 recommendations.....	70
Figure 4.18: Mean annual collective dose from 2010-2016 .....	72
Figure 4.19: Ambient dose equivalent in areas around the treatment room .....	73
Figure 4.20: Ambient dose equivalent to areas around the control console room.....	74
Figure 4.21: Ambient dose equivalent at different areas in the control console room .....	75
Figure 4.22: Dose rate measurements in treatment room .....	76
Figure 4.23: Dose rate measurement in the control console room .....	77
Figure 4.24: Dose rate measurement in the controlled area.....	78
Figure 4.25: Annual dose rate in the treatment room .....	79
Figure 4.26: Annual dose rate in the control console room .....	80



## ACRONYMS AND ABBREVIATIONS



<b>ALARA-</b>	As Low As Reasonably Achievable
<b>ARPANSA-</b>	Australian Radiation Protection And Nuclear Safety Agency
<b>BEIR-</b>	Biological Effects of Ionising Radiation
<b>BSS-</b>	Basic Safety Standards
<b>CNS-</b>	Central Nervous System
<b>CT-</b>	Computed Tomography
<b>DNA-</b>	Deoxyribonucleic Acid
<b>DDREF-</b>	Dose and Dose Rate Effectiveness Factor
<b>EAR-</b>	Excess Absolute Risk
<b>ERR-</b>	Excess Relative Risk
<b>GSR-</b>	General Safety Requirements
<b>GI-</b>	Gastro Intestinal
<b>IAEA-</b>	International Atomic Energy Agency
<b>ICRP-</b>	International Commission on Radiological Protection
<b>ICRU-</b>	International Commission on Radiation Units and measurements
<b>LET-</b>	Linear Energy Transfer
<b>MRI-</b>	Magnetic Resonance Imaging
<b>NCRP-</b>	National Council on Radiation Protection
<b>PC-</b>	Personal Computer
<b>RPO-</b>	Radiation Protection Officer
<b>SRS-</b>	Safety Report Series
<b>TLD-</b>	Thermoluminescence Dosimeter
<b>mSv -</b>	milli-Sievert
<b>mSv/a-</b>	milli-Sievert per annum

**mSv/hr-** milli-Sievert per hour

**Gy/week-** Gray per week



## ABSTRACT

The National centre for Radiotherapy and Nuclear Medicine at the Korle-bu Teaching Hospital in Ghana uses a Theratron Equinox 100 Cobalt-60 teletherapy machine that was commissioned in 2014 with a source activity of 370.4TBq.

The prime objective of this research was to estimate the risk and probability of cancer induction to workers and also to evaluate the level of radiation safety at the facility. Data was collected by means of TLDs and personal dose records available between the periods February 2010 and April 2016.

The results from 2010-2016 were used to compute the mean annual dose, mean annual collective dose as well as risk assessments using the ICRP 1990 and 2007 recommendations. Ambient dose rate measurements were also done using a Thermo electron survey meter. The Results showed that mean effective dose recorded from TLDs used in this research ranged from 0.08mSv-0.36mSv while dose records from 2010-2016 showed mean annual effective doses ranged between 0.23mSv-0.65mSv. Mean annual collective dose was 0.09 manSv.

Annual cancer risk estimates also showed that workers probability of developing cancers had a mean value of  $2.37 \times 10^{-2} \pm 7.75 \times 10^{-3}$  while risk of passing hereditary traits to offspring born after exposure showed a mean value  $3.96 \times 10^{-3} \pm 1.29 \times 10^{-3}$  according to the ICRP 1990 recommendations and ICRP 2007 showed that possibility of cancer induction to workers showed a mean value of  $2.03 \times 10^{-2} \pm 1.61 \times 10^{-3}$ . Mean annual dose rates did not exceed 14.8mSv/a, 5mSv/a and 0.74mSv/a for the treatment room, control console room and the controlled area respectively. This shows that workers at the facility

are not likely to exceed the recommended dose limit within a year while working at the facility. Ambient dose rates did not exceed  $7.39\mu\text{Sv/hr}$ ,  $2.80\mu\text{Sv/hr}$  and  $0.37\mu\text{Sv/hr}$  for the treatment room, control console room and the controlled area respectively. These values obtained are below the recommended limit of  $20\mu\text{Sv/hr}$ .



## CHAPTER ONE

### 1 INTRODUCTION

#### 1.1 BACKGROUND

The use of ionizing radiation for treatment and diagnosis in medicine is increasing and offers great benefit to patients but also plays a significant role in radiation exposure to workers and the general public. There has been a rise in public interest in the number of accidents that occur in medical application of ionizing radiation recently even though the widespread use of radiation sources has generally been peaceful ( IAEA, 2014).

There has been reports on the sharp increase of radiation exposure to staff and key personnel working in areas that are potentially exposed to ionizing radiation due to medical activities in both diagnostic and therapeutic applications in recent years (UNSCEAR, 2008).

This may be as a result of the loss of control of radiation sources which gives rise to unplanned or emergency exposures to workers, patients and members of the general public. Occupational radiation exposure is defined by the International Atomic Energy Agency (IAEA) as the radiation exposure incurred by a worker which is attributable to the worker's occupation and received or committed during a period of work which is not excluded exposure (IAEA: STI/PUB/1145, 2003, IAEA,2014). Excluded exposure defined in the context of occupational exposure means the aspect of exposure which results from naturally occurring background radiation, provided that any relevant action level, or levels, for the workplace are not exceeded and that the appropriate nuclear regulatory authority approves its exclusion. Therefore, any kind of radiation incurred in the line of work by a radiation worker is regarded as occupational exposure. It is necessary and customary to

monitor individual workers who are occupationally exposed to external radiation with personal dosimeters. Personal monitoring and dose assessment is done to gather and provide information on the actual exposure levels of workers involved in the use of ionizing radiations and also to ensure good working practices. Teletherapy or treatment over long distances was originally applied to the use of  $^{60}\text{Co}$  units for external beam therapy which involves the use of ionizing radiation for treatment of diseases such as cancers. It is a multidisciplinary approach which involves a variety of professionals from different background. The main aim of radiotherapy is to deliver high dose of radiation to tumour volume or cancer cells while sparing the surrounding healthy tissue and ensuring the safety of health personnel. According to (IAEA: SRS-No 47 ,2006) about half or almost all cancer patients are treated by radiotherapy, either as part of their curative treatment ,adjuvant or palliation treatment. Since high radiation doses are required for cancer therapy, scatter radiations associated with the process pose detrimental risk to occupational staff and other health personnel whose activities are directly or indirectly associated with the use of the radiation. The teletherapy treatment machine being used at the National Centre for Radiotherapy and Nuclear Medicine, Korle-Bu employs radioisotope  $^{60}\text{Co}$  of about 370.4 TGBq activity as a radiation source and was commissioned in the year 2014. In this type of teletherapy machines ,scatter radiations arise from different sources including radiation scattered from the patient, leakage and scattered radiation from the treatment head of the machine and radiations scattered from the floor, wall or ceiling (UNSCEAR, 2008). Radiotherapy professionals requiring individual monitoring include radiation oncologists, medical physicists, radiotherapy physics, radiotherapy technologists, maintenance and

engineering staff and nurses or other staff who must spend time with patients who contain radioactive sources (López, Govinda, & Podgorsak, 2005).

Aside personal monitoring, designated areas called either controlled or supervised areas within a teletherapy facilities also needs to have workplace monitoring to reduce occupational radiation exposure.

A Controlled area is defined in the glossary of the basic safety standard (BSS) as a limited-access area in which specific measures for protection and safety are or could be required for controlling radiation exposures or preventing the spread of contamination in normal working conditions and preventing or limiting the extent of potential exposures (IAEA Safety Standards Series, GRS Part 3 , 2014). Controlled areas in Teletherapy include all irradiation rooms (treatment rooms), all radiation source storage and handling areas, and the radiation control console room. The controlled area is usually supervised by an individual in charge of radiation protection, the Radiation Protection Officer. (López et al., 2005) suggest that occupational exposure monitoring goes beyond measuring and determining personal dose equivalent  $H_p(10)$  , but it includes interpretation and assessment.

A Supervised area is defined as any other area which is not already designated as a controlled area but where occupational exposure conditions need to be kept under review even though specific protection measures and safety provisions are not normally needed (IAEA Safety Standards.GSR Part3, 2104). Supervised areas may include areas surrounding radioactive source storage and handling and patient's rooms. Individual occupational exposure can be monitored by using dosimeters such as thermoluminescent dosimeter or film badges which are usually worn on the front of the upper torso of the

human body and integrate exposure over a given period. The position of the dosimeter is due to the fact that in teletherapy procedures, the whole body is assumed to be fairly uniformly exposed (López et al., 2005). The results obtained from the readout, may be expressed in personal dose equivalent,  $H_p(10)$ , absorbed dose, D, or effective dose, E. The workplace can also be monitored by measuring the ambient dose equivalent rate with the use of area monitors in teletherapy while source storage area monitoring is done with the survey meter. This is accomplished by taking integrated or instantaneous readings at locations beyond primary or secondary barriers at the facility.

The instantaneous measurements of the dose-equivalent are appropriate in determination of compliance with the shielding design goals if allowances are made for all of the factors that influence the projected weekly dose equivalent at the appropriate locations behind the barrier (NCRP report; no. 151,2005). Individual monitoring also serves as a way to verify the effectiveness of radiation control measures in the workplace. It serves as a useful measure for detecting changes in radiation levels in the workplace and to provide information in the event of accidental exposures. The report of National Council on Radiation Protection (NCRP report no. 151) sets the occupational dose limit for persons working in the controlled area to be  $5 \text{ mSv} \cdot \text{y}^{-1}$  ( $0.10 \text{ mSv} / \text{week}$ ) and  $1 \text{ mSv} \cdot \text{y}^{-1}$  ( $0.02 \text{ mSv} / \text{week}$ ) for those working in the Supervised area (NCRP report; no. 151, 2005).

In order to reduce radiation doses below the limits set forth by the NCRP, there is the need to plan and conduct work with sources of ionizing radiation to keep doses as low as reasonably achievable.

## **1.2 STATEMENT OF PROBLEM**

The protection of patients, staff and members of the general public from the perceived risk of ionizing radiation in Radiotherapy practice is essential ( IAEA SF-1,2006).

It is therefore important that radiation protection practice is included in the individual's continuous professional development. One of the hazards of working in a radiotherapy facility is the possibility of long term exposure to low-level radiation and its associated biological effects. The commissioning of the new Equinox Theratron 100 <sup>60</sup>Co teletherapy machine at the National Centre for Radiotherapy and Nuclear Medicine in 2014 replaced an older GWGP-80 Cobalt-60 teletherapy machine. Over the years a lot of research has focussed mainly on the compliance with dose limits set and approved by international bodies but indeed no amount of radiation can be safe enough no matter how little. The risks posed by such radiation exposure no matter how small in the line of work especially the probability of cancer induction have to be estimated to develop a safety culture at workplaces that will seek to reduce occupational exposure to doses As Low As Reasonably Achievable (ALARA)

## **1.3 OBJECTIVES AND GOALS OF THE STUDY**

The goal of this research is to assess the occupational radiation dose and monitor the level of radiations within and outside the control and treatment rooms of the teletherapy facility at the National Centre for Radiotherapy and Nuclear Medicine at Korle-Bu Teaching Hospital by using thermoluminescent dosimeters (TLDs) for staff monitoring and survey meter for workplace monitoring.

### **1.3.1 The specific objectives of this research are to:**

1. Assess the occupational radiation dose by placing thermoluminescent dosimeters (TLDs) at some selected points in the control room and the simulation room.
2. Use the results obtained to compute the risks associated with the radiation dose received and the probability of cancer induction using the ICRP 1990 and 2007 recommendations respectively
3. The accumulated dose records for key staff from the periods between 2010-2016 will be assessed and compared to results from the TLDs used in this work
4. Assess the level of radiation at the workplace by randomly measuring the instantaneous dose rate with a survey meter at specified locations in the treatment room during beam-off position at various distances from the collimator.
5. Measure the instantaneous dose rate dose during beam-off position at various distances from the collimator at the control room, the treatment room, the lobby in-between the control and treatment rooms as well as the outpatient department
6. The results obtained from the dose rate readings over a period will be computed into ambient dose rates and annual dose rates and the results compared with international standards.

### **1.4 RELEVANCE AND JUSTIFICATION OF THE STUDY**

The results from this research would establish a confirmation of a quality assurance program or provide the need to scale it up if found to be inadequate at the teletherapy facility particularly for personnel as well as other people at the receiving end of medical exposures.

This work will also provide a more current database and improve knowledge as a follow up to the re-evaluation of radiation safety at the teletherapy department conducted by Opoku S.Y and Asare-Sawiri in 2012.

The confidence of key personnel in the facility with regards to their protection against ionising radiation will increase the general well-being and dedication to duty .This research will also establish how safe it is to work at the teletherapy facility.

Data on occupational exposure of radiation workers and their mitigation measures remain scarce in Ghana. It is therefore important to understand the risk factors for occupational exposure among radiation workers to inform policy decisions on occupational exposure as well as safety policies and programmes for radiation workers. This study would be helpful in the protection of workers and setting standards of good practice at the teletherapy facility. It would also serve purpose of providing information about the actual level of radiation exposure to workers and conformation of good working practice set by the Nuclear Regulatory Authority of Ghana. The establishment of investigation levels through occupational dose assessment and workplace monitoring serves as a tool used to determine the need to review working procedures and performance of systems in place. The regular assessment of occupational radiation exposure and the analysis of the associated trends are important to track the changes that have taken place over time due to regulatory operations or technological improvement. According to the ALARA principle of radiation protection recommended by BSS (IAEA: Safety Series No. 115, 1996), many exposures may involve some degree of risk and therefore any unnecessary exposure must be avoided and all doses must be kept as low as it is reasonable achievable, taken into account the economic and social consideration. There are three principles according to (IAEA: Safety Series No. 115,

1996) that can be applied in prevention and control of exposure of radiation workers to radiation hazards: remove the hazard, guard the hazard, and guard the worker. These principles means that radiation working facilities should be properly designed and that appropriate equipment and shielding be provided to ensure the maximum amount of protection. Guard the worker refers to the periodic or regular measurement of the radiation level in the working environment and continuous personnel monitoring. Article I.37 – I.40 of the BSS (IAEA: Safety Series No. 115, 1996) requires licensees in collaboration with employers to implement programmes for monitoring the workplace.

## **1.5 SCOPE AND DELIMITATION**

Three major aspects of radiation protection in the teletherapy exists, personnel, patient and workplace monitoring. Usually, it is best practise to justify radiation exposure to the patient based on the levels that will be beneficial to the patient and as such, dose limits do not apply in dose delivery to the patient and diagnostic reference levels are used instead.

The research will therefore cover aspects of radiation safety to the radiotherapists and people in the immediate surroundings of the treatment area

To overcome the research problem, this study will focus on determining the amount of radiation dose received by workers at the teletherapy facility of the National Centre for Radiotherapy and Nuclear Medicine at The Korle-Bu Teaching Hospital to determine the radiation dose of workers, personal dose equivalent. Effective dose would be determined from the readout of the TLDs which would be used for the purpose of this research. The results would be compared to workers dose records at the Radiation Protection Institute of the Ghana Atomic Energy Commission and the results compared to dose records over a

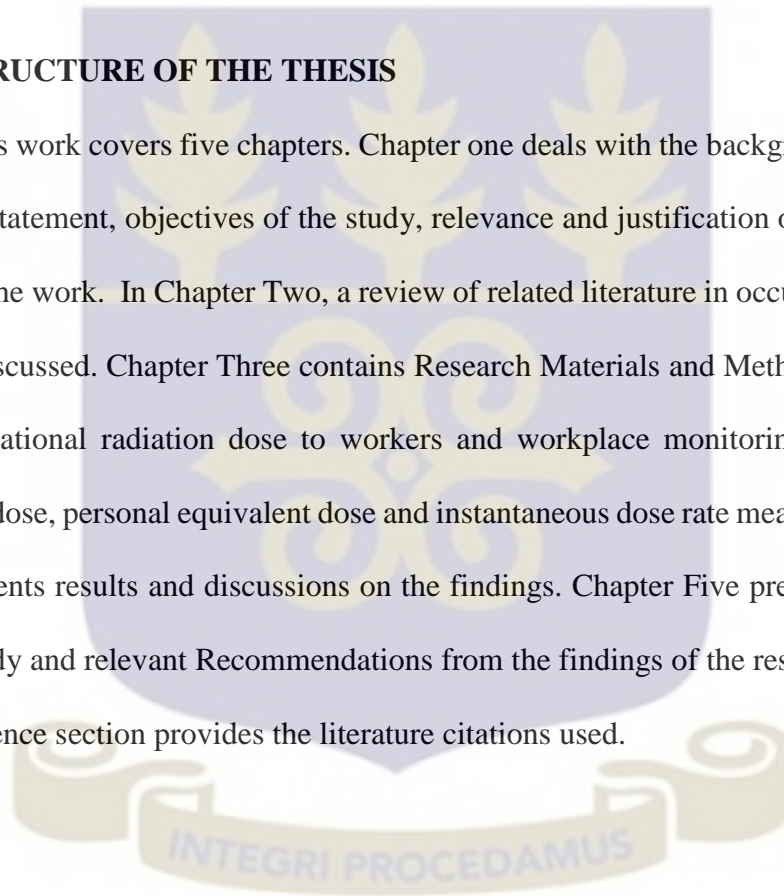
period of five (5) years (February 2010-April 2016) and the variations and associated risks evaluated.

.The level of radiations at the treatment room, the control area and the simulator rooms would also be determined at various distances from the centre of the collimator at beam off and beam on positions and the results compared to internationally accepted limits.

## **1.6 STRUCTURE OF THE THESIS**

This thesis work covers five chapters. Chapter one deals with the background of the study, problem statement, objectives of the study, relevance and justification of the research and scope of the work. In Chapter Two, a review of related literature in occupational exposure will be discussed. Chapter Three contains Research Materials and Methods used to assess the occupational radiation dose to workers and workplace monitoring; calculations of effective dose, personal equivalent dose and instantaneous dose rate measurement. Chapter Four presents results and discussions on the findings. Chapter Five presents Conclusions of the study and relevant Recommendations from the findings of the research work.

The reference section provides the literature citations used.



## CHAPTER TWO

### 2 LITERATURE REVIEW

This chapter provides an overview of the origin of radiation, workplace monitoring, occupational radiation exposure, occupational radiation protection and workplace monitoring.

#### 2.1 HISTORY OF RADIATION

From Cember (2008), there are three sources from naturally occurring sources of radiation and the oldest source is cosmic radiation, which is believed to have originated at the birth of the universe, about 13–14 billion years ago. A second source is the primordial radioactive elements which were formed when the earth was created about 4.5 billion years ago. Cosmogenic radioactivity ranks as the third major source of naturally occurring radioactivity. However, production of cosmogenic radioactivity is a continual process as cosmic radiation interacts with the atmosphere to produce radionuclides (Cember & Johnson, 2008).

##### 2.1.1 Radiation sources

Radiations in medical procedures are primarily from the radioactive sources used in the diagnosis as well as treatment of the patient. X-rays produced and emitted by equipment through the bremsstrahlung process is also another source of radiation resulting from medical procedures. This implies that the major sources of radiation in radiotherapy are due to the use of radioactive isotopes.

### 2.1.2 Radioactivity

Radioactivity may be defined as spontaneous nuclear disintegration of unstable atoms that results in the formation of new and more stable elements. These transformations are characterized by one of several different mechanisms, including alpha-particle emission, beta-particle and positron emission, and electron capture. Each of these reactions may or may not be accompanied by gamma radiation. Radioactivity was discovered by Henri Becquerel in 1896.

The radiations produced may be in the form of particles, electromagnetic radiation or both (Khan, 2010). Further studies by Rutherford and Soddy, 1902 and subsequently Bateman in 1910 came out with laws that governed the process of exponential decay of radioactive substances with time. A typical radioactive decay consists of an unstable parent nucleus that disintegrates into a daughter nucleus with a decay constant often accompanied by the release of energy.

#### 2.1.2.1 Cobalt-60 decay scheme

Cobalt-60 is produced artificially by neutron activation of the isotope Co-59, Co-60 decays by beta decay to the stable isotope nickel-60 ( $^{60}\text{Ni}$ ). The excited nickel nucleus emits two gamma rays with energies of 1.17 and 1.33 MeV, hence the overall nuclear equation of the reaction is

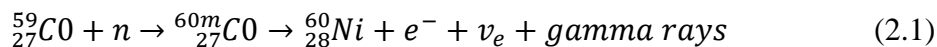


Fig shows the decay scheme of Co-60 where the main beta ( $\beta$ ) transitions are shown,

Energy transfers between the three levels generate six different gamma-ray frequencies

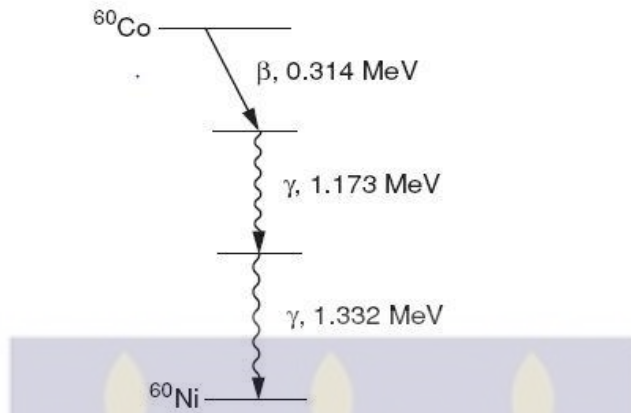


Figure 2.1: Cobalt-60 decay scheme

### 2.1.2.2 Stochastic effects of radiation

Genetic information that would be necessary for the production and functioning of a new organism is contained in the chromosomes of the germ cells. The normal human somatic cell contains 46 chromosomes; the matured sperm and ovary each carry 23 chromosomes. When an ovum is fertilized by a sperm, the resulting cell, called a zygote, contains the full complement of 46 chromosomes. During the 9-month gestation period, the fertilized egg, by successive cellular divisions and differentiation, develops into a new individual. In the course of the cellular divisions, the chromosomes are exactly duplicated, so that all the cells in the body contain the same genetic information. The units of information in the chromosomes are called genes. Each gene is an enormously complex macromolecule called deoxyribonucleic acid (DNA), in which the genetic information is coded according to the sequence of certain molecular subassemblies called bases (Cember & Johnson, 2008).

