ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS FOR RADIOLOGICAL PROCEDURES IN SELECTEDTEACHING HOSPITALS IN NORTH EASTERN NIGERIA

BY

JOSEPH DLAMA ZIRA

PhD/2014 647004F

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (PhD) DEGREE IN RADIOGRAPHY AND RADIOLOGICAL SCIENCES (RADIATION, ENVIRONMENTAL PROTECTION AND DOSIMETRY)

DEPARTMENT OF RADIOGRAPHY AND RADIOLOGICAL SCIENCES,

FACULTY OF HEALTH SCIENCE AND TECHNOLOGY,

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SUPERVISOR: VEN. PROFESSOR NZOTTA C. CHRISTIAN

MARCH, 2018

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Dr. Hyacienth U Chiegwu **Date**

(Head of Department)

APPROVAL PAGE

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Thanks be to God almighty who always gives me victory in Christ Jesus and through me he spreads everywhere the fragrance of Him. I am just an unworthy servant he chooses to display his splendor and glory. I return all glory and honour to Him, for seeing me through in the course of this work. In Christ is hid all the treasures of wisdom and knowledge Colossians 2:3 (KJV)

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to other concerned persons whose names were not mentioned, please accept my gratitude. To God be the Glory now and forever more. Amen.

DEDICATION

This work is dedicated to my Lord and Savior Jesus Christ in whom is hid all the treasures of wisdom and knowledge. Colossians 2:3 (KJV)

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATION

LIST OF APPENDICES

LIST OFABBREVIATIONS

kVp…….. Kilo voltage peak or tube potential

mAs……..... Milli ampere seconds or tube current

ESD…… Entrance skin dose

DAP……. Dose area product

FSD……. Focus to skin distance

IVU……. Intravenous urography

HSG…… Hysterosalpingography

RUG……... Retrograde urethrography

CERT..... Center for Energy Research and Training

MLO…… Medio-lateral oblique

CC……..... Cranio-caudal view

ARPANSA……. Australian Radiation protection and Nuclear safety Agency

CEC……. Committee for European commission

UK……... United Kingdom

DRLs……. Diagnostic reference levels

CT……. Computed tomography

CTDI…… Computed tomography dose index

DLP…… Dose length product.

IRMER……..Ionizing Radiation Medical Exposure Regulation

AP…….Anterior Posterior

ICRP……International Commission on Radiological Protection

IPEM…….Institute of Physicist and Engineering in Medicine

ABSTRACT

This work is a prospective cross-sectional study carried out to establish DRLs for adult radiological procedures in some selected teaching hospitals in North Eastern Nigeria. A total 1080 patients were enlisted in this study, thirty patients each for 36 different procedures comprising of fourteen common radiographic and dental x-ray examinations, twelve contrast examinations, four mammography and six computed tomography examinations. Thermoluminiscent dosimeter chips and dose area product meter were used to obtain the dose values. Computed tomography dose index and dose length products were obtained from the computed tomography monitor. The DRL for posterior anterior (PA) chest and lateral x-ray obtained in this work were 0.59 mGy and 1.02 mGy, PA skull and lateral skull x-ray were 1.02 mGy and 1.01 mGy. The DRL for PA elbow and lateral elbow were 0.57 mGy and 1.77mGy. AP shoulder and lateral x-ray were 0.71 mGy and 0.83 mGy. The DRL for dorsi-plantar foot and dorsi-plantar oblique foot in this work were 0.58 mGy and 0.61 mGy .Dose values for contrast studieswere6.68mGy, 10.66mGy.cm^2 for IVU, 2.31 mGy, 3.67mGy.cm^2 for HSG, 2.66 mGy, 8.98mGy.cm^2 for barium meal, 12.78 mGy, 20.64 mGy.cm^2 for barium enema, 2.73 mGy and 6.56 mGy.cm^2 for barium swallow and 2.05 mGy, 7.77 mGy.cm^2 for RUG. Diagnostic reference levels for cranio-caudal and medio-lateral oblique were 0.63 and 1.04 mGy while CT head, chest and abdomen are67.90 mGy, 18.38 mGy and 19.20 mGy. This study has established DRLs in two teaching hospitals in North Eastern Nigeria which is useful for formulation of National DRLs.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Diagnostic reference level (DRL) is defined as an investigation level used as a tool to aid optimization of protection in the medical exposures of patients for diagnostic and interventional procedures (International Commission on Radiological Protection (ICRP), 2017). Established DRLs are used to identify unusually high radiation doses for radiological examinations (Donald *et al.,* 2012; Jeska *et al.,* 2014). They are suggested action levels above which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses (Wallace, 2010). Diagnostic reference levels is an optimization tool to ensure patients are adequately protected and it is deemed to be an important mechanism for the management of patient dose to ensure it is within the medical purpose of x-ray examination (Carroll, 2014). In the recommendation of international commission of Radiological protection (ICRP, Report 103), the principle for setting DRLs are enumerated, the local, regional and national objectives is clearly defined, including the degree of the specification of clinical and technical conditions for medical imaging task. The selected value of the DRL is based on the relevant regional, national and local data, the quantity used for the DRLs can be obtained in practical way (ICRP,2017).The use of diagnostic reference levels has been supported by national and international advisory bodies (Donald *et al.,* 2012). These and other organizations have provided guidelines on measuring radiation dose and setting diagnostic reference levels (ICRP, 2011).The concept of investigation levels for diagnostic medical exposures was first proposed by the International Commission of Radiological protection (ICRP) in its 1990 recommendations, and further developed into diagnostic reference levels (DRL) in 1996 in ICRP publication

73. (Hart *et al.*,2012). The numerical values of diagnostic reference levels are advisory however; implementation of the DRLs concept may be required by regulatory and professional bodies(Wallace, 2010).Diagnostic reference levels (DRLs) are optimization tools used as special type of dose constraints above which doses must be reviewed and considered above acceptable levels, especially if acceptable image quality can be achieved at lower doses.(Muhammed *et al.,* 2016).Optimizing the protection of patients, and maintaining appropriate good practice is a priority for all diagnostic radiological examinations (Muhammed *et al.,* 2016). Many studies carried out to measure entrance surface dose (ESD) in different countries and their results were compared with dose levels recommended by relevant organizations. Also, organizations such as the National Radiological Protection Board (NRPB) and International Atomic Energy Agency (IAEA) recommended the use of dose constraints or investigation levels to provide guidance for medical exposures (IAEA, 2012). In the United States, Greece, Brazil and Bangladesh, investigations showed that patients dose from common x-ray examinations were below the reference levels set by International Commission on Radiological Protection (ICRP publication 60, 1991). In contrast, in China and Tanzania researchers reported that the average ESDs were comparatively high for x-ray examinations (Gholami *et al.,* 2015)

The radiation protection system for patients referred for medical exposures in diagnostic radiology is governed by principles of justification, optimization and dose limit (ICRP, 2017). The consideration of DRLsgives you an idea of the radiation doses received for standard size patients (Roshan *et al*., 2011). Diagnostic radiological examination is justified if the benefits to the individual patients from the medical diagnosis are obtained with good quality image. (Jeska *et al*., 2014).Once medical exposure is justified it means, that the radiological examination must be carried out with the equipment and exposure parameters that ensure doses to patients as low as reasonably practicable consistent with

intended diagnostic purpose (Wallace, 2010). The medical field over the years has benefited enormously from the use of x-ray radiation with various new developments associated with diagnosis and therapy(Jeska *et al*., 2014).Radiation can be a major risk in radiology and the growing use and increasing complexity of radiologic examination have been accompanied by public health concerns resulting from radiation exposure to both patients and personnel (Axiesson, 2011).It is known that of all man made sources of radiation, diagnostic x-rays contribute the largest part to the collective population dose, and are the most encountered radiation in diagnostic radiology leading to injurious somatic and genetic effects on human beings (UNSCEAR, 2012).

X-ray is the most frequently used ionizing radiation for diagnostic imaging and it plays a significant role in effective health care delivery both in developed and developing countries (Olowookere *et al.,* 2012). Several studies reported the need to establish diagnostic reference levels in Nigeria (Olowookere *et al.,* 2012; Sharifat *et al.,* 2010). DRLs permit individuals and institutions performing radiological procedures to compare the radiation dose in their center with other established work so as to check their performance. (Sharifat *et al.*,2010). X-ray is said to be the major contributor to the collective effective dose of the general public (Johnson and Brennan, 2012). The need for radiation dose assessment for the patient during diagnostic x-ray examinations has been highlighted with the increasing knowledge of hazard of ionizing radiation (Johnson and Brennan, 2012). Because of the deleterious effects of x-rays, it is necessary to protect patients undergoing diagnostic and therapeutic procedures. The aim of any diagnostic radiological x-ray examination is to produce images of sufficient and optimum quality with doses justified and optimized. The assessment of dose includes the contributions from primary beams, scattered and leakage radiation(Nzotta and Udeh, 2013)