### 2.1.2.3 Cancer

The carcinogenic effects that can develop after exposure to doses of doses of 1 Gy (100 rads) or more of gamma radiation at high dose rates are well documented and consistent. The excess relative risk (ERR) from BEIR VII committee are based on the mortality data during the period 1950–2000, among 86,572 Japanese atomic-bomb survivors whose radiation doses are reasonably known. The ERR is a prospective metric of the increased likelihood of developing cancer as a result of exposure to ionizing radiation and this depends on several factors such as age, sex, and dose history. It is defined as

$$ERR = \frac{\text{Cancer incidence in exposed population}}{\text{Cancer incidence in unexposed population}} - 1 \quad (2.2)$$

A different method used to estimate radiation risk to a population from a given radiation dose is the excess absolute risk (EAR). The EAR tells how many cases or deaths may be attributed to the exposure. It is therefore also called the attributable risk (Cember & Johnson, 2008). EAR is defined by

$$EAR = \text{exposed population incidence rate} - \text{control population incidence rate.} \quad (2.3)$$

### 2.1.2.4 Deterministic effects of radiation

#### 2.1.2.4.1 Acute Effects

Acute whole-body radiation overexposure affects all the organs and systems of the body. However, since not all organs and organ systems are equally sensitive to radiation, the pattern of response, or disease syndrome, in an overexposed individual depends on the magnitude of the dose. The acute radiation syndrome is subdivided into three classes. In order of increasing severity, these are the hemopoietic, GI and CNS syndromes. Certain effects are common to all categories; these includes the following:

- nausea and vomiting
- malaise and fatigue
- increased temperature
- blood changes (Cember & Johnson, 2008)

#### 2.1.2.4.2 Delayed Effects

The delayed effects of radiation may be due either to a single large overexposure or continuing low-level overexposure over a period of time. Continuing overexposure can be due to exposure to external radiation fields or can result from inhalation or ingestion of a radioisotope which then becomes fixed in the body through chemical reaction with the tissue protein or, because of the chemical similarity of the radioisotope with normal metabolites, may be systemically absorbed within certain organs and tissues. In either case, the internally deposited radioisotope may continue to irradiate the tissue for a long time. Delayed effects may include heart disease, stroke, and diseases of the blood-forming, digestive, and respiratory systems (Cember & Johnson, 2008).

#### 2.1.2.4.3 Measurement of radiation dose

Half-life (T) is probably the most known property of radioactivity. After one-half life has elapsed, the number of radioactive decay events in a sample per unit time will be reduced by one-half. The decay rate or activity at any time t can be described mathematically:

$$A_t = A_0 e^{-[0.693t/T]} \quad (2.4)$$

Where:  $A_0$  = initial activity,  $A_t$  = final activity at time t, t = lapsed time T = isotope half-life

The amount of radioactivity present in a material does not depend on the size or weight of a quantity of material. A large quantity of material can contain a very small amount of radioactivity, or a very small amount of material can have a high amount of radioactivity. For example, uranium-238, with a 4.5-billion-year half-life, has only 0.00015 curies of activity per pound, while cobalt-60, with a 5.3-year half-life, has close to about 513 kilo curies of activity per pound. This specific activity or curies per unit mass, of a radioisotope depends on the unique radioactive half-life and dictates the time it takes for half the radioactive atoms to decay. In terms of disintegration per unit time,  $1 \mu\text{Ci} = 2,220,000 \text{ dpm}$ . The SI system of units has adopted the use of Becquerel (Bq) as the unit of radioactivity. One curie is equivalent to 37 billion Bq.

Even though majority of the requirements for the standards are qualitative, the standards also establish quantitative limits and guidance levels. Based on these reasons, the main physical quantities used in the standards are the rate of nuclear transformation of radionuclides and the energy absorbed by a unit mass of a substance exposed to radiation. The unit of activity is the reciprocal second, representing the number of nuclear disintegrations per second, which is termed the Becquerel (Bq) while the unit of absorbed dose is the joule per kilogram, termed the gray (Gy). The absorbed dose is the basic physical dosimetric quantity of the standards (Hashim, 2009). However, it is not entirely satisfactory for radiation protection purposes because effectiveness in damaging human tissue differs for different types of ionizing radiation. Consequently, the absorbed dose averaged over a tissue or organ is multiplied by a radiation weighting factor to take account of the effectiveness of the given type of radiation in inducing health effects; the resulting

quantity is termed the equivalent dose, IAEA (2005). Mathematically, the equivalent dose ( $H_T$ ) can be expressed as:

$$H_T = \sum DW_R \quad (2.5)$$

Where,  $D$ : Absorbed dose, and  $W_R$ : Radiation weighting factor

The quantity equivalent dose is used when individual organs or tissues are irradiated, but the likelihood of stochastic effects due to a given equivalent dose varies for different organs and tissues. Consequently, the equivalent dose to each organ and tissue is multiplied by a tissue weighting factor based on the sensitivity of the organ to radiation. The sum total of such weighted equivalent doses for all exposed tissues in an individual exposed to radiation is termed as the effective dose ( $E$ ), IAEA (2005).

$$E = \sum H_T W_T \quad (2.6)$$

Where,  $W_T$ : Tissue weighting factor  $H_T$ : Equivalent dose

The unit of equivalent dose and effective dose is the same as that of absorbed dose, namely joule per kilogram, but the name Sievert (Sv) is used in order to avoid confusion with the unit of absorbed dose (Gy)(IAEA, 2005).

## 2.2 OCCUPATIONAL RADIATION EXPOSURE

The senses of the human body cannot detect radiations in any way but excessive exposure to them may cause adverse health effects that may be felt immediately or in the aftermath. The uses of radiation measuring instruments are therefore necessary to detect the presence of such radiations and avoid possible exposure. The use of the most appropriate and

efficient instruments helps radiation exposures to be controlled, properly detected and the doses received to be kept as low as reasonably achievable (ALARA) (IAEA, 2004b). In addition, the term as low as reasonably achievable' means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety as well as considering societal and socioeconomic factors, and in relation to the utilization of atomic energy in the public interest (Brodsky, 1993).

### 2.2.1 Exposure

Exposure is a quantity that expresses the ability of radiation to ionize air and thereby create electric charges which can be collected and measured. Exposure  $X$ , is defined as the quotient of  $dQ/dm$ , where  $dQ$  is the absolute value of the total charge of the ions of one sign produced in air when all electrons liberated by photons in air of mass  $dm$  are completely stopped in air. The SI unit for exposure is Coulomb per kilogram (C/kg) but the older unit is Roentgen (R).  $1 \text{ R} = 2.58 \times 10^{-4} \text{ C/kg}$  of air.

$$X = \frac{dQ}{dm} \quad (2.7)$$

### 2.2.2 Linear energy transfer

The Linear Energy Transfer (LET) for a charged particle in a medium is defined as the quotient of  $dE/dl$ , where  $dE$  is the average energy locally imparted to the medium by a particle of specified energy traversing a distance  $dl$ . The SI unit for LET is J/m and is commonly expressed in keV/ $\mu\text{m}$ . Linear energy transfer (LET) is defined mathematically as

$$L_{\Delta} = \left[ \frac{dE}{dl} \right] \quad (2.8)$$

where  $dE$  is the energy lost in traversing distance  $dl$  and  $\Delta$  is an upper bound on the energy transferred in any single collision.

### 2.2.3 Kerma

The quantity Kerma (K), which stands for Kinetic Energy Released in the Medium, is defined as the quotient of  $dE_{tr}/dm$ , where  $dE_{tr}$  is the sum of the initial kinetic energies of all the charged ionizing particles (electrons and positrons) liberated by uncharged particles (photons) in a material of mass  $dm$ .

$$K = \frac{dE_{tr}}{m} \quad (2.9)$$

The SI unit for kerma is the same as for absorbed dose, i.e. J/kg (1 Gy).

### 2.2.4 Particle Fluence

The particle fluence  $\phi$  is the quotient of  $dN/dA$ , where  $dN$  is the number of particle incident on a sphere of cross-section area  $dA$ .

$$\Phi = \frac{dN}{dA} \quad (2.10)$$

The SI unit for particle fluence is  $m^{-2}$ .

## 2.3 RADIATION MEASURING INSTRUMENT

Radiation measuring instruments are needed to detect and quantify two types of exposure: external exposure to penetrating radiations emitted by sources outside the human body; and internal exposure which is associated with radioactive materials which are in a form

capable of entering and interacting with the human body (IAEA, 2004b). However, there are mainly four basic types of radiation measuring instrument that may be used in the workplace:

- Dose rate meters used to measure the external exposure.
- Dosimeters which indicate the cumulative external exposure.
- Surface contamination meters which indicate the potential internal exposure when a radioactive substance is distributed over a surface.
- Airborne contamination meters and gas monitors which indicate the internal exposure when a radioactive substance is distributed within an atmosphere. (IAEA, 2004b)

### **2.3.1 Dose rate meters and Dosimeters**

A dose rate meter absorbs energy from penetrating radiation. A suitable and efficient instrument which is matched to the specific task should be capable of providing direct readings of the dose equivalent rate in micro Sieverts per hour (mSv/hr) and a smaller number of instruments show the absorbed dose rate in micrograys per hour ( $\text{mGyh}^{-1}$ ). These usually respond only to X-ray, gamma and beta radiations. Specialized instruments are necessary to measure neutron dose equivalent rates (IAEA, 2004b).

A dosimeter measures the cumulative energy absorbed as a consequence of exposure to ionizing radiation. Personal dosimeters must be worn by radiation workers to measure their radiation level. Passive dosimeters routinely monitor cumulative doses resulting from an external exposure and active dosimeters provide an immediate reading of the dose in micro Sieverts (mSv) and may also provide an immediate alarm signal when the measured dose approaches a value pre-set by the manufacturer or user. Integrating dose rate meters and

dosimeters are used to assess an external exposure in a rapidly changing environment, for example:

- A task of short duration has to be carried out in the presence of high dose rates;
- The source, for example an X-ray machine emits radiation pulses of short duration (IAEA, 2004b).

### 2.3.2 Thermoluminescent Dosimeters

Many different crystals emit light if they are heated after having been exposed to radiation. This effect is called thermoluminescence, and dosimeters based on this effect are called thermoluminescent dosimeters (TLD). Some of these TLD crystals include LiF, CaF<sub>2</sub>:Mn (CaF<sub>2</sub> containing a small amount of added Mn, which functions as an activator, CaSO<sub>4</sub>:Tm, Li<sub>2</sub>B<sub>4</sub>O<sub>7</sub>:Cu, and LiF:Mg,Ti. Absorption of energy from the radiation excites the atoms in the crystal, which results in the production of free electrons and holes in the thermoluminescent crystal. These are trapped by the activators or by imperfections in the crystalline lattice, thereby locking the excitation energy in the crystal. Heating the crystal releases the excitation energy as light. Measurement of the emitted-light intensity leads to a glow curve (Fig. 9-23). Trapped excited electrons also spontaneously fall down to the ground state even at low temperatures. At room temperatures, trapped electrons fall down to the ground state at a rate of about  $10^{-8} - 10^{-7}$  percent per second. This leads to fewer trapped electrons at readout, and consequently to a smaller dose at readout than originally recorded, as shown in the following example. Thermoluminescent materials are found in the form of loose powder, disks, squares, and rods. For personal monitoring, one or more small pieces of thermoluminescent material about 50mg each are placed into a small holder

that is worn by the person being monitored. After being worn for the prescribed period of time, the TLD material is heated and the intensity of the resulting luminescence is measured with a photomultiplier tube whose output signal, after amplification, is applied to a suitable readout instrument, such as a digital voltmeter. The instrument is calibrated by measuring the intensity of light from thermoluminescent phosphors that had been exposed to known doses of radiation (Cember & Johnson, 2008).

### **2.3.2.1 Basic radiation instrument components**

Commercially available radiation detection instruments are often described and procured on the basis of their essential components. The key components include:

- a) The detector: The detector contains a medium which absorbs radiation energy and converts it into a signal. Electrical charge usually forms the signal. Examples of some detectors include:
  - ✓ Gas filled detectors
  - ✓ Ionization chambers
  - ✓ Proportional counters
  - ✓ Geiger-Müller counters
  - ✓ Scintillation counters
  - ✓ Solid state detectors
- b) The amplifier: The signals from a detector may need to be electronically amplified.
- c) The processor: According to the type of instrument, the processor may be a device to measure the size or number of signals produced by the detector. It may also translate the quantity measured in appropriate radiological units.

- d) The display: The measurement is presented either in a digital format or as an analogue display showing a pointer on a graduated scale.
- e) The radiation: Ionizing radiations (alpha or beta particles, gamma or X rays, or neutrons) which enter the detector need to be absorbed to be detected.
- f) Ionization: The process in which the detector medium absorbs radiation energy (IAEA, 2004b).

## **2.4 RADIOTHERAPY**

Radiotherapy treatment is one of the modalities that is used in cancer treatment either alone or in combination with surgery or chemotherapy. The radiation oncologist prescribes a treatment method to cure or control the disease by delivering high dose to the malignant tissues and avoiding any unacceptable damage to the normal tissues. However, the prescribed doses are often constrained by tolerance doses for normal tissue. The International Commission on Radiation Units and Measurements (ICRU report No.24) has recommended that the dose delivered should be within + 5% of the prescribed dose. This is because, if the dose to the target is 5% too low, it may result in a clinically detectable reduction in tumour control or to the normal tissues, 5% too high may lead to significant increase in normal tissue complication probability. The optimal radiotherapy treatment requires the following:

- Accurate diagnosis
- Accurate determination of the target volume and critical organs at risk
- Proper dose prescription
- Correct delivery of the prescribed treatment and diligent follow-up.

- Careful documentation of every phase of the radiation treatment process for clinical evaluation (Fadlalla, 2010).

The Components of typical radiotherapy department are:

- Diagnostic facilities (CT, MRI,)
- Simulator,
- Mould room
- Treatment planning
- teletherapy treatment units
- Clinic rooms, beds

#### **2.4.1 Radiation Protection and Work Practice:**

##### **2.4.1.1 Justification:**

Any exposure to radiation is considered not justified if the exposure is of no benefit and this benefit must clearly outweigh the radiation risk (Fadlalla, 2010). The decision to recommend and perform a radio therapeutic procedure depends on a professional judgment of the benefits that contribute to the health of the patient, while taking cognizance of any risks of biological effects that might be caused by exposure to ionizing radiation. The beneficence of the therapeutic procedure to the patient will be the most important consideration and the direct health benefits to the individual as well as the benefits to society. The risks will be the possible hazards that may emanate from the effects of ionizing radiation as a result of the exposure to radiation. The objective of radiotherapy is to deliver a radiation dose to a selected target volume of an organ or tissue for the purpose of killing cells with the least possible risk to surrounding healthy cells. Such therapy results in

absorbed doses that are orders of magnitude higher than those encountered in diagnostic studies. The potential for complications of such a procedure with normal tissue is significant. Some effects will often be an unavoidable part and properly accounted for as part of a properly justified procedure. Therefore, the justification for each procedure should be carefully considered such that the benefits are obviously more than the risks involved as well as potency of the procedure.

The option of using other procedures, including surgery or chemotherapy, either alone or in combination with radiotherapy is primarily decided by the choice of procedure of the patient, professional advice from the practitioner, available resources as well as availability of alternative procedures.(Fadlalla, 2010)

There are special cases where there will be a need for further justification, including medical exposure of the pregnant or potentially pregnant patient and staff, as biological effects of ionizing radiation to the embryo or fetus is more radiosensitive than the mature adult patient and staff., medical exposures involving children under the age of eighteen (18) years also requires a higher level of justification since they are also relatively more radio sensitive (ARPANSA, 2008)

#### **2.4.1.2 Optimization**

Once a radiotherapeutic procedure is appropriately justified, it should be performed so that the dose to the patient is as low as reasonably achievable (ALARA) to attain the desired therapeutic effect. Dose limits do not apply to clinically justified procedures since the procedure is expected to be directly beneficial to the patient. In radiotherapy, it is also

important to account for the dose to the target volume and the surrounding tissues as well since dose not properly delivered may not achieve the desired therapeutic effect. Dose planning should be done with dose distribution and protection of surrounding tissues outside the target volume forming a prominent part of the process and this forms the basis for optimization for protection (ARPANSA, 2008)

#### **2.4.1.3 Design and Operational Considerations**

The effects of radiation exposure on tissues surrounding the target volume have to be evaluated by the radiation oncologist and the variations accounted for. The continuous detection of over exposure to surrounding tissues of the target volume to be different from the expected clinical outcomes which could be as a result of equipment failure, system error or possibly human related errors will be of great concern to the regulatory authority. In most cases of accidental exposure, the possible effects are not reversible but will form a basis for proper medical care and guidance in the aftermath. Furthermore, steps must be taken to inform the regulatory authority of such overdoses or even under doses than the intended dose to be delivered.

Multiple safeguards i.e. the defence in depth principle in the design and usage of all critical components of radiotherapy equipment should aim to prevent maladministration of the radiation dose such that detrimental effect on the patient can be mitigated (ARPANSA, 2008)

#### **2.4.1.4 Dose Limitation**

The Occupational Exposure of any worker should be controlled so that the limits stated in Table 2.1 will not be exceeded. For apprentices of 16 to 18 years of age who are training for employment involving exposure to radiation and for students of age 16 to 18 who are required to use sources in the course of their studies, the occupational exposure should be controlled to ensure that the limits in Table 1 are not exceeded. The estimated average doses to the relevant critical groups of members of the public that are attributable to practices should not exceed limits but in special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year. Dose limits do not apply for medical exposures, but dose constraints are adopted for optimization purposes. Expected individual doses during therapeutic procedures should be compared with the appropriate dose constraints and protective measures that predict doses below dose constraints should be chosen. Dose constraints can be used for optimizing protection in the planning stage for each radiation source. Anticipated individual doses should be compared with the appropriate dose constraints, and only protective measures that predict doses below dose constraints should be chosen.

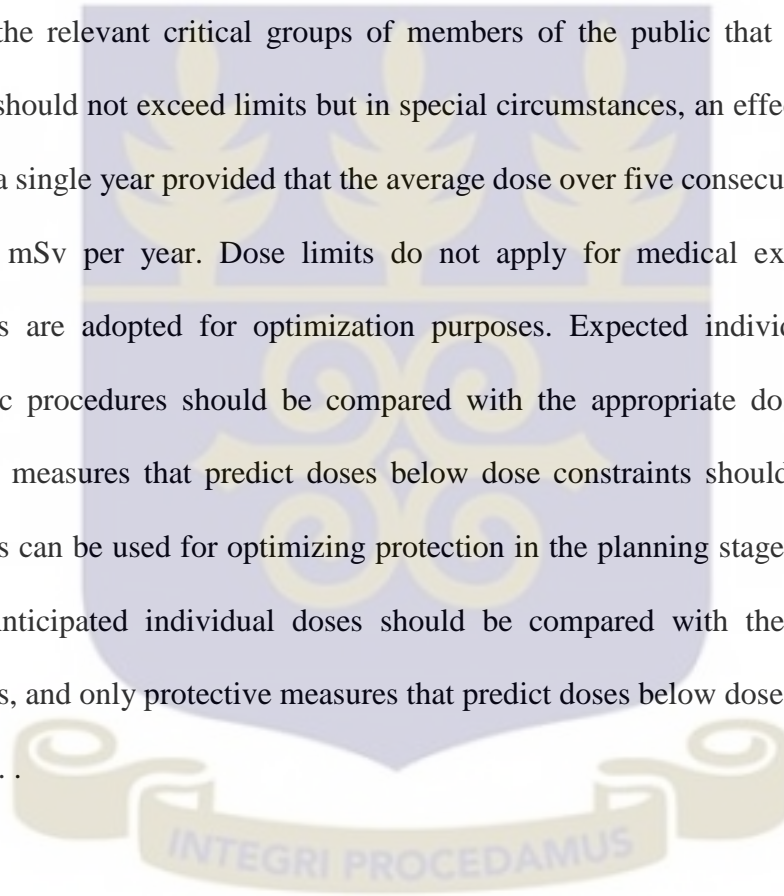


Table 2.1: Annual Dose Limits (ARPANSA, 2008)

Exposure Type	Annual Dose limits (mSv/yr)	Lens of the eye (mSv/yr)	Extremities (hands and feet) or the skin (mSv/yr)
Occupational exposure (worker)	an effective dose of 20 mSv per year averaged over five consecutive years; but not more than 50 mSv in any single year	150	500
Apprentices	6	50	150
Public	1	15	50

## 2.5 CLASSIFICATION OF AREAS:-

The areas in radiotherapy facility should be classified as controlled or supervised areas.

### 2.5.1 Controlled Area

According to the BSS, Controlled Areas: are defined as any area in which specific protective measures or safety provisions are or could be required for:

- (a) controlling normal exposures or preventing the spread of contamination during normal working conditions; and
- (b) preventing or limiting the extent of potential exposures. These areas will require special access restrictions by means of door interlocks and signs when sources are exposed.

The controlled areas in the radiotherapy department are the treatment rooms for all external beam treatment (ARPANSA, 2008).

### **2.5.2 Supervised Areas**

The supervised area consists of places not already designated as a controlled area but where occupational exposure conditions need to be kept under review even though specific protection measures and safety provisions are not normally needed. The supervised areas in a radiotherapy department are the operating consoles and any area where calculated exposure rates through shielding barriers are likely to result in exposures of 1 mSv in a year (Fadlalla, 2010).

### **2.5.3 Occupational Exposure**

To reduce occupational radiation exposure to as low as reasonably achievable (ALARA), there is the need for building design, shielding, equipment and procedures to be adequately designed and tested. The provision of adequate shielding should always be considered for any type of radiation source. A prior assessment of potential occupational doses should identify the type, form and thickness of shielding required have to be conducted and incorporated in the design and specifications of the facility and equipment to meet safety requirements. The advice of a Qualified Expert and/or RPO should be sought before new procedures and equipment are introduced or significant modifications are made to the radiotherapy facilities, equipment or procedures, since levels of radiation protection or safe practice may be affected change of radiation source should also be done in consultation with a qualified expert and the RPO (ARPANSA, 2008).