The Australian radiation protection and Nuclear safety Agency(ARPANSA), (2014) suggested that the DRLs is the 75th percentile (Third quartile) of the spread of mean doses of common protocols as recorded from data submitted to the National diagnostic reference service (ARPANSA, 2014). A local facility reference levels (FRLs) is defined as the mean value of the spread of doses for common protocols surveyed at the Local Radiology facility (Abdullahi*et al*., 2015). The major objective of DRLs is to help avoid excessive radiation dose to the patient that does not contribute additional clinical information to diagnostic Radiology task (ARPANSA, 2014). DRL should be selected by professional medical bodies' often in conjunction with health and radiation protection authorities and their values would be specific to a country or a region. DRL are a guide to encourage good clinical practice (Donald *et al.*, 2010). Diagnostic reference levels are a quality assurance and quality improvement tool for controlling radiation dose (Donald *et al.*, 2010). They are intended to be a reasonable indication of dose for average size patients and to provide guidance on what is achievable with current good practice rather than optimum performance (Donald *et al.*, 2012). The objective of the study is to establish DRLs for radiology procedures in major referral centers in North eastern Nigeria.

1.2 Statement of the Problem

Increasing concerns over radiation doses received by patients and the associated radiation risks have become a major issue in recent years. (Rehani, 2015). Reducing radiation dose in radiological examination is of utmost importance particularly in the light of continued increase in the number of new modalities and examinations performed annually (NCRP, 2010). In Nigeria, in spite of the large number of x-ray examinations carried out yearly, the dose information available is grossly inadequate. In addition, there are no evidence of published data indicating the establishment of diagnostic reference levels for radiologic examination in Nigeria (Micheal *et al.*, 2016). The need for

optimization of patient protection through implementation of measures to keep doses to patients undergoing radiology examination within acceptable ranges for the clinical purpose of each examination has been a topic of global recognition (Institute of Physics and Engineering in Medicine (IPEM) , 2015).Diagnostic Reference Levels (DRLs), which is the recommended tool in achieving optimization of doses, is yet to be set or unavailable for radiology procedures in Nigeria (Olarinoye and Sharifat, 2008; Olowookere, 2012; Nworgu and Bamidele,2010). Absence of DRLs could result to unsafe practice which poses detrimental effects on patients as a result of increase in patient's dose and consequent radiation risks. Without DRLs the hospitals, clinics and diagnostic centers cannot measure their performance. The regulatory and professional bodies saddled with the responsibility of licensing, monitoring and authorizing the practice and dispensing of radiation doses to patients will have no idea of DRL values in our region. Practices are presently referenced to United Kingdom radiological practice standards, European commission (EC) and Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). More so, IPEM (2004) recommends that every country and or facility should have or set its DRLs, because practices and advancement in technology varies from one country to another and hence one country's DRL cannot be a good representation of another. To the best of researcher's knowledge and based on literature search, there are no documented DRLs or radiation dose assessments for radiological procedures in any facility in North Eastern Nigeria. Identifying situations where the level of patient dose is usually highcannot be determined without dose assessment. The relationship between dose values and anthropometric/technical parameters has not been assessed in teaching hospitals in North eastern Nigeria, hence they are not yet known.

1.3 Aim of the Study

i. The aim of this study is to establish diagnostic reference levels for Radiological examinations in two teaching hospitals in North Eastern Nigeria which will act as a guide for practice of radiology in Nigeria. Primary measurements to be carried out includes entrance skin dose (ESD) for radiography and dental examinations, mean glandular dose (MGD) for mammography examinations, dose area product (DAP) for fluoroscopy and computed tomography dose index (CTDI) and dose length product (DLP) for computed tomography examinations.

The aim of this study would be achieved through the following objectives.

1.4 Objectives of the study

i. To measure the mean values of anthropometric and technical parameters of patients undergoing different Radiological examinations

ii. To measure the mean radiation doses (ESD, MGD, DAP, CTDI ,DLP)received by patients undergoing various radiological examinations involving the use of ionizing radiation.

iii. To determine the relationship between mean doses received by patients and anthropometric parameters.

iv. To compare the patients mean radiation doses received and anthropo-technical parameters for the hospitals.

v. To establish diagnostic reference levels for conventional radiography, dental radiography, mammography, fluoroscopy and Computed tomography examinations in the hospitals under study.

1.5 Significance of the Study

i. This study will provide DRLs which will be used as a guidance for optimization and will also help to reduce unnecessary doses and the consequent radiation risks in North Eastern Nigeria.

ii. The established DRLs in this work will permit individuals and institutions performing radiological procedures to compare the radiation doses used in their centers with other established work used as standard.

iii. The study will improve local, regional and national distributions of observed doses for general medical imaging task by reducing the frequency of unjustified high dose values that do not contribute to the clinical objective of the procedure.

iv. This study on DRLs in this region is intended to serve as a simple test for identifying situations where the level of patient dose is unusually high and to know whether the protection of patients has been adequately optimized.

v. The study will promote a narrow range of doses that represent good practice for more specific medical imaging task it will also promote optimum range of doses for a specific medical imaging protocol.

vi. The study will provide dosimetric data that will educate and alert regulatory bodies, professional bodies and professionals like radiographers, radiologist and medical physicist on the radiation doses delivered during various Radiological examinations.

vii. This research work may serve as reference document to regulatory authorities like International Atomic Energy Agency, Nigerian Nuclear Regulatory Authority, professional and academic groups involved in the practical implementation of DRLs.

1.6 Research Question

i. What is the dose received by patients during conventional radiography examination, dental x-ray examination, mammography examination, fluoroscopy examination and computed tomography examination in North Eastern Nigeria?
ii. What is the relationship between dose received by patients and antropotechnical parameters?
iii. How optimized are our Radiological practices in North Eastern Nigeria?
iv. What is the DRLs for conventional radiography examination, dental x-ray examination, mammography examination, fluoroscopy examination and computed tomography examination in North Eastern Nigeria?

1.7 Scope of the Study

The study was conducted at the Radiology departments of two University Teaching Hospitals in North Eastern Nigeria. They include Abubakar Tafawa Balewa University Teaching Hospital, Bauchi and Federal Teaching Hospital, Gombe. The study focused on major and most frequently requested Radiological examinations using imaging modalities like conventional radiography, dental radiography, computed Tomography, Mammography and Fluoroscopy examinations. Data were obtained from October 2015 to January 2017.

1.8 Definition of Terms

Absorbed Dose: The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the point of interest. The SI unit is Jkg^{-1} with the special name gray (G*y*).

Stochastic Effect: These are radiation effects that have no threshold dose value below which they will not occur. It is probabilistic with chances of occurrence increasing with each radiation effect. Examples include induction of cancer and genetic effects.

Deterministic or non-stochastic: these are biologic somatic effects of ionizing radiation that can be directly related to the dose received or the effects in which the severity increases with the dose of radiation received. They may have a threshold dose below which they may not occur example includes erythema (Visible reddening of the skin), epilation (loss of the hair), hematopoietic syndrome, gastrointestinal syndrome and cerebrovascular syndrome.

Dose: Radiation dose is defined as the energy absorbed or deposited per unit mass in tissue. It is measured in J/kg. As used in this study, dose is the same as the absorbed dose unless specified as "equivalent dose" or "effective dose".

Effective Dose: The sum, over specified tissues, of the products of the equivalent dose in a tissue and the tissue weighting factor for that tissue. Effective dose is measured in Sieverts (S*v*). Stochastic risk factors are usually stated relative to effective dose.

Equivalent Dose: A quantity used for radiation protection purposes that take into account the different probability of effects that occur with the same absorbed dose delivered by radiations with different radiation weighting factors. Equivalent dose is measured in S*v*.

most fluoroscopy equipment, the last image of the real-time image series can be saved (last image hold), and on newer equipment the last several seconds of fluoroscopy is much less than for fluorography.

Kerma: Abbreviation for kinetic energy released in matter, the amount of energy transferred from the x-ray beam to charged particles per unit mass in the medium of interest. For diagnostic x-ray procedures, this is equivalent to absorbed dose in the specified medium (e.g. air, soft tissue, bone). Kerma is measured in G*y*.