## **2.6 PERSONAL MONITORING**

All persons operating or otherwise dealing with radiotherapy equipment or radioactive sources for radiotherapy purposes should be monitored with personal radiation monitors (such as film or, or TLDs) or any other dosimeters approved by the Nuclear Regulatory Authority. Unless there is evidence to suggest that the exposure is effectively controlled by the shielding design with an effective dose below 1 mSv per year. The monitors should be provided and assessed by a personal radiation monitoring service licensed by the Nuclear Regulatory Authority of Ghana. The monitors should normally be worn on the most exposed area of the body and this normally between the waist and the shoulder, and under any protective garments. In some circumstances, two dosimeters are deemed more and accepted universally as international best practice appropriate (for pregnant staff).

The length of time for which a monitor will be allocated will depend on the expected doses to be received during the wearing period. Personal radiation monitors should be changed at regular intervals, and the appropriate monitoring period should be determined by the type of radiation and the type of procedures being carried out. For teletherapy techniques a monitoring period should be two months and not more than three month. Where an unusual exposure situation with potential for a reportable dose occurs the monitor should be processed immediately and a replacement provided (ARPANSA, 2008; Fadlalla, 2010).

### **2.6.1 Pregnant Staff**

If an occupationally exposed female employee declares a pregnancy, the foetus needs to be afforded the same level of protection as a member of the public. This may be achieved by controlling the exposure of the employee so that the dose received by the foetus is less

than the public effective dose limit of 1 mSv for the remainder of the pregnancy. The Legal Person should assess the likely dose to the foetus of a pregnant employee from each work activity. This will usually require an examination of the employee's personal monitoring records and an assessment of the likelihood of incidents leading to radiation exposure of the foetus. If the foetus could receive more than 1 mSv over the declared term of the pregnancy, a change in work practice or job description should be discussed and agreed to with the employee. The most appropriate action is to reallocate the duties of the pregnant employee to duties with a low risk of radiation exposure. In cases where the radiation exposure might not be predictably controlled, it would be prudent to provide an occupationally exposed pregnant employee with an electronic personal dose monitor to allow monitoring of the employee's dose on a daily basis. Another alternative is to provide the pregnant employee with another passive dosimeters (e.g. film, TLD etc.) to monitor abdominal dose, if such dose could be controlled to be less than 2mSv, this will ensure that the fetus dose will not exceed 1mSv in the remainder period of pregnancy (ARPANSA, 2008).

## **2.6.2 Unintended Exposure**

### **2.6.2.1 System of Recording and Reporting**

In each radiotherapy facility there should be a system instituted where all relevant information relating to radiation work is recorded, documented and when necessary, reported to management. This is a key factor in control of exposures and maintenance of a safe working environment. The record should be maintained.

### **2.6.2.2 The Workplace Radiation Monitoring Program**

The workplace monitoring program should include:

- a) the quantities to be measured;
- b) where and when the measurements are to be made and at what frequency;
- c) the most appropriate measurement methods and procedures
- d) reference levels and the actions to be taken if they are exceeded (ARPANSA, 2008).

### **2.6.2.3 Occupationally Exposed Worker Records**

Occupationally exposed workers records should include:

- a) information on the general nature of the employee's work and their assessed doses;
- b) when a worker is or has been occupationally exposed while under the employment of more than one employer, information on the dates of employment with each employer and the doses from each such employment; and
- c) records of any doses due to accidents or incidents including references to reports of any relevant investigations (ARPANSA, 2008).

### **2.6.2.4 Treatment records**

The Records must be kept of all relevant aspects of the treatment including:

- session and Summary Record information
- records all treatment parameters
- dose calculations
- dose measurements

- Treatment records should be kept for lengthy periods - up to 30 years - because of potential for re-treatment (ARPANSA, 2008).



## CHAPTER THREE

### 3 MATERIALS AND METHOD

This chapter outlines the materials and methods used to acquire and assess dose received by radiotherapists and workers who are mostly in the controlled area of the teletherapy department of the Korle-Bu teaching hospital as well as dose rate measurements at different points within the facility. This section also provides methods used to analyse the data to establish dose distribution trends.

#### 3.1 MATERIALS

This research work uses Thermo-Luminescent Dosimeters (TLDs), Gamma survey meter, and automatic WINREM 6600 TLD reader to assess exposure. A tape measure to measure distances, dose records of occupationally exposed workers at the teletherapy facility from 2010-2016 were also used in this research. The choice of dosimeter depends on the objectives of the monitoring program and the method of interpreting the data. The basic choice for penetrating radiation has usually been a dosimeter giving information on the personal dose equivalent at 10mm depth

##### 3.1.1 Thermoluminescent Dosimeter (TLD) badge

A TLD badge consists of a set of thermoluminescent dosimeter chips enclosed in a plastic holder with filters (Podgorsak, 2005).

The TLD chips mostly used are made of Lithium Fluoride doped with Magnesium, Copper, and Phosphorus (LiF: Mg, Cu, P). TLDs are passive radiation detectors which are designed to measure cumulative radiation doses resulting from an external exposure. They are used to measure dose in soft tissues at a defined depth below a specified point on the body at 10mm ( $H_p10$ ) for strongly penetrating radiation and at a depth of 0.07mm ( $H_p0.07$ ) for weakly penetrating radiation respectively. TLD badge worn by occupationally exposed workers at the teletherapy facility of the Korle-bu Teaching hospital is shown in Fig 3.1



Figure 3.1: TLD badge for personal monitoring at the facility

### 3.1.2 Operation principle of the Thermoluminescence detector

A TLD is a phosphor, such as lithium fluoride (LiF) or calcium fluoride (CaF), in a solid crystal structure. When a TLD is exposed to ionizing radiation at ambient temperatures, the radiation interacts with the phosphor crystal and deposits all or part of the incident energy in that material. Some of the atoms in the material that absorb that energy become ionized, producing free electrons and areas lacking one or more electrons, called electron

holes. Imperfections in the crystal lattice structure act as sites where free electrons can become trapped and locked up into place.

The vacancy is soon filled by another electron from the same band, and this process repeats itself many times. The result is that, while electrons travel free in the conduction band, electron-holes travel free in the valence band. Soon, electrons in the conduction band fall into electron traps in the forbidden band, and holes rise to hole traps in the same band. Heating the crystal causes the crystal lattice to vibrate, releasing the trapped electrons in the process. Released electrons return to the original ground state, releasing the captured energy from ionization as light, hence the name thermoluminescent. Released light is counted using photomultiplier tubes (PMT) and the number of photons counted is proportional to the quantity of radiation striking the phosphor.

### **3.1.3 Automatic HARSHAW 6600 TLD reader**

The HARSHAW 6600 TLD automatic reader is used to read the cumulative dose received on TLD cards. The system consists of two major components: the TLD Reader and the Windows Radiation Evaluation and Management System (WinREMS) software resident on a dedicated personal computer (PC), which is connected to the Reader via a serial communications port. A typical workstation of the automatic TLD HARSHAW 6600 is shown in Fig 3.2

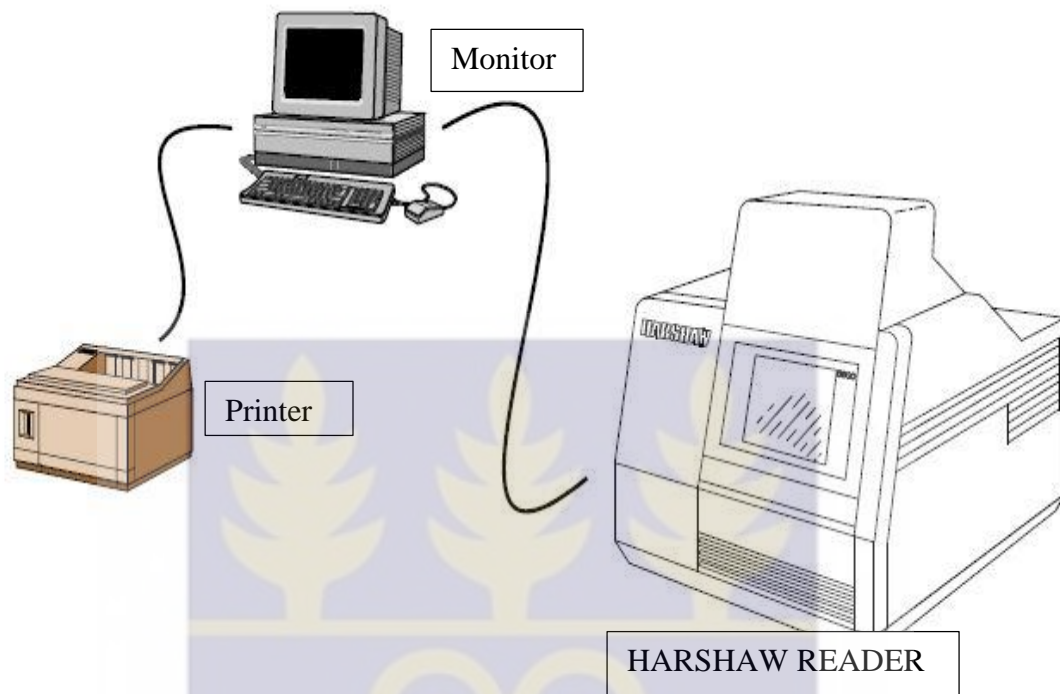


Figure 3.2: TLD 6600 workstation

### 3.1.4 Dose rate meter

This is a portable radiation detection and measurement instrument used to check personnel, equipment and facilities for radioactive contamination, or to measure external or ambient ionizing radiation fields (to evaluate the direct exposure hazard). The instruments are designed to be handheld, are battery powered and of low mass to allow easy manipulation. Other features include an easily readable display, in counts or radiation dose, and an audible indication of the count rate. These features, among others, makes this detector one of the most used detectors.

The survey meter used in this work is a Rad-eye G10 gamma survey meter (Fig 3.3) specifically designed for gamma survey from background up to personal safety levels and

used by first responders, Nuclear power industry, radiography and radiation protection purposes. The Rad-eye G-10 measures deep dose rate measurements. It was manufactured in Germany by Thermo electron Scientific Inc.



Figure 3.3: Rad eye G-10 gamma survey meter

Table 3.1 Technical specifications of the Rad-eye G10 survey meter

Detector	Energy compensated GM tube
Measuring range	0.5 $\mu$ Sv/h -100 mSv/h
Energy range	50keV- 3MeV

Survey meters have been used widely for workplace monitoring, including the successful assessment of adequate worker and public protection and safety.

### 3.1.5 Theratron Equinox 100 Co-60 teletherapy machine

The Theratron equinox 100 Co-60 teletherapy machine was installed in 2014 to replace an older GWGP-80 cobalt-60 teletherapy machine which was installed in 2002.

Table 3.2: Technical specifications of the Theratron Equinox 100 teletherapy equipment

Model number	2117
source	Co-60
Source half life	5.27 years
Activity(measured as at February 22,2014)	370.4 (TBq)
Dose rate(measured as at February 22,2014)	184.63 cGy/min

## 3.2 METHODS

### 3.2.1 Occupational dose assessment

TLDs consisting of lithium fluoride doped with titanium and magnesium were placed at some selected points around the facility where occupationally exposed workers were likely to be on a regular day at work for a period of 31 days. The selected points included seating places and working tables in the control console room and the simulation room to measure the deep dose that may arise from external exposure.

The results if analysed would be extrapolated to represent the mean annual effective doses and would then be compared to dose records of occupationally exposed workers and both sets of data assessed. A total of twenty (20) workers, including radiotherapists and other staff deemed to warrant assessment due to work schedules and frequency of visits to the

controlled areas on a regular working day. The purpose of this is to investigate if there is any reasonable distinction between the existing records and records measured by the TLDs used in this work.

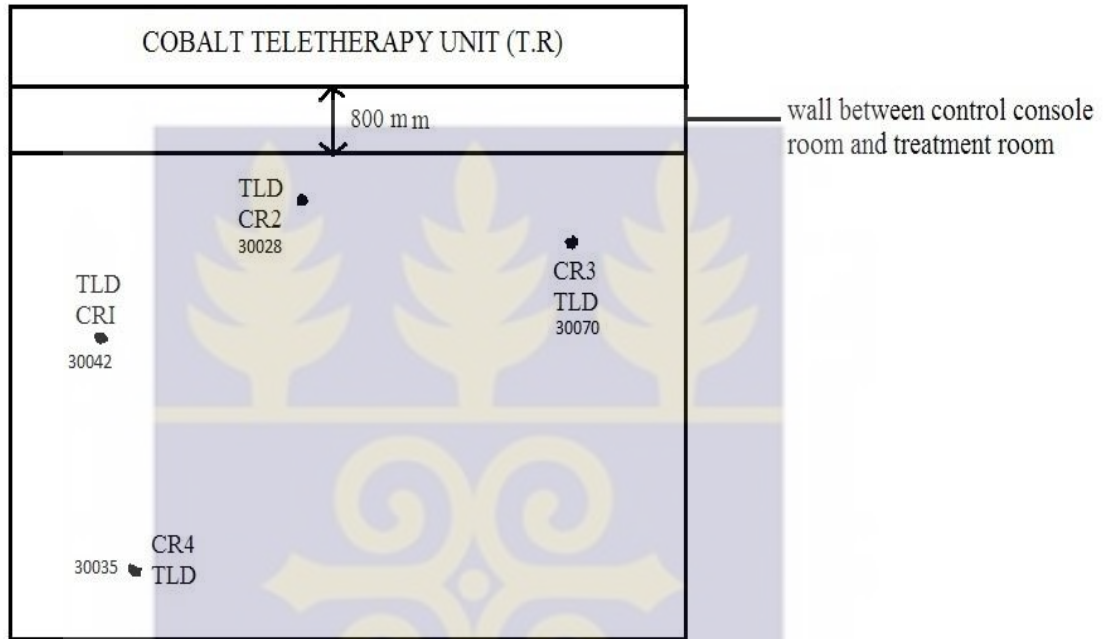
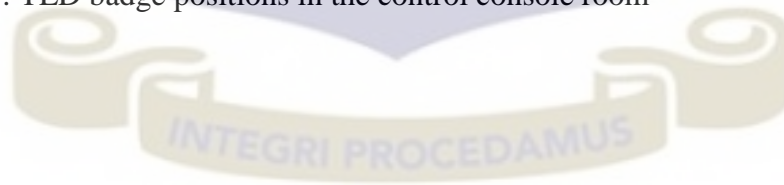


Figure 3.4: TLD badge positions in the control console room



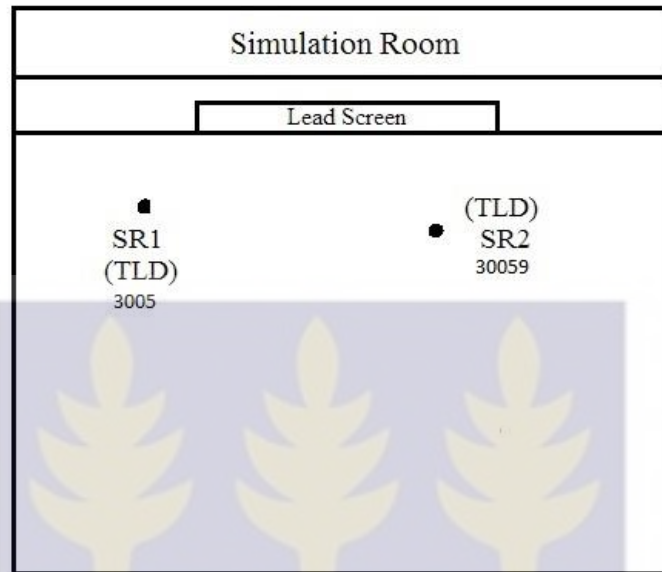


Figure 3.5: TLD badge positions in the simulation room

Assessment of dose distribution to workers and the public is a very important aspect of radiation protection and is indicative of the general safety practices of any particular country. The deep dose equivalent,  $H_p(10)$  is the surrogate for effective dose and as such will be the quantity of major concern of this work. TLD results and occupationally exposed workers personal dose records for a period of 5 years (February 2010-April 2016) will be assessed by calculating the following quantities;

### 3.2.2 The mean annual effective dose(E)

Dose limits have been set for the occupationally exposed worker for all justified practices and this is interpreted mainly in effective doses(E) .

Effective dose calculations was determined from occupational doses from the teletherapy department from (2010-2016) using the following expressions;

The effective dose is defined as a summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor:

$$E = \sum_T W_T H_T \quad (3.1)$$

Where  $H_T$  is the equivalent dose in tissue T and  $W_T$  is the tissue weighting factor for tissue.

$$H_T = \sum_R W_R D_{T,R} \quad (3.2)$$

Where  $W_R$  is the radiation weighting factor for radiation R and  $D_{T,R}$  is the average absorbed dose in the organ or tissue T. The unit of effective dose is J/kg, with a special name Sievert (Sv)

$$\text{The mean effective dose, } E_m = \frac{\sum W_T H_T}{N} \quad (3.3)$$

N = number of measurement cycles in a year.

### 3.2.3 Estimation of annual Collective dose(S)

The annual collective effective dose, S, is given by

$$S = \sum_{j=1}^r N_j E_{ji} \quad (3.4)$$

Where  $E_{ji}$  is the annual effective dose calculated for the  $j^{\text{th}}$  reading of the  $i^{\text{th}}$  worker and N is the number of workers in a facility and r is the number of measurement cycles in a year.

### 3.2.4 Workplace monitoring

Soon after Roentgen discovered X-rays in 1895 and Becquerel discovered natural radioactivity in 1896 it became apparent that medical uses of ionizing radiation was not only useful for the diagnosis and treatment of disease but was also harmful to human tissue(Podgorsak, 2005) through:

- Direct clinical effects at very high doses.
- Potential for delayed effects such as induction of malignancies.
- Potential for genetic effects

The harmful effects of X-rays that were detected in early radiation workers due to overexposure to radiation has led to fear among the public and workers including radiotherapists and other occupationally exposed workers. This notion even though not scientifically backed with any kind of empirical data can lead to apprehension among radiotherapists and other workers during treatment and this could lead to human errors which may be detrimental to the patient.

Even though safety assessments were conducted prior to the commissioning of the facility in 2014, the source in its storage position still undergoes some decay and possible gamma radiation leakage. The radiation from the source is also scattered by materials in its path of travel including the collimator, tray, block, patient, etc. and scattered photons have energies closer to that of the incident beam, these arguments suggests that there is a need to regularly monitor several locations in the treatment room during beam off positions as well as several points in the control console room and the controlled areas during beam on positions and compare the results to the approved limits set by the regulatory authority and other acceptable dose limits to protect occupationally exposed workers.

### **3.2.5 Dose rate measurement points**

The dose rate layout and points were selected and measured with the aid of a measuring tape.

A similar investigation was conducted at the facility by (Opoku S.Y and Asare-Sawiri, 2012) on the older GWGP cobalt -60 facility and information about the layout and selection of reference points formed the basis for this work.

### 3.2.6 Treatment room

The reference point from where measurements were taken in the treatment room was the centre of the collimator and measurements were taken at different distances in the beam off positions.

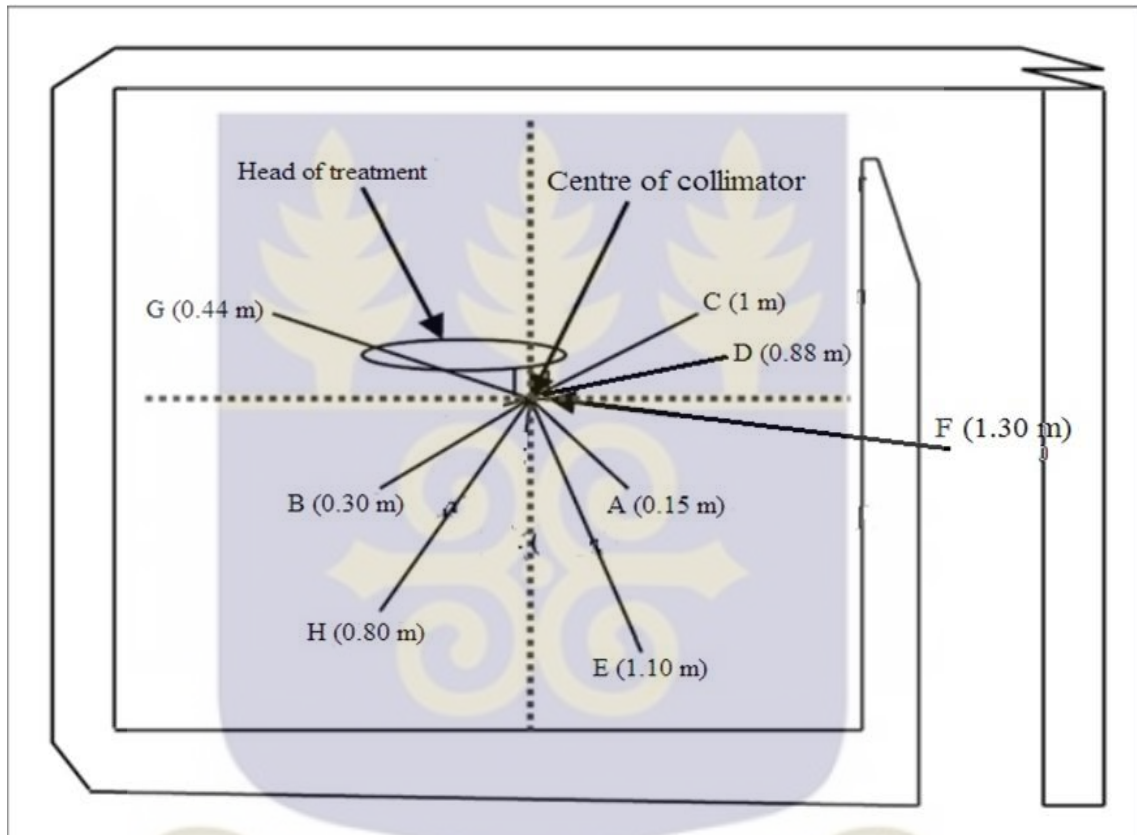


Figure 3.6: Measurement points in the treatment room

### 3.2.7 Control console room

The centre of the door to the maze and door to the control console room were the reference points used for the measurements at the control console room and other parts of the

controlled area. These locations are positions where the radiation therapists are usually found while in the working area.(Opoku and Asare-Sawiri, 2012).