Dose Constrain: These are dose limiting policies for patients, staff and the general public. A prospective and source-related restriction on the individual dose from a source, which provides a basic level of protection for the most highly exposed individuals from a source, and serves as an upper bound on the dose in optimization of protection for that source. For occupational exposures, the dose constraint is a value of individual dose used to limit the range of options considered in the process of optimization. For public exposure, the dose constraint is an upper bound on the annual doses that members of the public should receive from the planned operation of any controlled source.

Diagnostic Reference Level Quantity: is a commonly and easily measured or determined radiation metric that assesses the amount of ionizing radiation used to perform a medical imaging task.

Diagnostic Reference Level Value: an arbitrary notional value of a DRL quantity set at 75^{th} percentile of the distribution of the mean doses of the distribution of the DRL quantity obtained for surveys.

Diagnostic Reference Level Process: is the cyclical process of establishing DRL values, using them as a tool for optimization.

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Review

2.1.1 Diagnostic reference Levels

Diagnostic reference levels were first mentioned by the International Commission on Radiological Protection (ICRP) in 1990 and subsequently recommended in greater detail in 1996 from the 1996 report (ICRP 73, 1996).The Commission now recommends the use of diagnostic reference levels for patients. These levels which are a form of investigation level, apply to an easily measured quantity, usually the absorbed dose in air, or in a tissue equivalent material at the surface of a simple standard phantom or representative patient. The diagnostic reference level is intended for use as a simple test for identifying situations where the level of patient dose or administered activity is unusually high. If it is found that procedures are consistently causing the relevant diagnostic reference level to be exceeded, there should be a local review of procedures and the equipment in order to determine whether the protection has been adequately optimized. If not, measures aimed at reduction of dose should be taken (Jenia and Madan, 2015).

Diagnostic reference levels are subject to professional judgment and do not provide a dividing line between good and bad practice. It is inappropriate to use them for regulatory or commercial purposes. Diagnostic reference levels apply to medical exposure, not to occupational and public exposure. Thus, they have no link to dose limits or constraints. Ideally, they should be the result of a general optimization of protection. In practice, this is unrealistically difficult and it is simpler to choose the initial values as a percentile point on the observed distribution of doses to patients. The values should be selected by

professional medical bodies and reviewed at intervals that represent a compromise between the necessary stability and the long-term changes in the observed dose distributions. The selected values will be specific to a country and or region (Jenia and Madan, 2015). Diagnostic reference levels are not the suggested or ideal dose for a particular procedure or an absolute upper limit for dose. Rather, they represent the dose level at which an investigation of the appropriateness of the dose should be initiated. In conjunction with an image quality assessment, a qualified medical physicist should work with the radiographer to determine whether or not the required level of image quality could be attained at lower dose levels. Thus, reference levels act as "trigger levels" to initiate quality improvement. Their primary value is to identify dose levels that may be unnecessarily high - that is, to identify those situations where it may be possible to reduce dose without compromising the required level of image quality. In keeping radiation dose to patients to a minimum in hospitals, it is needful to be able to estimate prior to medical examination the dose to patients as a function of radiographic exposure parameters (Edmonds, 2014). Monitoring of patients during the examination has been a major way of assessing radiation dose received in diagnostic and therapeutic radiology (Egbe *et al*., 2010). For the purpose of optimization in radiation protection, dose delivered to patients during diagnosis is studied with assessment of image quality (Johnson and Brenan 2012). This is a common practice in many parts of the world for those who present with clinical cases requiring x-ray examination which are often times not properly done and this is largely due to lack of facilities and suitable qualified personnel. As a result, there is no sufficient information about patient's radiation dose (Ragulla *et al*., 2014).

Radiation dosimetry is required to assess the risk associated with x-ray exposure and to inform medical radiation professionals of the levels of exposure received (Shrimpton *et al.*, 2011). Patient dose measurement is an integral part of optimization process (Sharifat *et al.*,

2010). Quality management of any medical x-ray imaging procedure shouldinclude monitoring of radiation dose (Shrimpton *et al.,* 2011). A major goal of the quality program for all forms of x-ray imaging is to minimize radiation risk without degrading clinical performance (Shrimpton *et al.,* 2011). In order to interpret correctly the relationship between a change in the numerical value of a quantity used as a diagnostic reference level and the corresponding change in patient tissue doses that determine the relative patient risk, the following considerations are important:

(a) The numerical value of the diagnostic reference level should be tied to defined clinical and technical requirements for the medical imaging task. A selected numerical value for one situation may not be applicable to different clinical and technical requirements, even if the same area of the body is being imaged. The requirements can be general or specific.