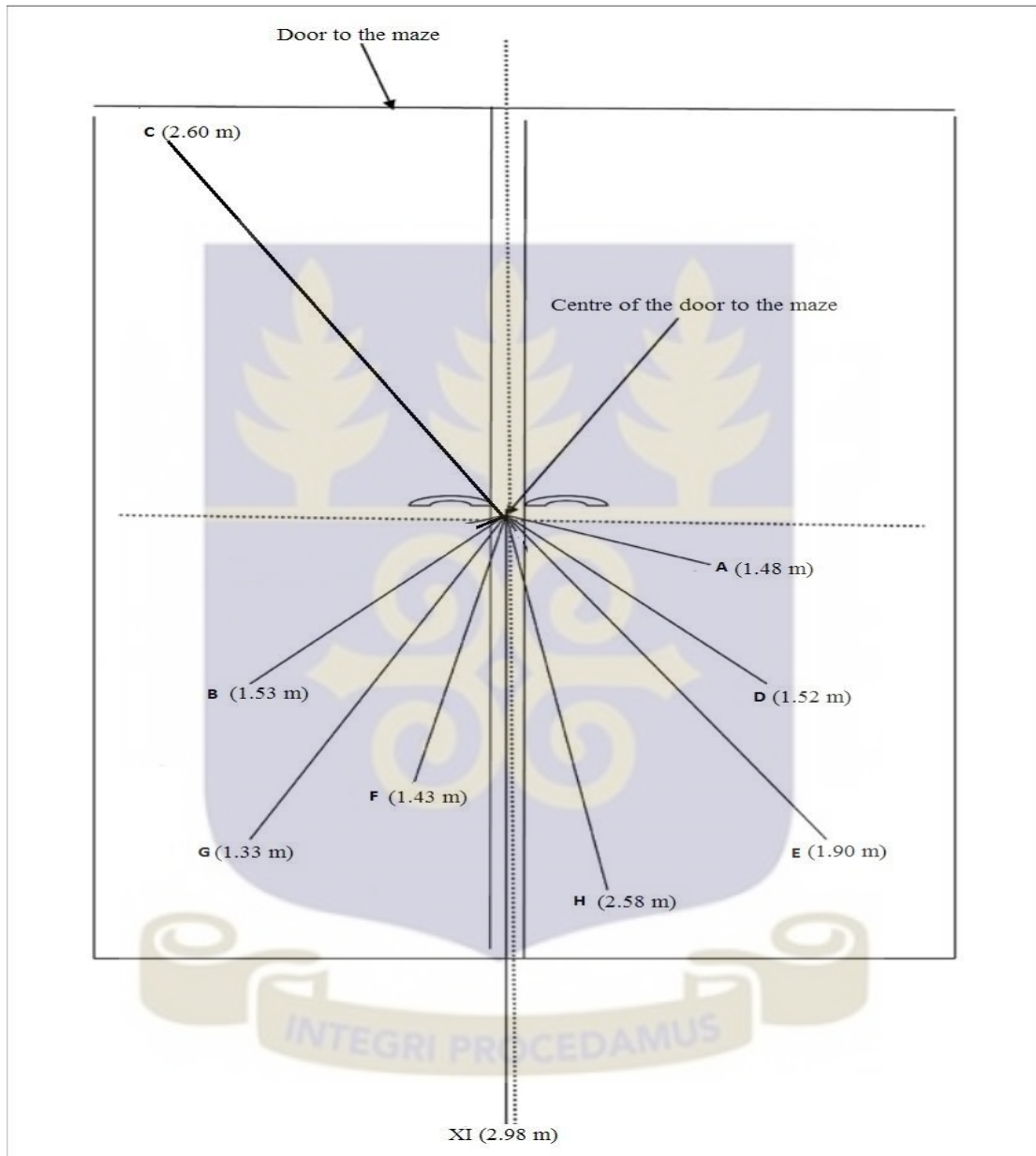


Figure 3.7: Measurement points in the controlled area

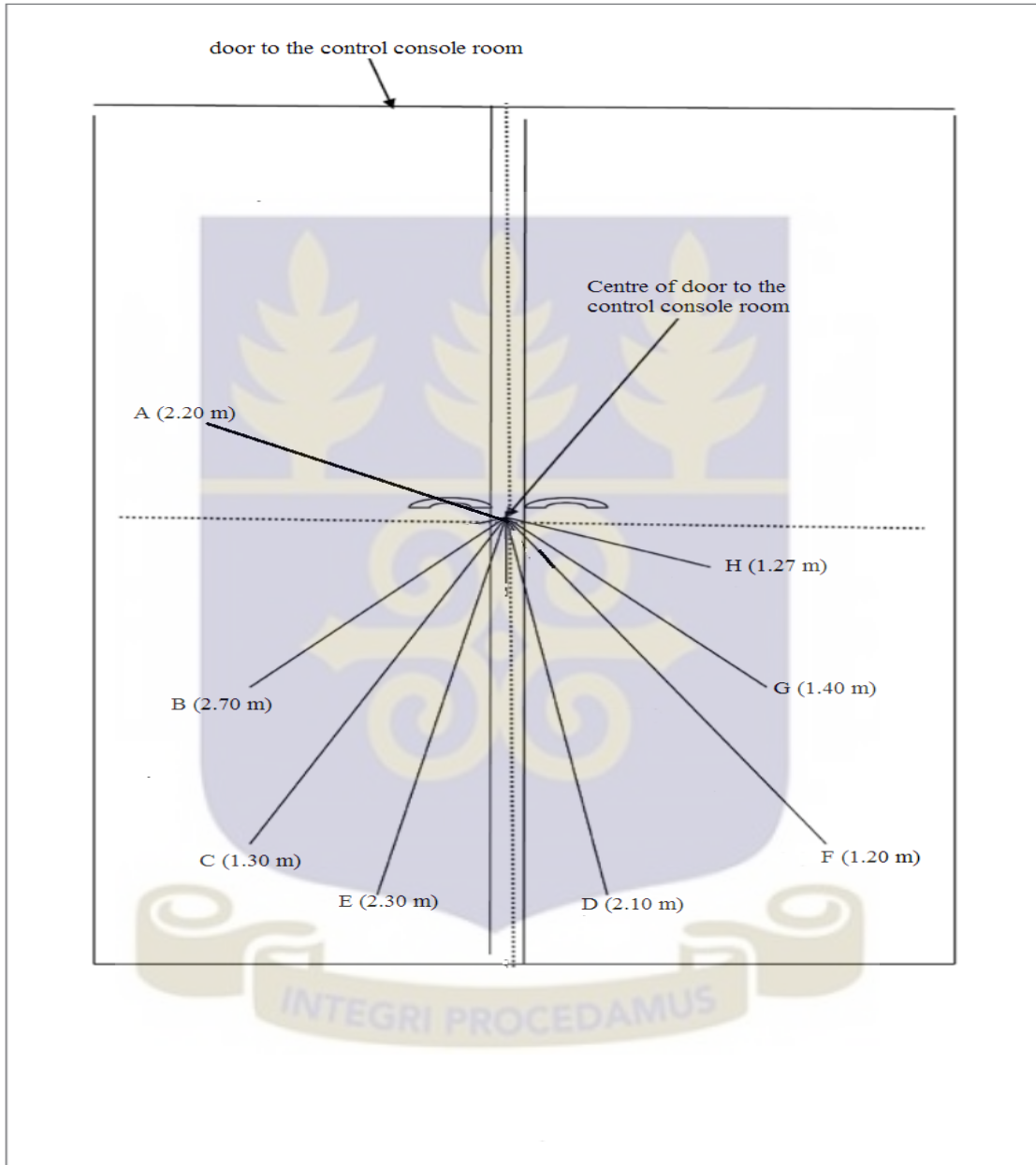


Figure 3.8: Measurement points in the control console room

### **3.3 RISK ESTIMATION**

Radiological protection has always been grounded in the latest understanding of the biological effects induced by exposure to radiation. In considering stochastic effects, though, the focus is primarily on cancers, hereditary disorders are nowadays also taken into account. The 2007 recommendations of the International Commission on Radiological Protection (ICRP) retains its fundamental hypothesis for the induction of stochastic effects of linearity of dose and effect without threshold and a dose and dose-rate effectiveness factor (DDREF) of 2 to derive nominal risk coefficients for low doses and low dose rates of exposures.

The ICRP notes that for the purposes of radiological protection, it is scientifically plausible to assume that the incidence of cancer or hereditary disorders will rise in direct proportion to an increase in the equivalent dose in the relevant organs and tissues, below about 100 mSv. The ICRP also considered issues such as cellular adaptive responses, genomic instability and bystander signalling but notes that ‘since the estimation of nominal cancer risk coefficients is based upon direct human epidemiological data, any contribution from these biological mechanisms would be included in that estimate’.

#### **3.3.1 Nominal Risk Coefficients**

Nominal risk coefficients are dependent on sex and age at exposure to estimate the lifetime risk population. Cancer risks have not changed much since 1990. The ICRP also continues to consider that a dose and dose-rate effectiveness factor (DDREF) of 2 is still appropriate in order to derive nominal risk coefficients for low doses and low dose rates. These assumptions were considered compatible with exposure situation of those workers exposed

in Ghana. The risk coefficient values given in table 1 from 1990 and 2007 ICRP recommendations were adopted for the risk estimations.

**Table 3.1: Detriment-adjusted nominal risk coefficients for stochastic effects after exposure to radiation at low dose rate ( $10^{-2} \text{ Sv}^{-1}$ )**

Exposed population	Cancer		Heritable effects		Total detriment	
	2007	1990	2007	1990	2007	1990
<b>Whole</b>	5.5	6.0	0.2	1.3	5.7	7.3
<b>Adult</b>	4.1	4.8	0.1	0.8	4.2	5.6

The 2007 values were based upon data on cancer incidence weighted for lethality and life impairment, whereas the 1990 values were based upon the fatal cancer risk weighted for non-fatal cancer, relative years lost for cancer and life impairment for non-fatal cancer. The combined detriment from stochastic effects (somatic and hereditary) has remained unchanged at around  $5\% \text{ Sv}^{-1}$ . The 1990 and 2007 ICRP recommendations still retain nominal representation for risk estimation.

### 3.3.2 Whole-Body Cancer Risk Estimation

The cancer risk estimation for occupationally exposed adult workers can be expressed mathematically as:

$$\text{Annual Cancer Risk, } AR_C = E_m * \text{Nominal Risk coefficient for adult} \quad (3.5)$$

Where  $E_m$  is the mean annual effective dose in Sievert ( $\text{Sv}$ )

Using ICRP 2007 recommendations,

$$\text{Annual cancer risk, } AR_C(2007) = E_m(Sv) * 4.1 \times 10^{-2} Sv^{-1} \quad (3.6)$$

Using ICRP 1990 recommendations,

$$\text{Annual cancer risk, } AR_C(1990) = E_m(Sv) * 4.8 \times 10^{-2} Sv^{-1} \quad (3.7)$$

$$\text{Lifetime cancer risk, } LRC = \text{Annual cancer risk} * 50 \quad (3.8)$$

The value 50 represents the commitment period of 50 years which is the period of possible dose accumulation over a lifetime.

### 3.3.3 Heritable Effects Risk Estimation

The heritable effects risks estimation for occupationally exposed adult workers is expressed mathematically as:

$$\text{Annual heritable effects risk} = E_m * \text{Nominal risk coefficient} \quad (3.9)$$

Where  $E_m$  is the mean annual effective dose in Sievert (Sv)

Using ICRP 2007 recommendations,

$$\text{Annual heritable effects risk, } AR_H(2007) = E_m(Sv) * 0.1 \times 10^{-2} Sv^{-1} \quad (3.10)$$

Using ICRP 1990 recommendations,

$$\text{Annual heritable effects risk, } AR_H(1990) = E_m(Sv) * 0.8 \times 10^{-2} Sv^{-1} \quad (3.11)$$

$$\text{Lifetime heritable effects risk, } LR_H = \text{Annual heritable effects risk} * 50 \quad (3.12)$$

### 3.3.4 Total Detriment Risk Estimation

The total detriment risk is a summation of the cancer and heritable effects risks which are the stochastic effects observed after exposure to radiation.

This can be expressed mathematically as:

$$\text{Annual total detriment risk} = E_m(Sv) * \text{Total detriment Risk coefficient} \quad (3.13)$$

Where  $E_m$  is the mean annual effective dose in Sievert ( $Sv$ )

Using ICRP 2007 recommendations,

$$\text{Annual total detriment risk, } AR_T(2007) = E_m(Sv) * 4.2 \times 10^{-2} Sv^{-1} \quad (3.14)$$

Using ICRP 1990 recommendations,

$$\text{Annual total detriment risk, } AR_T(1990) = E_m(Sv) * 5.6 \times 10^{-2} Sv^{-1} \quad (3.15)$$

Therefore,

$$\text{Lifetime total detriment risk, } LR_T = \text{Annual total detriment risk} * 50 \quad (3.16)$$

### 3.4 DETERMINATION OF AMBIENT DOSE EQUIVALENT

Ambient dose equivalent  $H^*(10)$  is an operational quantity used to demonstrate compliance with dose. Such quantities are defined by the International Commission on Radiological Protection (ICRP) in order to relate the radiation risk to a single dose quantity which takes account of the human as a receptor, of the different radiation sensitivities of various organs and tissues as well as the different radiation qualities. (Schuhmacher, H.1995)

For the purposes of routine radiation protection, it is desirable to characterize the potential irradiation of individuals in terms of a single dose equivalent quantity that would exist in a phantom approximating the human body. The phantom selected is the so-called ICRU sphere for which it is made up of made up of 30-cm-diameter tissue-equivalent plastics with a density of  $1 \text{ g/cm}^3$  and a mass composition of 76.2 % oxygen, 11.1 % carbon, 10.1 % hydrogen and 2.6 % nitrogen.

The “ambient dose equivalent”,  $H^*(d)$ , at a point in a radiation field is the dose equivalent that would be produced by the corresponding expanded and aligned field at a depth  $d$  in the ICRU sphere, on the radius opposing the direction of the aligned field. In an expanded field the fluence, its directional and energy distribution have the same values throughout the volume of interest as in the actual field at the point of reference. An expanded and aligned radiation field requires additionally that the fluence is unidirectional. For strongly penetrating radiations a reference depth,  $d$ , of 10 mm was recommended.

For measurements using a radiation measuring instrument, the dose is converted into ambient dose equivalent using the equation 3.17

Doses measured using the dose rate meter were converted to ambient dose equivalent using the equation below.

$$H^*(10) = N_H^* \cdot k^*(R) \cdot D \quad (3.17)$$

Where,  $N_H^*$  is the calibration factor of 1.12 for the thermo electron dose rate metre

$D$ , is the dose measured with the radiation monitoring instrument

$k^*(R)$  is the correction factor



## CHAPTER FOUR

### 4 RESULTS AND DISCUSSION

This section presents the results obtained from the research work and discussion of results. This includes data on the effective doses, collective doses and risk estimates due to external exposure to occupationally exposed workers in the teletherapy department using the TLD measurements from dose records as well as TLDs placed at various points at the facility. Data on dose rates and ambient dose equivalents measured at different distances from the collimator of the teletherapy facility using a gamma survey meter were also discussed.

#### 4.1 MEAN EFFECTIVE DOSE DISTRIBUTION FROM TLDS

The mean annual effective doses were computed from two different data sets, the first set of data from the TLDs that were placed at various points where workers especially radiotherapists are usually present on a typical work day in the simulation room as well as the control console room. Doses ranged from 0.8mSv - 0.37mSv, which shows that doses received from occupationally exposed workers at the facility are well below the acceptable dose limit of 5mSv/a. Mean dose of 0.2mSv also demonstrates good compliance with the set dose limits. TLDs numbered two (0.36mSv) and six (0.29mSv) were placed very close to the working desk of the control console and the simulation rooms respectively. and they recorded the highest doses just behind the walls between the room housing the teletherapy equipment and the console area in both rooms. This is shown in fig 4.1below

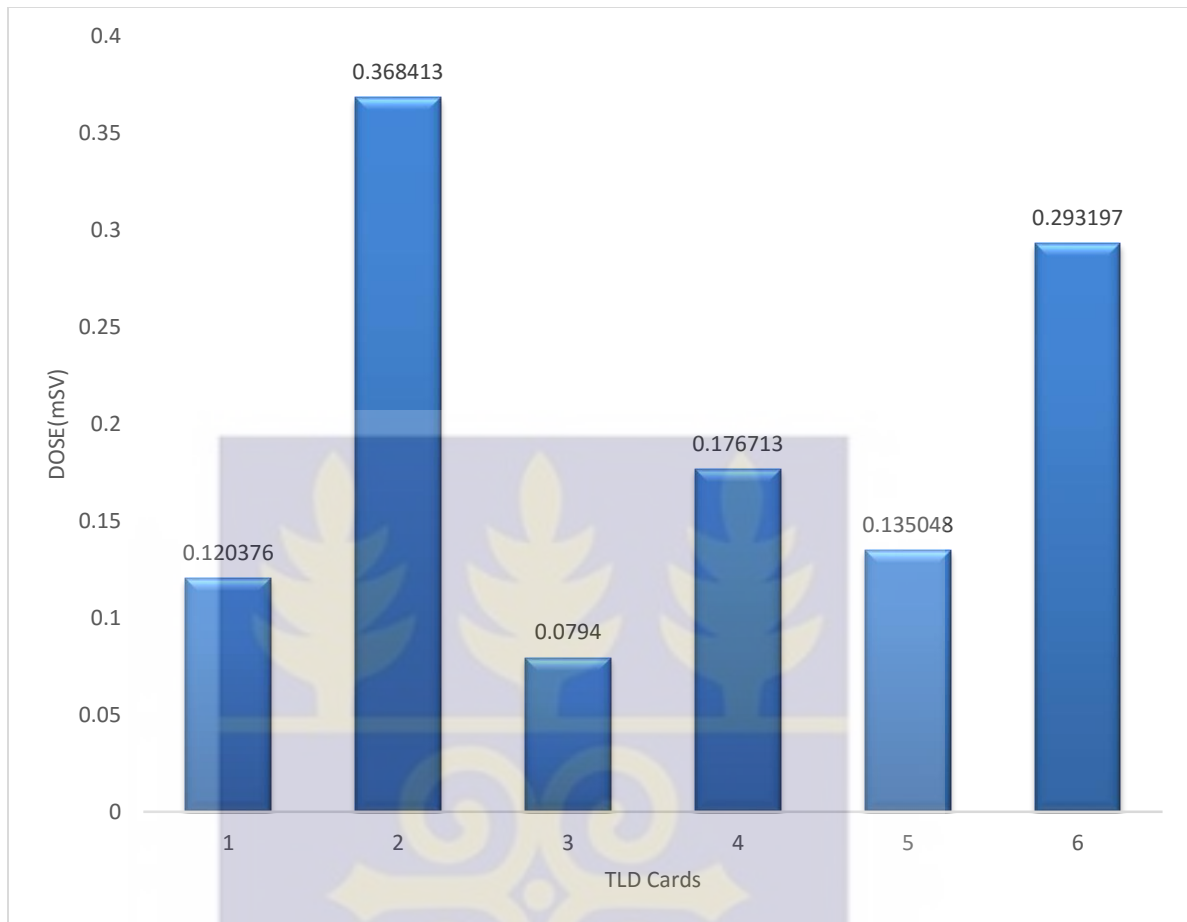


Figure 4.1: Mean annual effective doses from TLD cards

#### 4.2 MEAN ANNUAL EFFECTIVE DOSE FROM DOSE RECORDS

This was computed from available dose records for all occupationally exposed workers at the teletherapy department of the Korle-Bu Teaching Hospital as shown from fig 4.2 - fig 4.9. During this period, there has been a source change in 2012 as well as the commissioning of a new teletherapy machine to replace an older one in 2014. The data set used for this research was from 2010-2016 and covers all three recent most important changes relating to source of exposure and equipment. Minimum mean values of dose

recorded for the period was 0.40mSv while the data set showed a maximum mean values recorded for the period was 0.60mSv.

The minimum dose recorded in the year was in 2014 and this shows that the safety assessment prior to commissioning of the new Equinox Theratron 100 Co-60 equipment in that same year was properly done and optimization as well as shielding effectiveness of the facility was very high.

It is however a worrying trend that accumulated effective doses for 2016 were the highest and this calls for some investigative level of action to be taken even though the doses received was well below the prescribed dose limits.

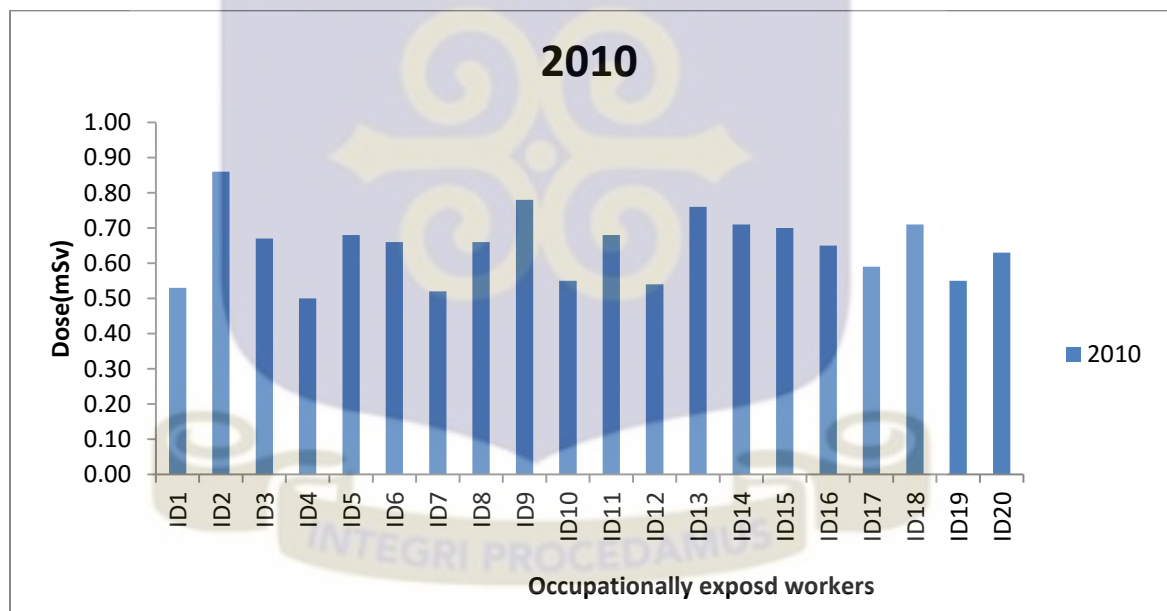


Figure 4.2: Mean annual effective dose of workers at the teletherapy department in 2010

Dose records from 2010 from showed effective doses ranging from 0.5mSv-0.86mSv as shown in fig 4.2 above.

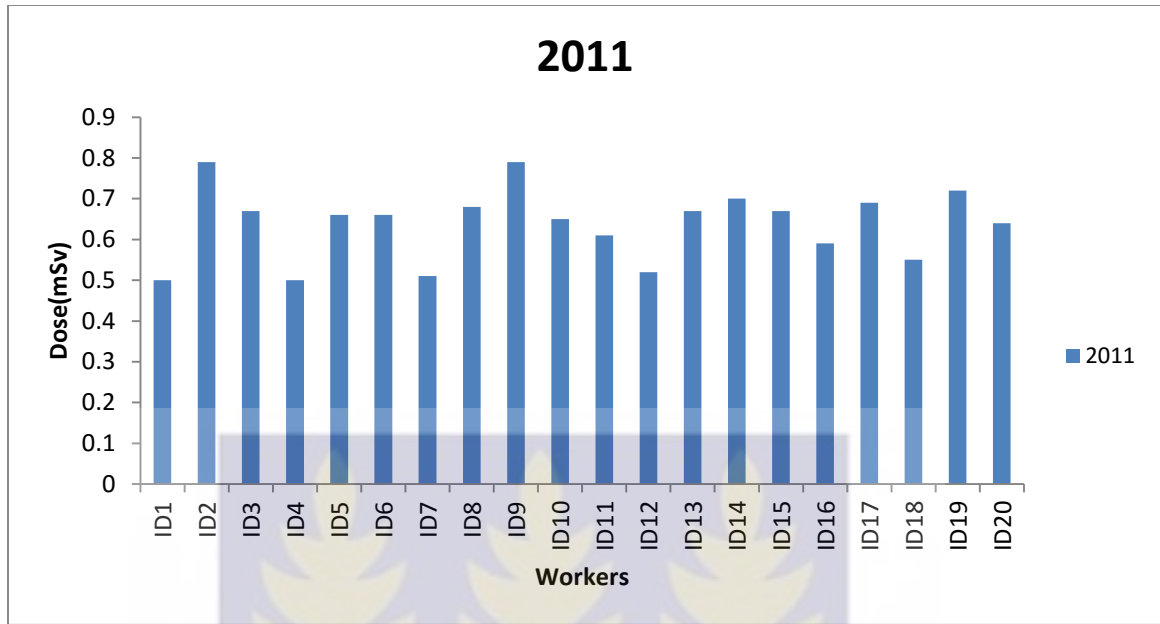


Figure 4.3: Mean annual effective dose of workers at the teletherapy department in 2011

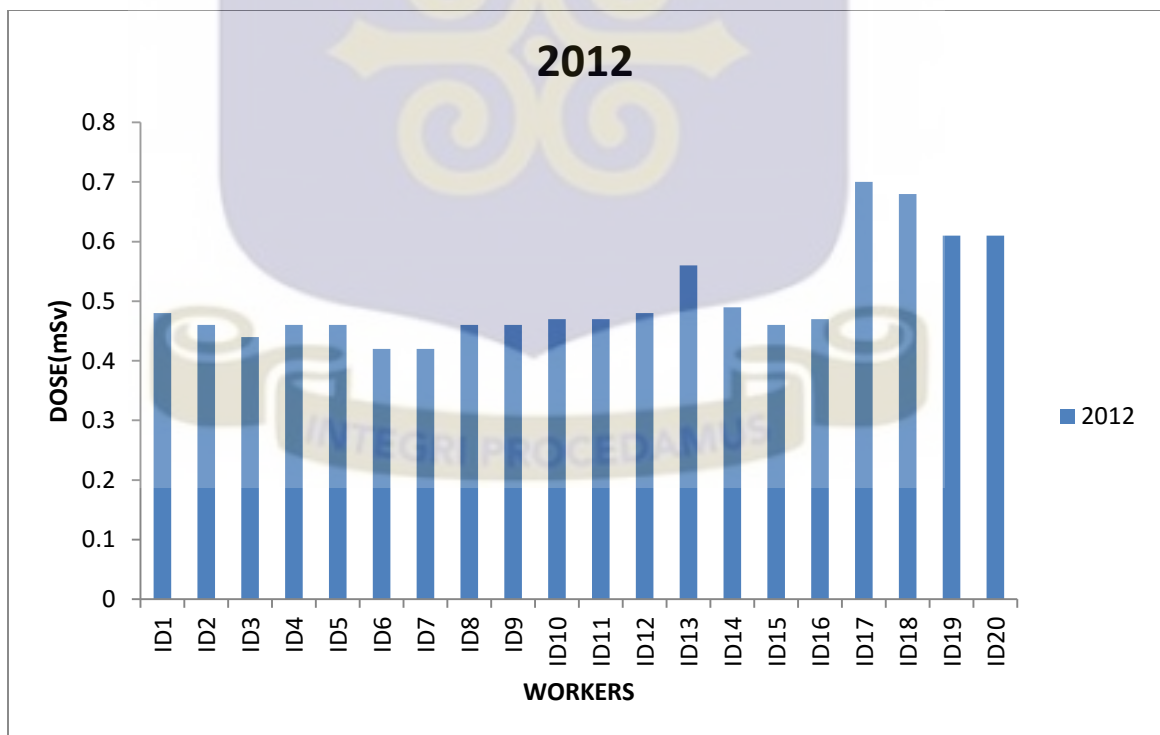


Figure 4.4: Mean annual effective dose of workers at the teletherapy department in 2012

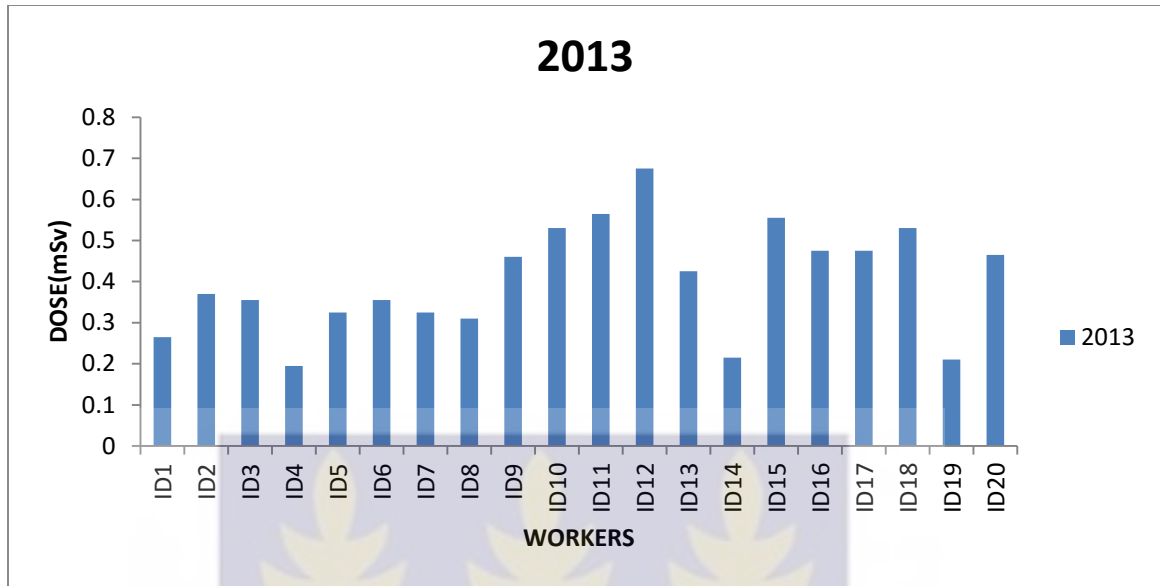


Figure 4.5: Mean annual effective dose of workers at the teletherapy department in 2013

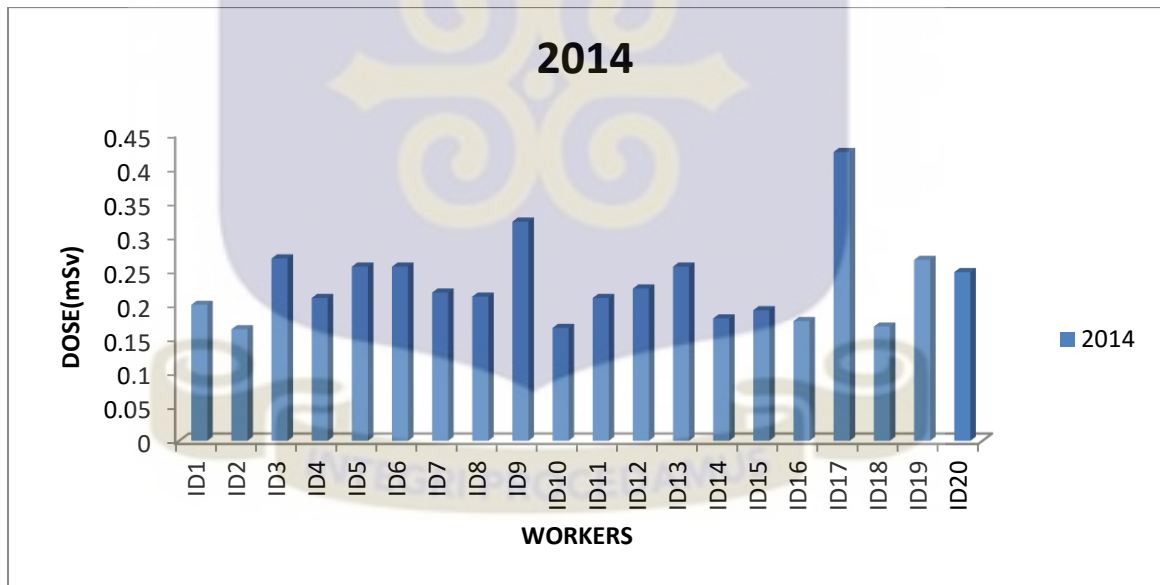


Figure 4.6: Mean annual effective dose of workers at the teletherapy department in 2014

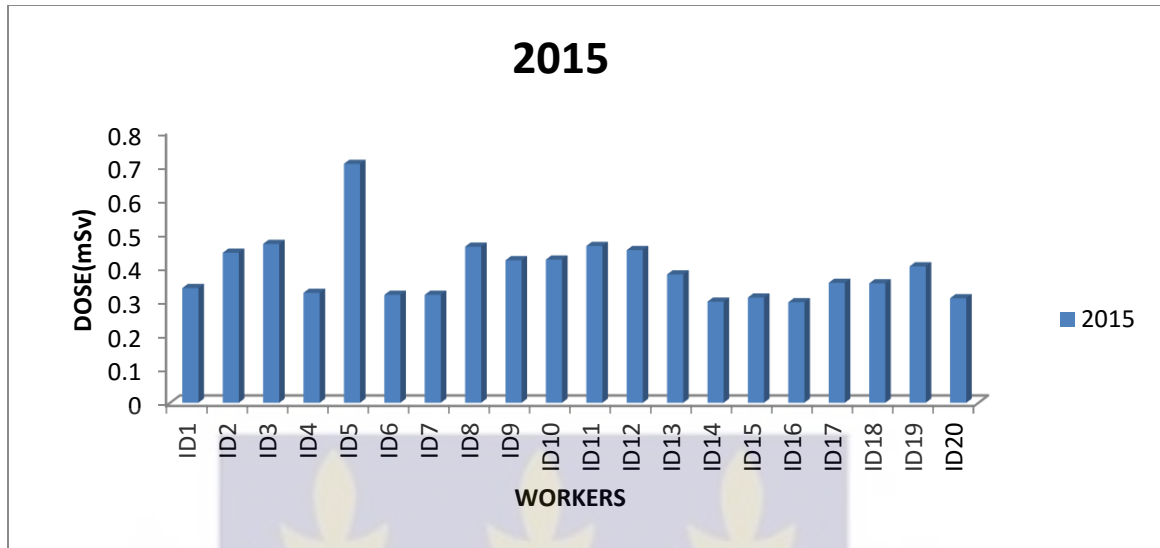


Figure 4.7: Mean annual effective dose of workers at the teletherapy department in 2015

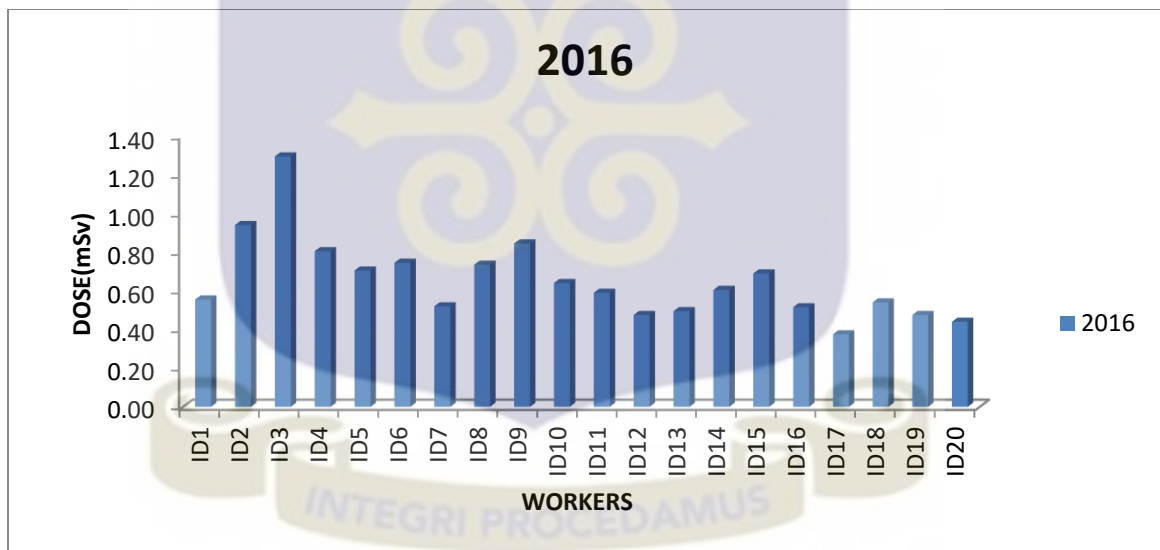


Figure 4.8: Mean annual effective dose of workers at the teletherapy department in 2016

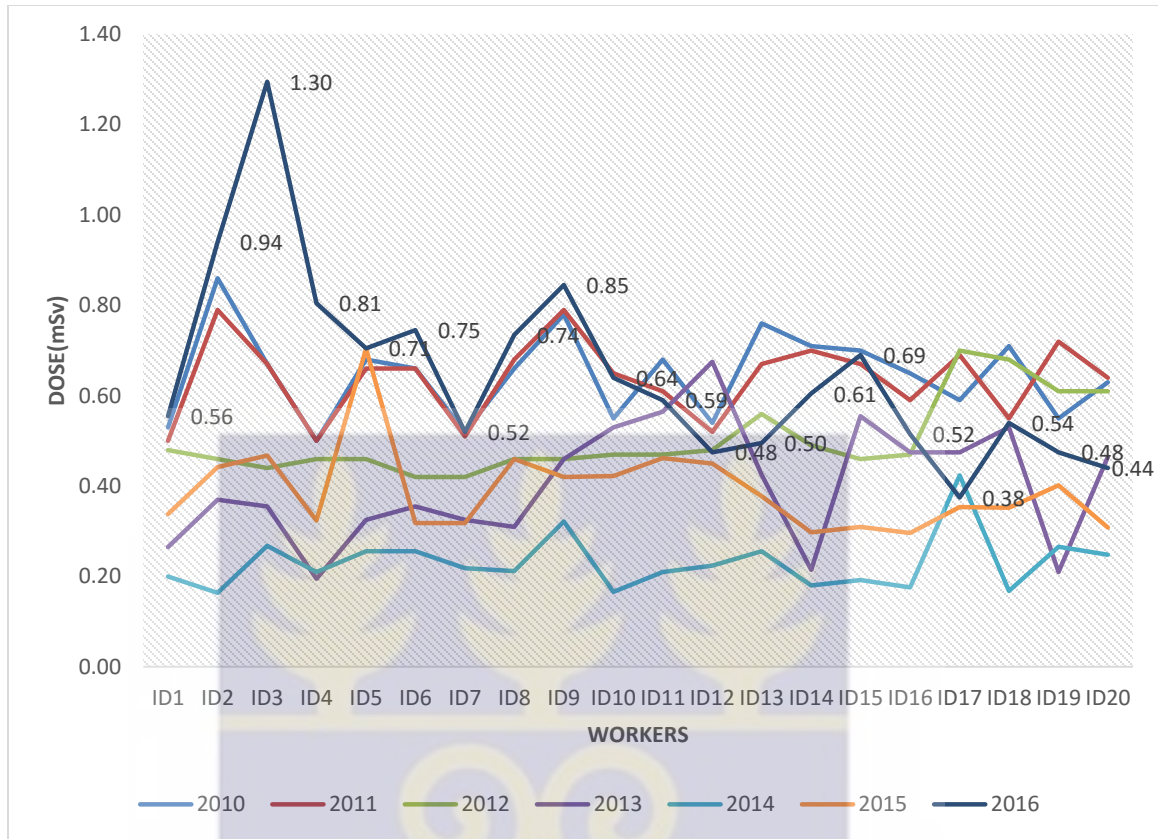


Figure 4.9: A graph showing the trend of effective doses received by occupationally exposed workers at the teletherapy facility at Korle-bu teaching hospital

Fig 4.9 shows the combined trend of doses received by all occupationally exposed workers between the periods 2010-2016. The least recorded mean annual effective dose received by a worker was in 2014 with a dose of 0.17mSv while the highest recorded mean effective dose was received in 2016 with 1.30mSv recorded. Doses dropped steadily from 2010-2014 with only 2012 experiencing some relatively high records of occupationally dose due to a faulty head that housed the radiation source which contributed leakage radiation at very high levels before beginning to increase from 2015. The mean values per year was  $0.50\text{mSv} \pm 0.17$  with minimum value for the period was 0.23mSv in 2014 and also recorded a maximum effective of 0.65mSv in 2010 and 2016. The year 2014 began the upward trend

in occupational radiation dose even though the equipment was newly installed in February, 2014. This could be accounted for due to the increase in workload from about 360 Gy/week to about 840 Gy/week as a result of the more automated function of the new teletherapy equipment.

### **4.3 RISK ASSESSMENT**

#### **4.3.1 Annual Cancer Risk Assessment (ICRP 1990 and 2007 Recommendations)**

The annual cancer risk was computed using the ICRP 60 and ICRP103 respectively for TLD cards placed at selected points in the working area of the teletherapy department and also computed from dose records of workers at the department for the periods from 2010-2016.

#### **4.3.2 Annual Cancer Risk assessment for TLDs (ICRP 1990 and 2007)**

This research work has indicated that dose records available are generally in agreement with the doses recorded from the TLDs that were used in this research and as a result, risk estimation was also estimated with the values obtained

The mean annual cancer risk recorded was  $9.39 \times 10^{-3} \pm 5.37 \times 10^{-3}$  and  $8.02 \times 10^{-3} \pm 4.59 \times 10^{-3}$  for the ICRP 1990 and 2007 risk models respectively.

The minimum cancer risk estimated was between  $3.81 \times 10^{-3}$  and  $1.77 \times 10^{-2}$  for the 1990 model and between  $3.26 \times 10^{-3}$  and  $1.51 \times 10^{-2}$  for the 2007 risk model. The minimum and maximum risk estimates were from TLD card number **30035** and **30028** respectively and

were both present in the control console room. Fig 4.10 and fig 4.11 shows the annual cancer risk using the ICRP 1990 and 2007 models respectively.

The total risk detriments according to the 1990 showed a mean value of

$1.09 \times 10^{-2} \pm 6.26 \times 10^{-3}$  with a minimum value of  $4.45 \times 10^{-3}$  and a maximum value of  $2.06 \times 10^{-2}$ .

The 2007 risk estimation model also shows a mean total detriment risk of

$8.21 \times 10^{-3} \pm 4.7 \times 10^{-3}$  with a minimum value of  $3.33 \times 10^{-3}$  and a maximum value of  $1.55 \times 10^{-2}$

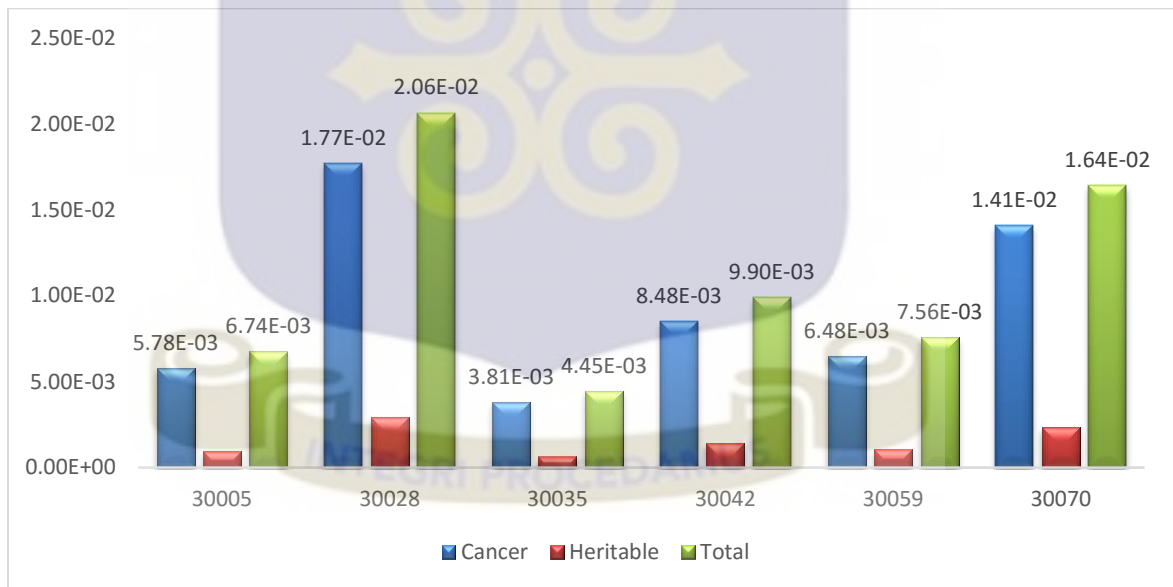


Figure 4.10: TLD cards annual risk using 1990 recommendations

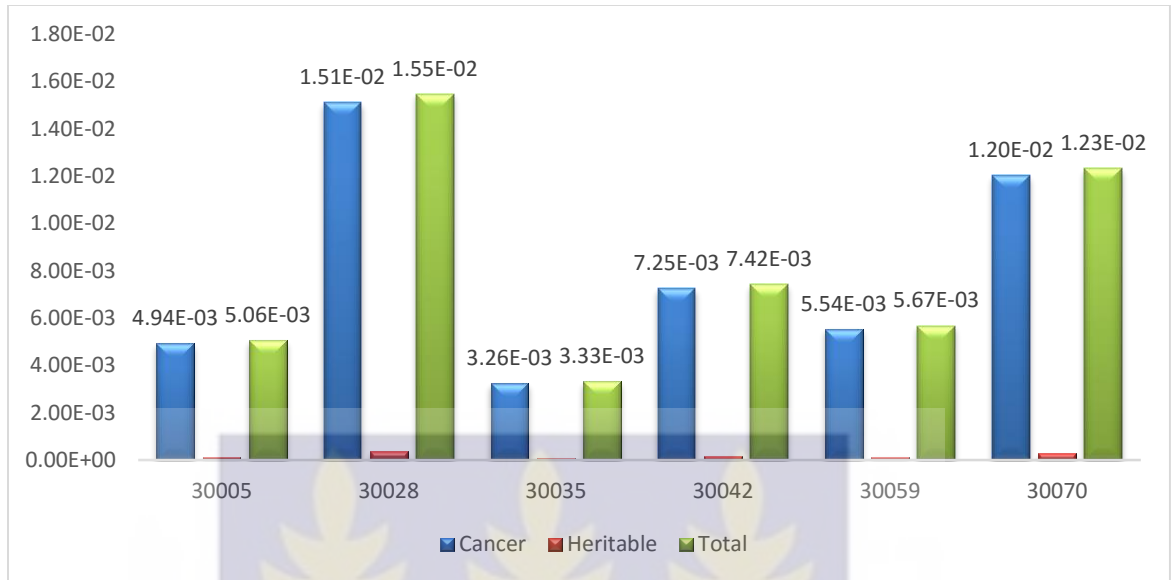


Figure 4.11: TLD cards annual risk using 2007 recommendations



### 4.3.3 Annual Cancer Risk assessment from dose records (ICRP 1990 and 2007)

The annual cancer risk was also computed for dose records from the period

(2010-2016) using the ICRP 1990 and 2007 models respectively.

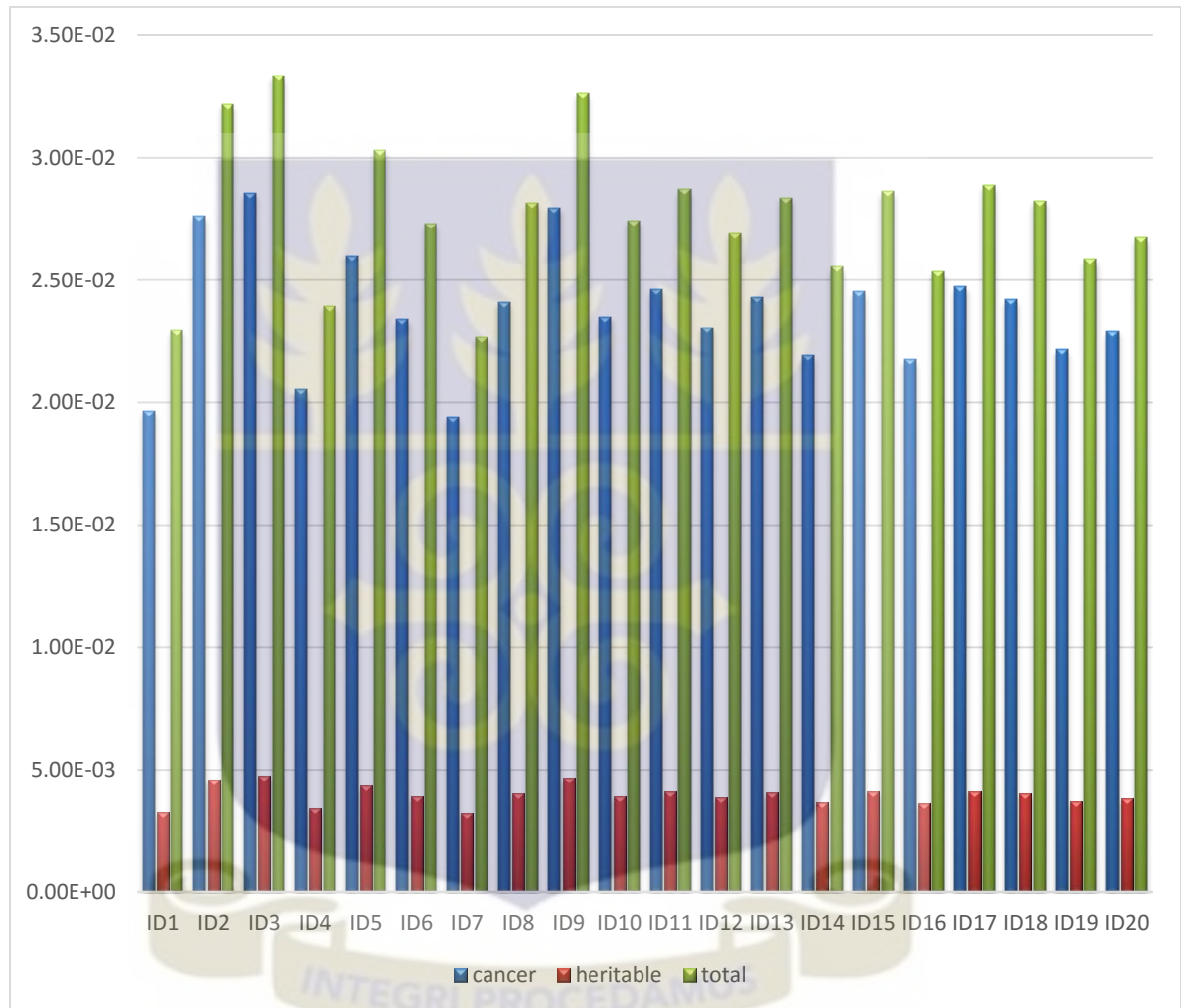


Figure 4.12: Mean annual cancer risk for workers (2010-2016) using ICRP 1990 recommendations

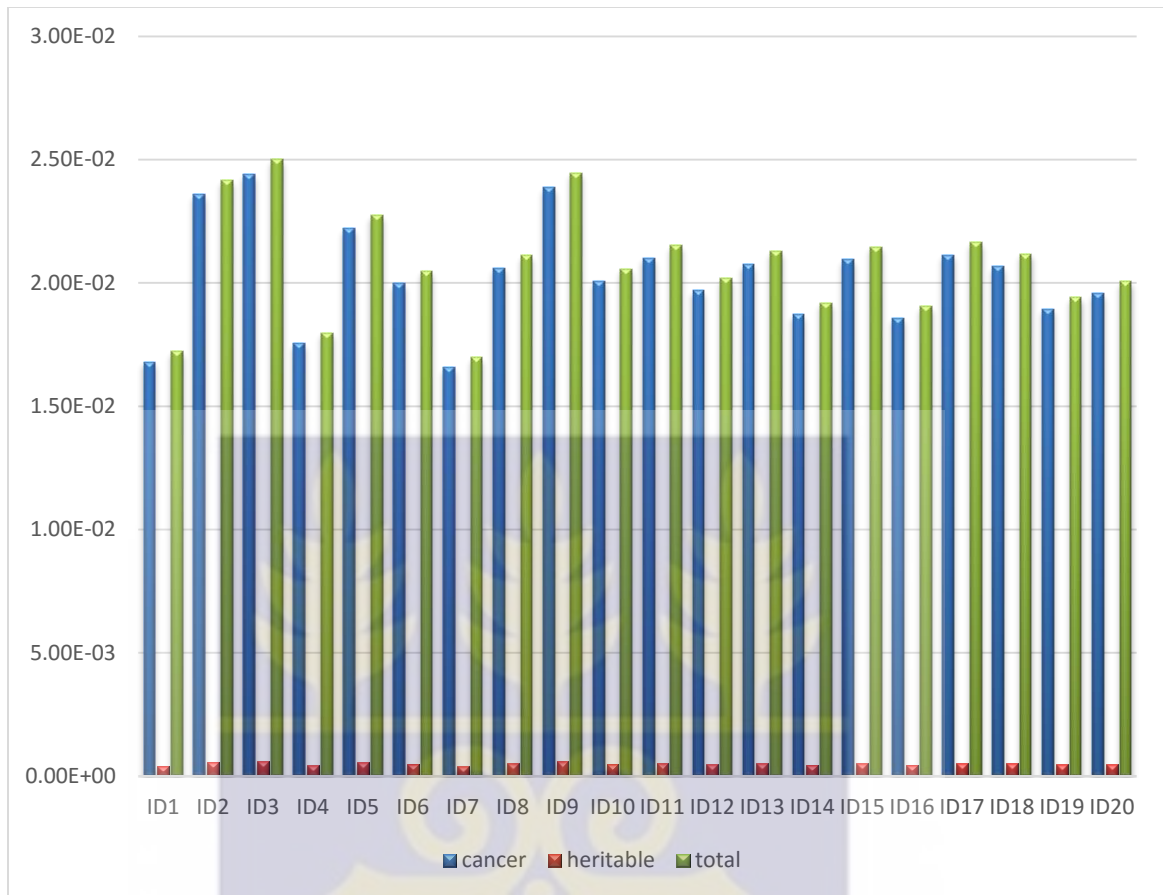


Figure 4.13: Mean annual cancer risk for workers (2010-2016) using ICRP 2007 recommendations



#### 4.4 ANNUAL LIFETIME CANCER RISK USING ICRP 1990 AND 2007 RECOMMENDATIONS

##### 4.4.1 Annual lifetime risk assessment for TLD

The annual lifetime risks for the doses recorded from the TLDs used in this research was also calculated using the ICRP 1990 and 2007 recommendations.

The mean annual lifetime risks estimated using the ICRP 1990 recommendations showed that, the probability of cancer induction during the period of survey was

$4.69 \times 10^{-1} \pm 2.68 \times 10^{-1}$  whiles the risks of cancer being transferred by an occupationally exposed worker through hereditary was  $7.82 \times 10^{-2} \pm 4.47 \times 10^{-2}$  while the total detriments was  $5.47 \times 10^{-1} \pm 3.13 \times 10^{-1}$ . This is shown graphically in Fig 4.14

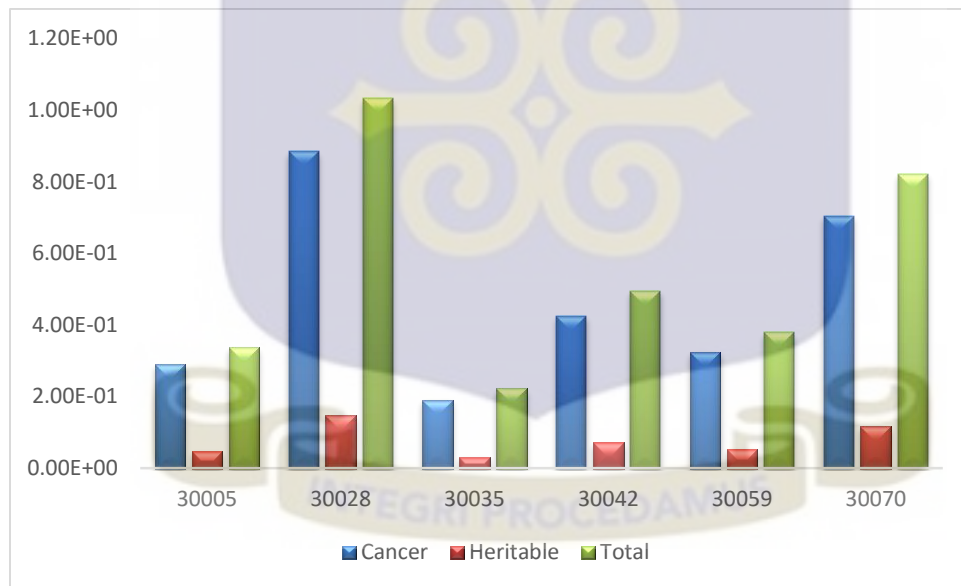


Figure 4.14: Mean annual lifetime risk for TLDs using ICRP 1990 Model

The mean annual lifetime risks was also computed using the ICRP 2007 recommendations and the risk associated with cancer induction of the radiation worker was  $4.01 \times 10^{-1} \pm 2.29 \times 10^{-1}$  while the heritable risk of cancer was

$9.78 \times 10^{-3} \pm 5.59 \times 10^{-3}$  and the total detriment risk was  $4.11 \times 10^{-1} \pm 2.35 \times 10^{-1}$  as shown in fig 4.15

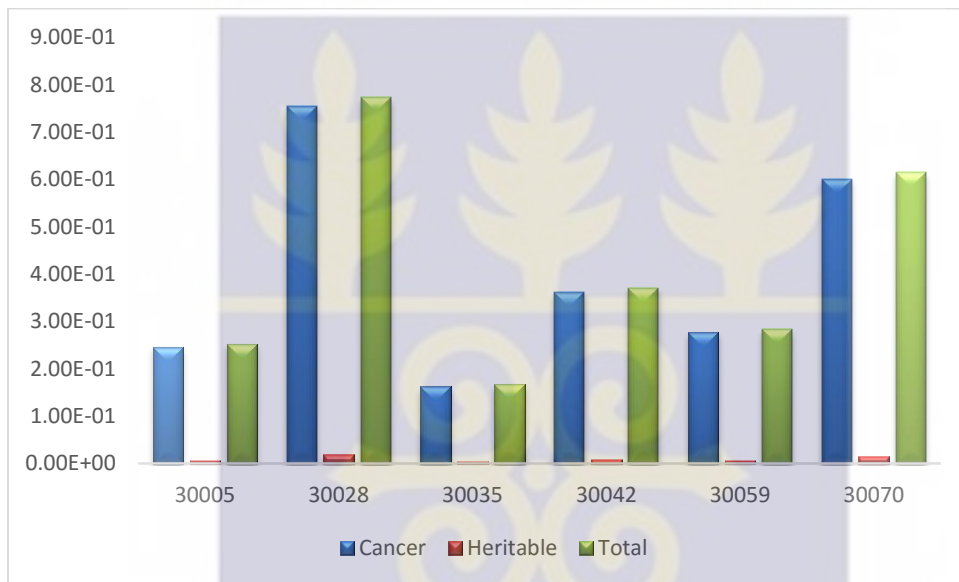


Figure 4.15: Mean annual lifetime risk for TLDs using ICRP 2007 Model



**4.4.2 Annual lifetime risk assessment from dose records (2010-2016)**

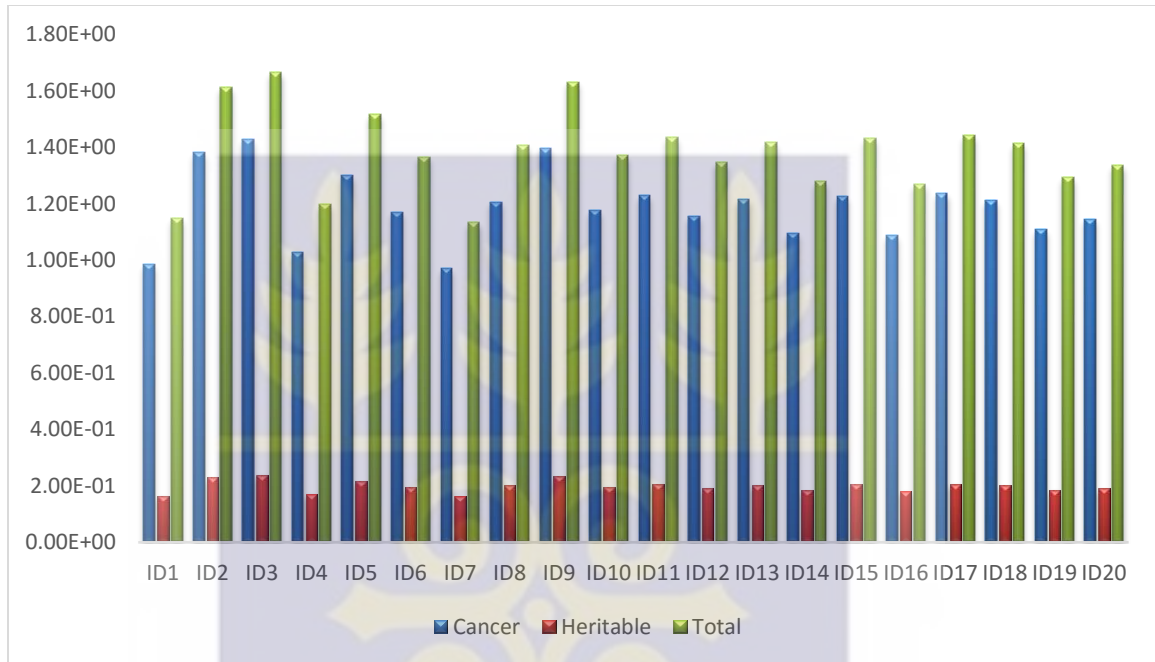


Figure 4.16: annual lifetime risk from dose records using 1990 recommendations



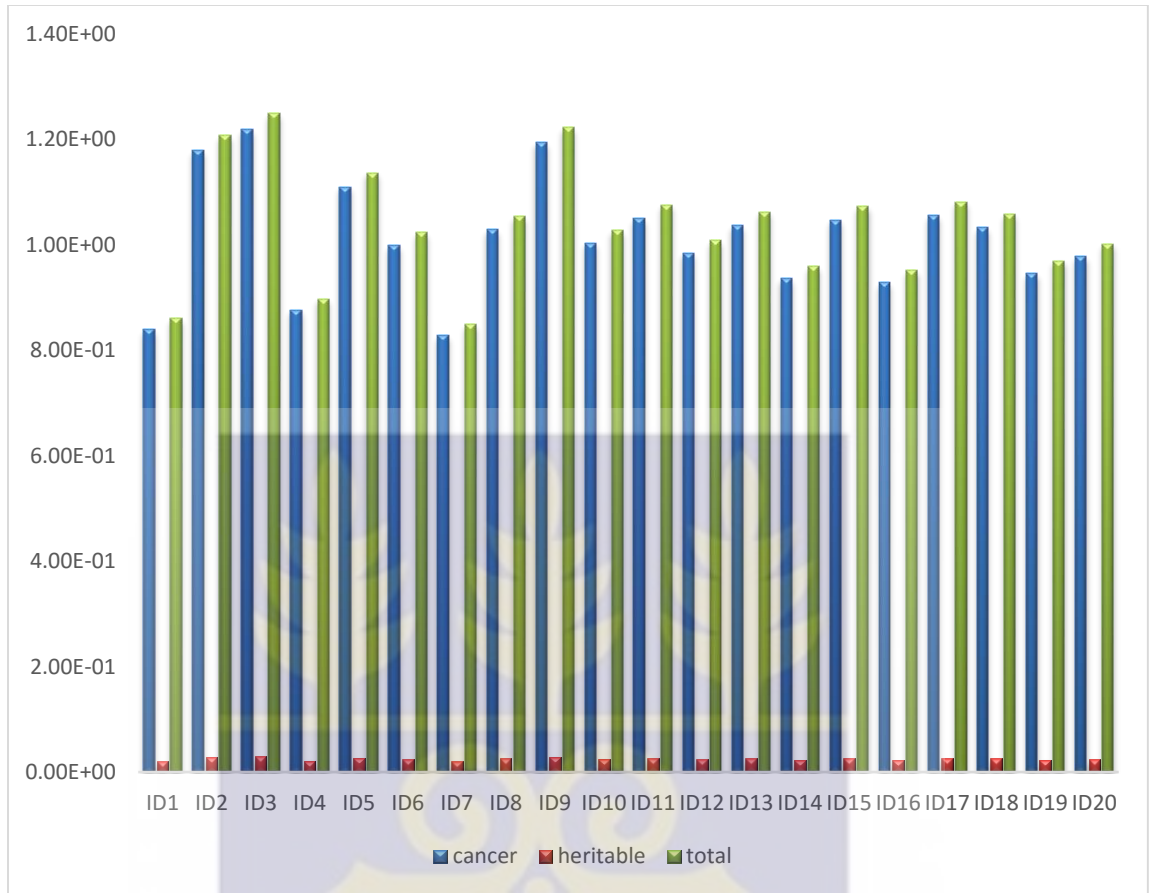


Figure 4.17: annual lifetime risk from dose records using 2007 recommendations

#### 4.5 MEAN ANNUAL COLLECTIVE DOSE

The mean annual collective dose for twenty workers who were deemed to be permanent staff members and were captured in the data for dose records was computed and the values ranged from  $4.6 \times 10^{-3}$  manSv (2014) and to as high as  $13 \times 10^{-3}$  manSv in 2016 as shown in Fig 4.18

These values over the period are however significantly lower than annual collective estimations in other countries and approved standards. The mean annual collective dose recorded for the period 2010-2016 was  $9.9 \times 10^{-3}$  man Sv  $\pm 3.2 \times 10^{-3}$  manSv as shown in

fig 4.18. This figure is slightly higher than a previous research figure of 0.01 between 2000-2009 but can be attributed to the fact that only radiotherapists and selected staff in a single facility were used for this research and also favourably comparable similar work in other countries as shown in Table 4.1

Table 4.1: Exposure to workers from medical use of radiation

Country	Period	Number of monitored workers 1000s)	Annual Collective dose (manSv)	Mean annual effective dose(mSv)
Japan	1990-1994	5.4	0.57	0.36
United States	1983-1989	307	12	0.04
United Kingdom	1985-1991	20	2	0.1
South Africa	1985-1989	2.27	0.4	1.35
Ghana	2000-2009	0.54	0.01	0.58
<b>Ghana (this work)</b>	<b>2010-2016</b>	<b>0.02</b>	<b>0.09</b>	<b>0.5</b>



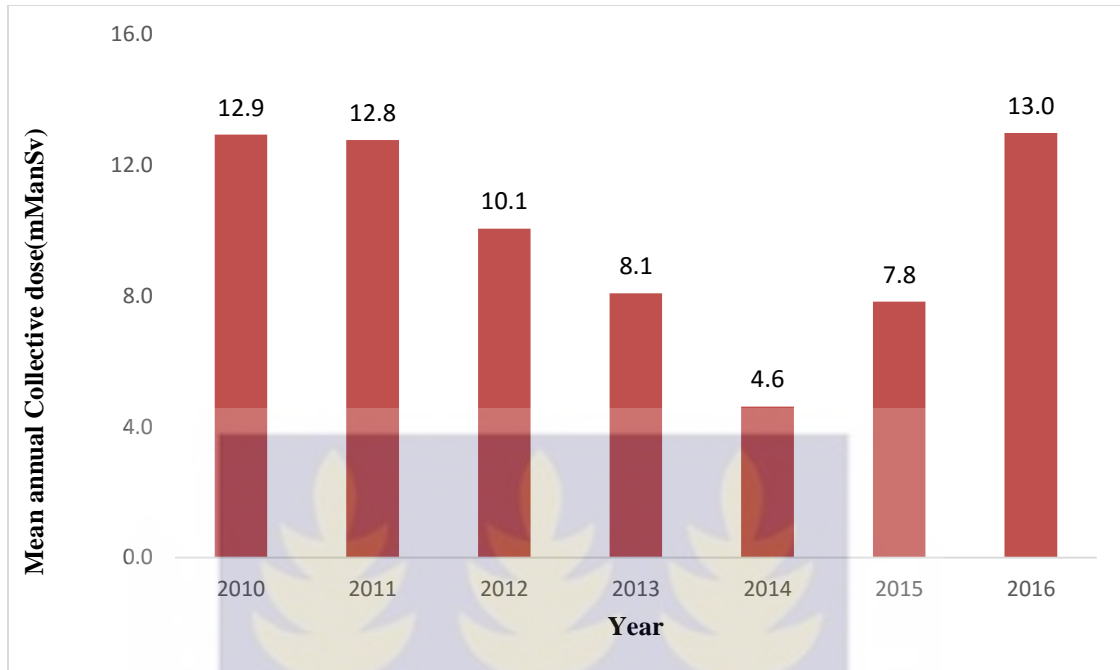


Figure 4.18: Mean annual collective dose from 2010-2016

## 4.6 AMBIENT DOSE RATE

### 4.6.1 Treatment Room

Dose rate measurement were taken five (5) for each location on five (5) different days and the mean values were used for computation of these results.

Ambient dose rate measurements in the treatment room showed recorded values between  $0.40\mu\text{Sv/h}$  (Location F) -  $7.39\mu\text{Sv/h}$  (Location A). The mean ambient dose rate recorded was  $3.28\mu\text{Sv/hr} \pm 2.67\mu\text{Sv/hr}$ . These points were close to the head casing that stored the high activity source.

Points E, F and H which were behind the maze in the treatment room recorded relatively ambient dose measurements of  $1.79\mu\text{Sv/h}$ ,  $0.4\mu\text{Sv/h}$  and  $1.5\mu\text{Sv/h}$  respectively. Fig 4.19 below shows the trend of ambient dose measurements in the treatment room.

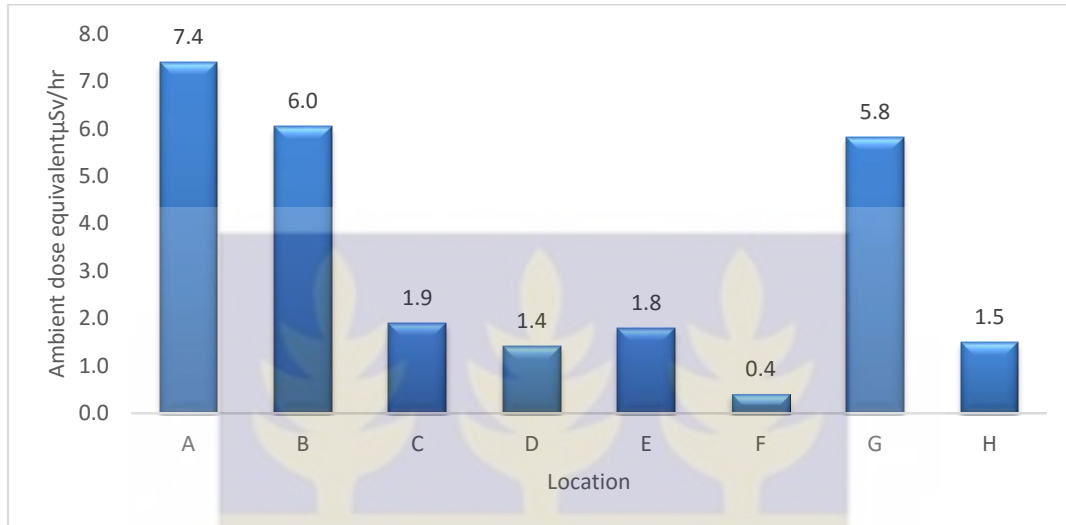


Figure 4.19: Ambient dose equivalent in areas around the treatment room

#### 4.6.2 Controlled area

Ambient dose rate measurements in the controlled area showed recorded values between  $0.26\mu\text{Sv/hr}$ (Location D) -  $0.37\mu\text{Sv/h}$ (Location G). The mean ambient dose rate recorded was  $0.31\mu\text{Sv/hr} \pm 0.04\mu\text{Sv/hr}$ . Fig 4.20 below shows the trend of ambient dose measurements in the treatment room.

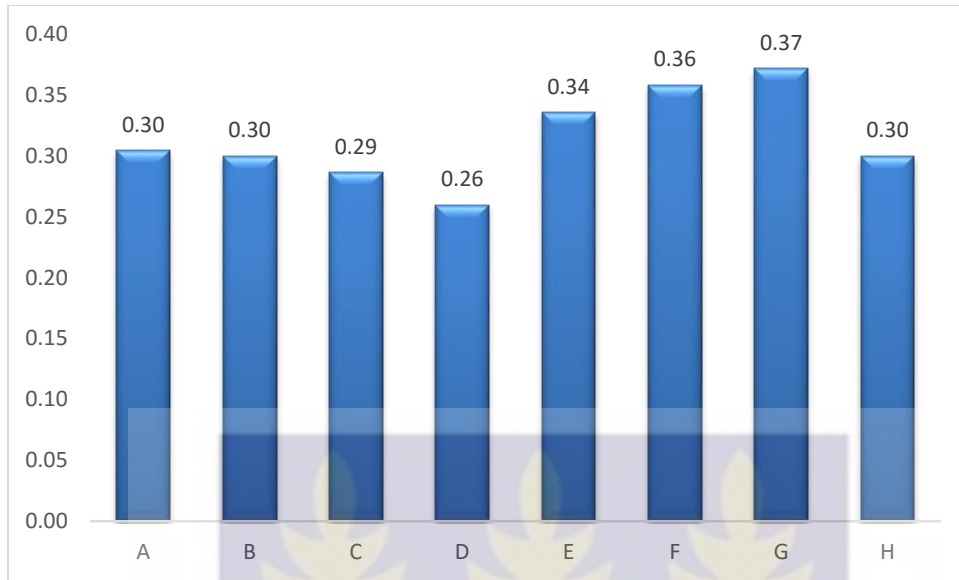


Figure 4.20: Ambient dose equivalent to areas around the control console room

#### 4.6.3 Control console room

Ambient dose rate measurements in the control console room showed recorded values between  $0.25\mu\text{Sv/h}$ (Point H) -  $2.78\mu\text{Sv/h}$ (Point F). The mean ambient dose rate recorded was  $1.42\mu\text{Sv/hr} \pm 0.9\mu\text{Sv/hr}$ .

Fig 4.21 below shows the trend of ambient dose measurements in the treatment room.



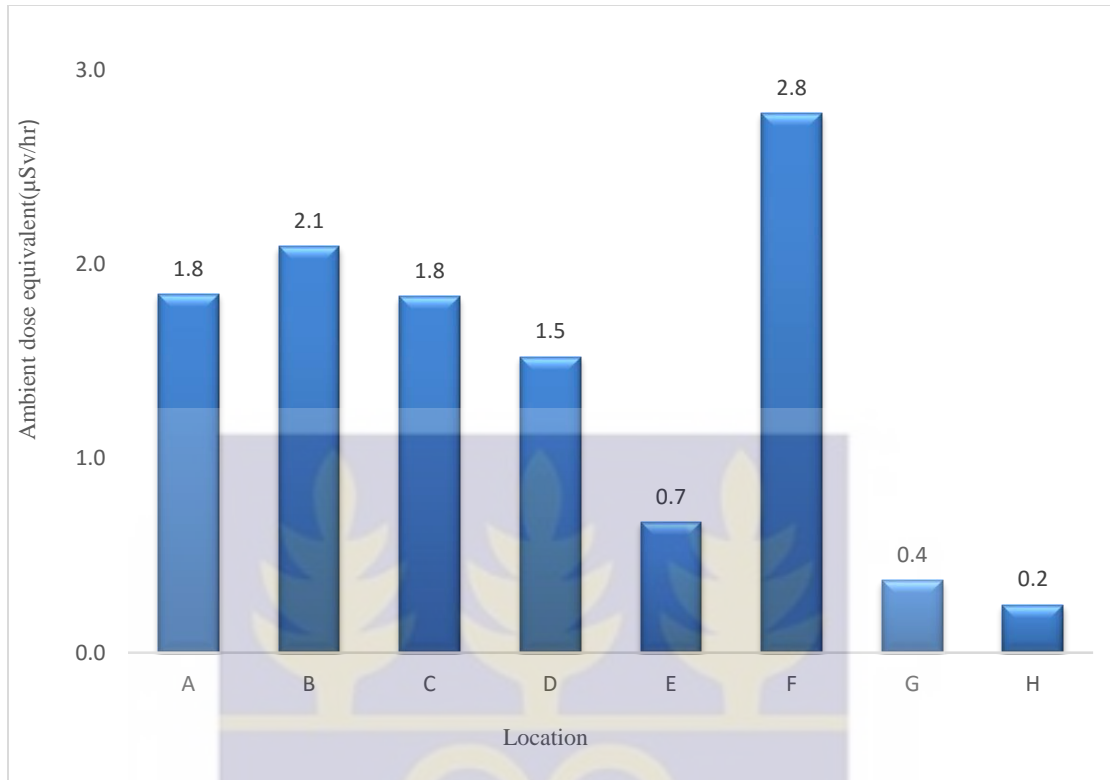


Figure 4.21: Ambient dose equivalent at different areas in the control console room

#### 4.7 INSTANTANEOUS DOSE RATES

Instantaneous dose rate measurements taken in the treatment room, control console area as well as other sections of the controlled area were well below the limit of  $7.5\mu\text{Sv/hr}$ . However radiations were understandably high at locations that were close to the head housing the source storage and leakage radiation were as high as  $3.3\mu\text{Sv/hr}$ .

#### 4.7.1 Treatment room

Instantaneous dose rates measured at different points at different distances from the center of the collimator in the treatment room showed an average dose rate measurement of  $1.47\mu\text{Sv/hr} \pm 1.19\mu\text{Sv/hr}$  while the values ranged from  $0.18\mu\text{Sv/hr} - 3.30\mu\text{Sv/hr}$  as shown in fig 4.22

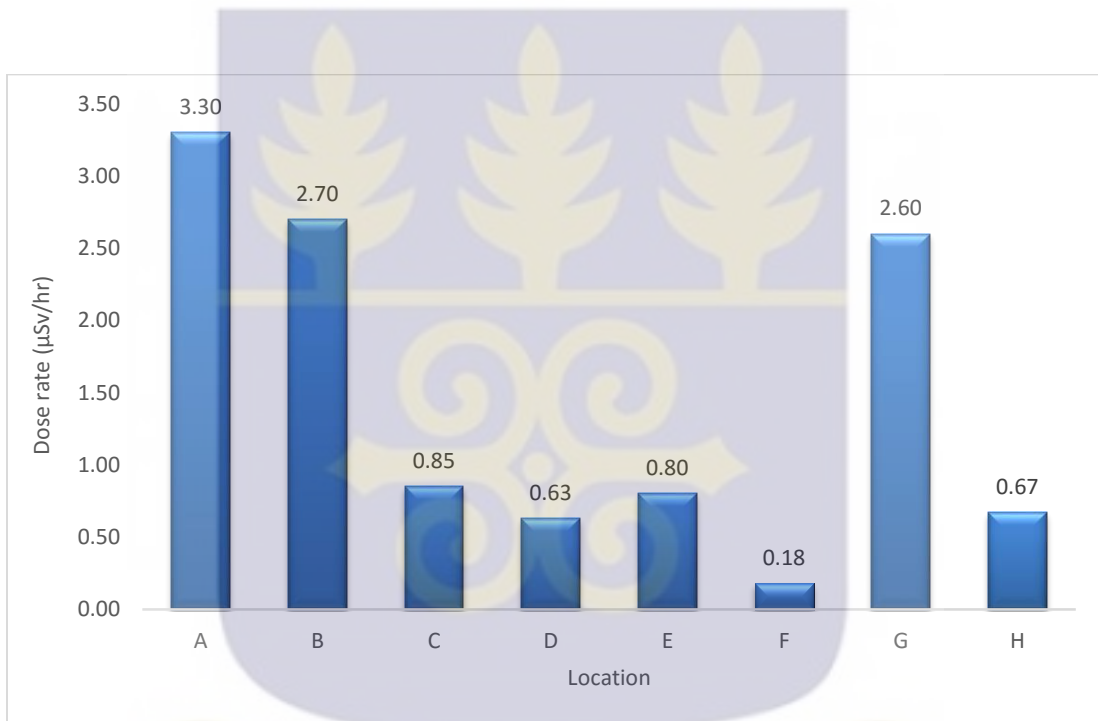


Figure 4.22: Dose rate measurements in treatment room

#### 4.7.2 Control console room

Instantaneous dose rate measurements recorded at different locations in the control console room recorded a mean dose rate value of  $0.14\mu\text{Sv/hr} \pm 0.02\mu\text{Sv/hr}$  with dose rates ranging from  $0.12\mu\text{Sv/hr} - 0.17\mu\text{Sv/hr}$  as shown in figure 4.23

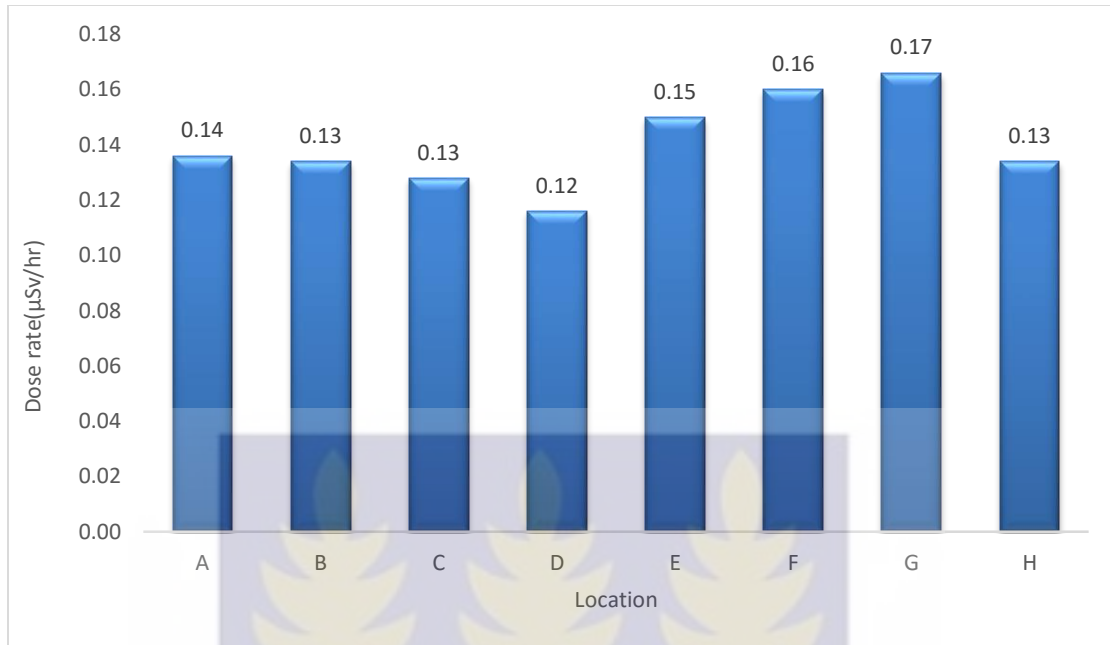


Figure 4.23: Dose rate measurement in the control console room

#### 4.7.3 Controlled area

The values recorded at different points in the controlled area ranged from 0.11μSv/h-1.24μSv/h. The mean dose rate recorded was 0.63μSv/hr ±0.27μSv/hr as shown in fig 4.24



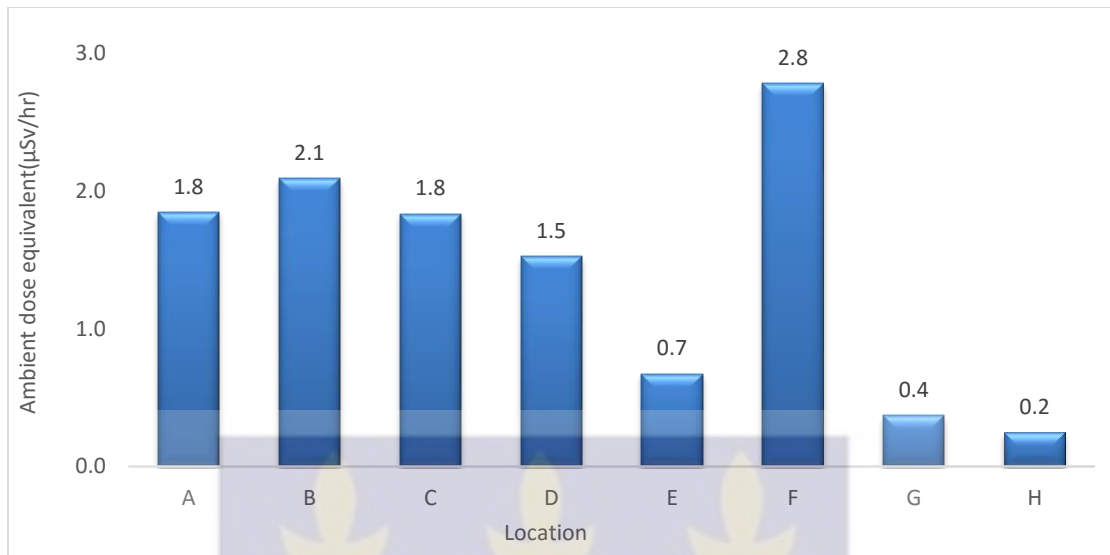


Figure 4.24: Dose rate measurement in the controlled area

#### 4.8 ANNUAL DOSE RATES

The annual dose rates were computed using the IAEA recommendations of 2000 man hours per year as the maximum number of hours a radiotherapist works at a radiotherapy facility with about ten percent (10%) of that period spent inside the treatment room. This is to give a vivid picture of the incident radiation on an occupationally exposed worker within a year and to ascertain whether effective dose that can be possibly absorbed by workers at the facility are within acceptable limits and the results also compared to dose records from TLDs.

#### 4.8.1 Annual dose rates (treatment room)

Based on the assumption that radiotherapists spend averagely 10 percent of their working hours in a year inside the treatment room, the annual dose rate computed is shown below in fig 4.25

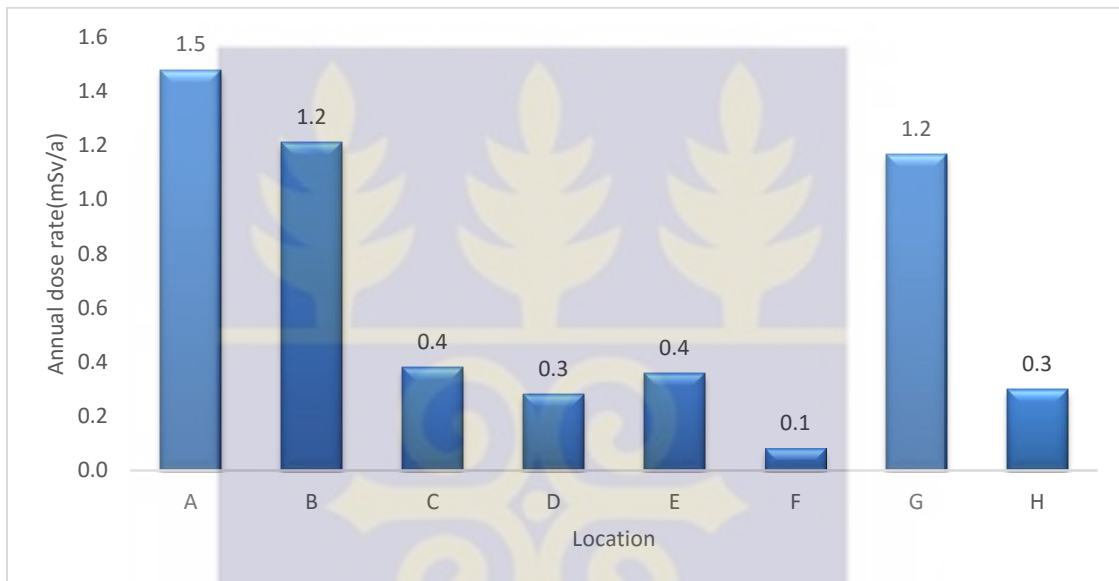


Figure 4.25: Annual dose rate in the treatment room

As shown above, workers are likely to be exposed to radiation levels between 0.1mSv/a-1.5mSv/a with an average of  $0.7\text{mSv/a} \pm 0.5\text{mSv/a}$ .

These values are still well below the recommended limit of 20mSv but should also be noted that this doses account for only 10% of their total time spent working in a radiation environment in a year.

#### 4.8.2 Annual dose rate (control console room)

Radiotherapists and other critical staff of the radiotherapy department spend about 90% of the total dedicated time for working within a year inside the control console room. This means that radiation levels around the control room will contribute significantly to the cumulative dose that will be obtained from the TLD badges, workers are likely to be exposed to radiation doses ranging from 0.44mSv/a to 5mSv/a with a mean value of 2.56mSv/a  $\pm$  1.62mSv/a as shown in fig 4.26

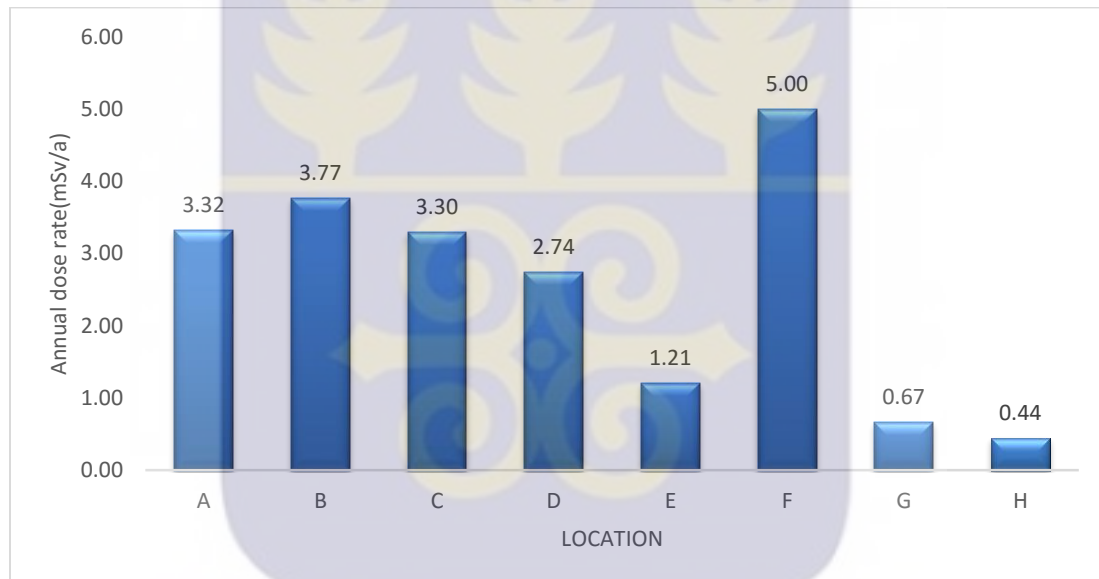


Figure 4.26: Annual dose rate in the control console room

## CHAPTER FIVE

### 5 CONCLUSION AND RECOMMENDATIONS

#### 5.1 CONCLUSION

Occupational radiation dose to staff working at the teletherapy department of the Korle Bu Teaching Hospital has been assessed using thermoluminescent dosimeters and a Rad eye survey meter was used to estimate ambient dose equivalent. The major findings in this work include:

- Staff at the department was generally exposed to very low ionizing radiation. The determination of the effective doses and collective dose formed the basis to estimate the risk and probability of stochastic effects.
- Mean effective doses recorded did not exceed 0.65mSv from the dose records while a relatively lower effective dose of 0.5mSv was recorded with separate TLDs. This implies that records available from personnel monitoring agreed generally with the TLDs used in this research.
- Results from the TLDs can therefore be said to have good agreement with personnel dose records. This suggests that both the service provider (facility) and the dosimetry service provider have been consistent in satisfying the critical aspect of staff monitoring.
- The annual collective effective dose estimated from 2010 to 2016 at the teletherapy facility also ranged from  $4.6 \times 10^{-3}$  man.Sv to  $13 \times 10^{-3}$  man.Sv with a mean value of  $9.9 \times 10^{-3}$  man.Sv which is much lower compared with other countries where large numbers of workers are occupationally exposed to ionizing radiation.

- Annual cancer risk estimates recorded mean values of  $2.37 \times 10^{-2} \pm 7.75 \times 10^{-3}$  and  $2.03 \times 10^{-2} \pm 6.62 \times 10^{-3}$  according to ICRP 1990 and 2007 recommendations respectively.
- Ambient dose measurement taken from the treatment room, control console room and the controlled areas of the facility did not exceed  $7.39\mu\text{Sv/h}$ ,  $0.37\mu\text{Sv/h}$  and  $2.78\mu\text{Sv/h}$  respectively and were all below the recommended dose limit of  $20\mu\text{Sv/h}$ .
- Mean annual dose rates did not exceed  $14.8\text{mSv/a}$ ,  $5\text{mSv/a}$  and  $0.74\text{mSv/a}$  in the treatment room, control console room and other sections of the controlled area respectively. This means that workers are not likely to reach the recommended dose limit for a year whiles they work at the facility but some sections of the treatment room have to be reviewed for optimisation.

## 5.2 RECOMMENDATIONS

Based on the concluding points highlighted above the following recommendations are addressed to the appropriate bodies to ensure optimal protection of staff and the general public.

### 5.2.1 To management of facilities:

- i. Ensure that warning signs are adequate and clear to prevent unwanted access to the controlled area where there is significant presence of ionization radiation

- ii. Liaise with the regulatory body to train and educate staff on the need for the development and participation of a safety culture at the workplace.
- iii. Provision of local rules and procedures at the workplace to be followed by all staff and it should be supervised by a qualified Radiation Safety Officer (RSO) at the facility.
- iv. The risk of cancer induction due to radiation to staff needs to be factored in incentives and remuneration as well as in compensation.
- v. Formulate a Radiation protection committee to advise the management regularly on best practices and new technologies.

**5.2.2 To Service Provider – Radiation Protection Institute (RPI):**

- i. Review and implement an effective system of recording and storing of dose records information of monitored workers.
- ii. Prompt reading and dispatching of TLD cards to clients on a regular basis to improve the regularity of monitoring cycles of at least 3 monthly cycles within a year.

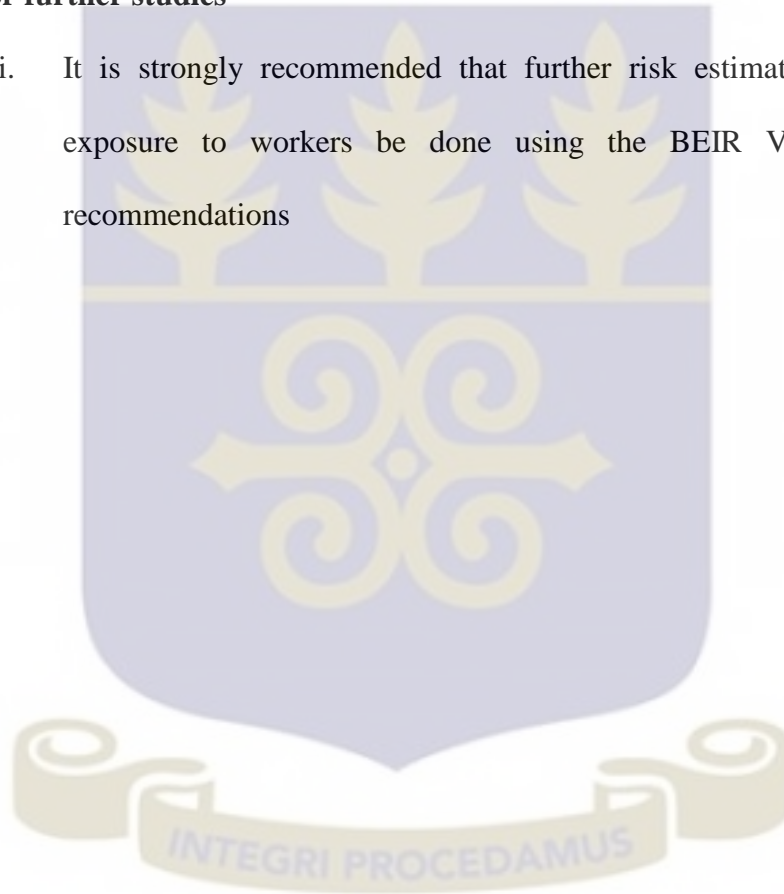
**5.2.3 To regulatory authority – Nuclear Regulatory Authority of Ghana:**

- I. Encourage all practices no matter the level of exposure to develop an ALARA culture for the facility.
- II. Enforce the need for the facility to conduct random checks in aspects of workplace monitoring even though doses received by workers are within allowed limits.

- III. Create platforms through the organisation of seminar and workshops that will bring together major industrial players to share ideas on modern trends and safety practices
- IV. Continuously provide training for staff and reviewing safety measures

#### **5.2.4 For further studies**

- i. It is strongly recommended that further risk estimation due radiation exposure to workers be done using the BEIR V and BEIR VII recommendations



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## APPENDIX

Table A. 1: Annual cancer risk assessment of occupationally exposed workers from 2010-2016

1990 Recommendations				2007 recommendations			
	Cancer	Heritable	Total		cancer	Heritable	Total
<b>Mean</b>	2.37E-02	3.96E-03	2.77E-02	<b>Mean</b>	2.03E-02	4.95E-04	2.08E-02
<b>min</b>	1.94E-02	3.24E-03	2.26E-02	<b>min</b>	1.66E-02	4.04E-04	1.70E-02
<b>max</b>	2.86E-02	4.76E-03	3.33E-02	<b>max</b>	2.44E-02	5.95E-04	2.50E-02
<b>SD</b>	2.52E-03	4.20E-04	2.94E-03	<b>SD</b>	2.15E-03	5.27E-05	2.21E-03

Table A. 2: Lifetime risk estimation of occupationally exposed workers from 2010-2016

1990 Recommendations				2007 recommendations			
	Cancer	Heritable	Total		cancer	Heritable	Total
<b>Mean</b>	4.95E-01	1.98E-01	4.95E-01	<b>Mean</b>	1.01E+00	2.47E-02	1.04E+00
<b>min</b>	9.71E-01	1.62E-01	1.13E+00	<b>min</b>	8.29E-01	2.02E-02	8.49E-01
<b>max</b>	1.43E+00	2.38E-01	1.67E+00	<b>max</b>	1.22E+00	2.98E-02	1.25E+00
<b>SD</b>	5.25E-02	2.10E-02	1.47E-01	<b>SD</b>	1.08E-01	2.63E-03	1.10E-01

Table A. 3: Risk estimate for TLDs using ICRP 1990 recommendations

CARD ID	Annual risk (ICRP 1990 MODEL)		
	Cancer	Heritable	<b>Total</b>
30005	5.78E-03	9.63E-04	6.74E-03
30028	1.77E-02	2.95E-03	2.06E-02
30035	3.81E-03	6.35E-04	4.45E-03
30042	8.48E-03	1.41E-03	9.90E-03
30059	6.48E-03	1.08E-03	7.56E-03
30070	1.41E-02	2.35E-03	1.64E-02
<b>mean</b>	<b>9.39E-03</b>	<b>1.56E-03</b>	<b>1.09E-02</b>
<b>min</b>	<b>3.81E-03</b>	<b>6.35E-04</b>	<b>4.45E-03</b>
<b>max</b>	<b>1.77E-02</b>	<b>2.95E-03</b>	<b>2.06E-02</b>
<b>SD</b>	<b>5.37E-03</b>	<b>8.95E-04</b>	<b>6.26E-03</b>



Table A. 4: Risk estimate for TLDs using ICRP 2007 recommendations

CARD ID	Annual risk (ICRP 2007 MODEL)		
	Cancer	Heritable	Total
30005	4.94E-03	1.20E-04	<b>5.06E-03</b>
30028	1.51E-02	3.68E-04	<b>1.55E-02</b>
30035	3.26E-03	7.94E-05	<b>3.33E-03</b>
30042	7.25E-03	1.77E-04	<b>7.42E-03</b>
30059	5.54E-03	1.35E-04	<b>5.67E-03</b>
30070	1.20E-02	2.93E-04	<b>1.23E-02</b>
<b>mean</b>	<b>8.02E-03</b>	<b>1.96E-04</b>	<b>8.21E-03</b>
<b>min</b>	<b>3.26E-03</b>	<b>7.94E-05</b>	<b>3.33E-03</b>
<b>max</b>	<b>1.51E-02</b>	<b>3.68E-04</b>	<b>1.55E-02</b>
<b>SD</b>	<b>4.59E-03</b>	<b>1.12E-04</b>	<b>4.70E-03</b>



Table A. 5: Estimated Lifetime risk for TLDs using ICRP 1990 recommendations

CARD ID	Lifetime risk (ICRP 1990 MODEL)		
	Cancer	Heritable	<b>Total</b>
30005	2.89E-01	4.82E-02	3.37E-01
30028	8.84E-01	1.47E-01	1.03E+00
30035	1.91E-01	3.18E-02	2.22E-01
30042	4.24E-01	7.07E-02	4.95E-01
30059	3.24E-01	5.40E-02	3.78E-01
30070	7.04E-01	1.17E-01	8.21E-01
<b>mean</b>	<b>4.69E-01</b>	<b>7.82E-02</b>	<b>5.47E-01</b>
<b>min</b>	<b>1.91E-01</b>	<b>3.18E-02</b>	<b>2.22E-01</b>
<b>max</b>	<b>8.84E-01</b>	<b>1.47E-01</b>	<b>1.03E+00</b>
<b>SD</b>	<b>2.68E-01</b>	<b>4.47E-02</b>	<b>3.13E-01</b>



Table A. 6: Estimated lifetime risk using ICRP 2007 recommendations

CARD ID	Lifetimerisk (ICRP 2007 MODEL)		
	Cancer	Heritable	Total
30005	2.47E-01	6.02E-03	<b>2.53E-01</b>
30028	7.55E-01	1.84E-02	<b>7.74E-01</b>
30035	1.63E-01	3.97E-03	<b>1.67E-01</b>
30042	3.62E-01	8.84E-03	<b>3.71E-01</b>
30059	2.77E-01	6.75E-03	<b>2.84E-01</b>
30070	6.01E-01	1.47E-02	<b>6.16E-01</b>
<b>mean</b>	<b>4.01E-01</b>	<b>9.78E-03</b>	<b>4.11E-01</b>
<b>min</b>	<b>1.63E-01</b>	<b>3.97E-03</b>	<b>1.67E-01</b>
<b>max</b>	<b>7.55E-01</b>	<b>1.84E-02</b>	<b>7.74E-01</b>
<b>SD</b>	<b>2.29E-01</b>	<b>5.59E-03</b>	<b>2.35E-01</b>



Table A. 7: Comparative probability of cancer/year induced by low-LET radiation

Source	Dose-response model	Probability
BEIR III	Linear-quadratic	1.10 to 3.20 x 10 <sup>-5</sup>
BEIR II	Linear	1.70 to 8.60 x 10 <sup>-5</sup>
UNSCEAR	Linear	1.10 to 2.50 x 10 <sup>-5</sup>
ICRP	Linear	1.26 x 10 <sup>-3</sup>

APPENDIX F

Table A. 8: Estimated probability of cancer death/year (BEIR III, 1980)

Dose-response model	Probability
Linear-quadratic	1.1 to 3.2 x 10 <sup>-5</sup>
Linear	2.4 to 7.2 x 10 <sup>-5</sup>
Quadratic	1.4 to 3.3 x 10 <sup>-5</sup>



Table A. 9: Daily dose rate measurement in the controlled area

LOCATION	Distance from the center of the collimator (m)	Dose rate( $\mu$ Sv/hr)					Average	SD	Min	Max
		DAY 1	DAY 2	DAY 3	DAY 4	DAY 5				
A	2.2	0.13	0.14	0.13	0.14	0.14	0.14	0.01	0.13	0.14
B	2.7	0.15	0.16	0.12	0.11	0.13	0.13	0.02	0.11	0.16
C	1.3	0.12	0.14	0.13	0.13	0.12	0.13	0.01	0.12	0.14
D	2.1	0.10	0.12	0.13	0.12	0.11	0.12	0.01	0.10	0.13
E	2.3	0.12	0.18	0.17	0.14	0.14	0.15	0.02	0.12	0.18
F	1.2	0.10	0.30	0.15	0.13	0.12	0.16	0.08	0.10	0.30
G	1.4	0.26	0.14	0.17	0.13	0.13	0.17	0.06	0.13	0.26
H	1.27	0.10	0.16	0.10	0.19	0.12	0.13	0.04	0.10	0.19

Table A. 10: Daily dose rate measurements in the control console room

LOCATION	Distance from the center of the collimator (m)	Dose rate( $\mu$ Sv/hr)					Average	SD	Min	Max
		DAY 1	DAY 2	DAY 3	DAY 4	DAY 5				
A	2.20	1.10	0.82	0.99	0.54	0.67	<b>0.82</b>	<b>0.23</b>	<b>0.54</b>	<b>1.10</b>
B	2.70	1.04	1.10	1.00	0.99	0.54	<b>0.93</b>	<b>0.22</b>	<b>0.54</b>	<b>1.10</b>
C	1.30	1.52	0.67	0.87	0.77	0.26	<b>0.82</b>	<b>0.46</b>	<b>0.26</b>	<b>1.52</b>
D	2.10	0.81	0.89	0.87	0.56	0.27	<b>0.68</b>	<b>0.26</b>	<b>0.27</b>	<b>0.89</b>
E	2.30	0.63	0.27	0.23	0.19	0.18	<b>0.30</b>	<b>0.19</b>	<b>0.18</b>	<b>0.63</b>
F	1.20	2.10	1.70	1.30	0.90	0.20	<b>1.24</b>	<b>0.73</b>	<b>0.20</b>	<b>2.10</b>
G	1.40	0.18	0.17	0.11	0.24	0.13	<b>0.17</b>	<b>0.05</b>	<b>0.11</b>	<b>0.24</b>
H	1.27	0.12	0.09	0.09	0.12	0.13	<b>0.11</b>	<b>0.02</b>	<b>0.09</b>	<b>0.13</b>

Table A. 11: Daily dose rate readings in the treatment room

LOCATION	Distance from the center of the collimator(m)	Dose rate( $\mu$ Sv/hr)					Mean	SD	Min	Max
		DAY 1	DAY 2	DAY 3	DAY 4	DAY 5				
A	0.15	3.30	2.67	2.10	1.54	2.14	<b>2.35</b>	<b>0.66</b>	<b>1.54</b>	<b>3.30</b>
B	0.30	2.70	1.16	1.12	1.11	1.13	<b>1.44</b>	<b>0.70</b>	<b>1.11</b>	<b>2.70</b>
C	1.00	0.85	0.99	1.13	0.83	0.92	<b>0.94</b>	<b>0.12</b>	<b>0.83</b>	<b>1.13</b>
D	0.88	0.63	0.57	0.93	0.82	0.61	<b>0.71</b>	<b>0.16</b>	<b>0.57</b>	<b>0.93</b>
E	1.10	0.80	0.17	0.17	0.14	0.15	<b>0.29</b>	<b>0.29</b>	<b>0.14</b>	<b>0.80</b>
F	1.30	0.18	0.19	0.15	0.13	0.12	<b>0.15</b>	<b>0.03</b>	<b>0.12</b>	<b>0.19</b>
G	0.44	2.60	1.91	1.17	2.13	2.03	<b>1.97</b>	<b>0.52</b>	<b>1.17</b>	<b>2.60</b>
H	0.80	0.67	0.78	0.90	0.79	0.62	<b>0.75</b>	<b>0.11</b>	<b>0.62</b>	<b>0.90</b>

Table A. 12: Mean annual effective dose of occupationally exposed workers

WORKER	2010	2011	2012	2013	2014	2015	2016	Mean	Min	Max	SD
ID1	0.53	0.50	0.48	0.27	0.20	0.34	0.56	0.41	0.20	0.56	0.14
ID2	0.86	0.79	0.46	0.37	0.16	0.44	0.94	0.58	0.16	0.94	0.29
ID3	0.67	0.67	0.44	0.36	0.27	0.47	1.30	0.60	0.27	1.30	0.34
ID4	0.50	0.50	0.46	0.20	0.21	0.32	0.81	0.43	0.20	0.81	0.21
ID5	0.68	0.66	0.46	0.33	0.26	0.70	0.71	0.54	0.26	0.71	0.19
ID6	0.66	0.66	0.42	0.36	0.26	0.32	0.75	0.49	0.26	0.75	0.20
ID7	0.52	0.51	0.42	0.33	0.22	0.32	0.52	0.40	0.22	0.52	0.12
ID8	0.66	0.68	0.46	0.31	0.21	0.46	0.74	0.50	0.21	0.74	0.20
ID9	0.78	0.79	0.46	0.46	0.32	0.42	0.85	0.58	0.32	0.85	0.21
ID10	0.55	0.65	0.47	0.53	0.17	0.42	0.64	0.49	0.17	0.65	0.16
ID11	0.68	0.61	0.47	0.57	0.21	0.46	0.59	0.51	0.21	0.68	0.15
ID12	0.54	0.52	0.48	0.68	0.22	0.45	0.48	0.48	0.22	0.68	0.14
ID13	0.76	0.67	0.56	0.43	0.26	0.38	0.50	0.51	0.26	0.76	0.17
ID14	0.71	0.70	0.49	0.22	0.18	0.30	0.61	0.46	0.18	0.71	0.23
ID15	0.70	0.67	0.46	0.56	0.19	0.31	0.69	0.51	0.19	0.70	0.20
ID16	0.65	0.59	0.47	0.48	0.18	0.30	0.52	0.45	0.18	0.65	0.17
ID17	0.59	0.69	0.70	0.48	0.42	0.35	0.38	0.52	0.35	0.70	0.14
ID18	0.71	0.55	0.68	0.53	0.17	0.35	0.54	0.50	0.17	0.71	0.19
ID19	0.55	0.72	0.61	0.21	0.27	0.40	0.48	0.46	0.21	0.72	0.18
ID20	0.63	0.64	0.61	0.47	0.25	0.31	0.44	0.48	0.25	0.64	0.16
<b>Mean values</b>	<b>0.65</b>	<b>0.64</b>	<b>0.50</b>	<b>0.40</b>	<b>0.23</b>	<b>0.39</b>	<b>0.65</b>				

Table A. 13: Effective Dose measurement of TLDs

<b>CARD ID</b>	<b>Dose(<math>\mu</math>Sv)</b>	<b>Dose(mSv)</b>
30005	120.38	0.12
30028	368.41	0.37
30035	79.40	0.08
30042	176.71	0.18
30059	135.05	0.14
30070	293.20	0.29
MEAN	195.52	0.20
MINIMUM	79.40	0.08
MAXIMUM	368.41	0.37
SD	111.87	0.11