(b) The relative tissue dose distribution in the body should not change appreciably among patients undergoing the selected medical imaging task. A proportional change in the measured quantity should correspond to a proportional and uniform percentage change in the individual tissue doses. If the relative tissue-dose distribution in the body is appreciably different from that used to establish the diagnostic reference level, due to a different field size, field location, beam quality or other technical factor that alters the internal dose distribution, then interpretation of a change in the measured quantity with regard to the change in tissue doses (and therefore the patient risk) would be ambiguous.

In setting diagnostic reference levels, regional and local authorized bodies and professional groups should be cognizant of these considerations.

2.1.2 Objective of Diagnostic Reference Level

The objective of Diagnostic reference level (DRL) is to avoid excessive radiation to the patient that does not contribute additional clinical information and value to the medical imaging task(IAEA,2002).

2.1.3 Uses of a Diagnostic Reference Level

Diagnostic Reference Level is used;

a) To improve a local regional or national distribution of observed results for a general medical imaging task, by reducing the frequency of unjustified high or low dose values;
b) To promote attainment of a narrower range of values that represent good practice for a more specific medical imaging task; or
c) Typically, diagnostic reference levels are used as investigation levels (as a quality assurance tool), they are advisory and not a dose limit, therefore should not be applied to individual patients.
d) The application of a Facility Reference Levels (FRLs) is for the local imaging facility to establish a reference dose for their common imaging protocols that can be used for internal and external comparison.
e) DRLs can also be used for international comparative dosimetry.

2.1.4 Applications of DRLs

DRLs, together with an optimization process, help reduce unnecessary patient doses and the consequent radiation risks.

A diagnostic reference level can be used to:

i. Improve local, regional, or national distributions of observed doses for a general medical imaging task, by reducing the frequency of unjustified high or low dose values
ii. Promote a narrower range of doses that represent good practice for a more specific medical imaging task
iii. Promote an optimum range of doses for a specified medical imaging protocol
iv. Provide a common dose metric for the comparison of FRLs between facilities, protocols and modalities
v. Assess the dose impact of the introduction of new protocols
vi. Provide compliance with the relevant state and territory regulatory requirements

Appropriate local review and action is required when the doses observed are consistently outside the selected diagnostic reference level, unless clinically justified. However this elevated dose with clinical justification should be an exception rather than the norm across multiple DRLs.

2.1.5 Uses of facility Reference Levels (FRLs), National and International DRLs

FRLs, NDRLs and International DRLs can be used to:

i. define radiation doses for common procedures
ii. compare DRLs protocol with other similar protocols
iii. compare with other imaging facilities

iv. compare with other regional or national DRLs

v. provide a comparative dose metric for optimization strategies

vi. Comply with state and territory regulatory requirements.

2.2 International and National Regulatory Requirements on DRLs

i. Australian Radiation Protection and Nuclear safety Agency (ARPANSA): State and territory regulatory bodies require implementation of the Australian Radiation protection and nuclear Agency (ARPANSA) code of practice (RPS14) which requires the development and application of diagnostic reference levels. The ARPANSA. Code of Practice (RPS14), Section 3.1.8 states that:"the responsible Person must establish a program to ensure that radiation doses administered to a patient for diagnostic purposes are:

a) Periodically compared with diagnostic reference levels (DRLs) for diagnostic procedures for which DRLs have been established in Australia; and

b) If DRLs are consistently exceeded, they should be reviewed to determine whether radiation has been optimized."

In addition, the ARPANSA Safety Guide, Section 7.8, suggests that:

"as part of the QA program, patient dose surveys are undertaken periodically to establish that the doses are acceptable when compared with published DRLs"

The Department of Health and Ageing (DoHA) Diagnostic Imaging Accreditation Scheme (DIAS), the Royal Australian and New Zealand College of Radiology (RANZOR) Quality and Accreditation Program and the Australian College on Healthcare Standards (ACHS) Equip 5 Accreditation Standards all require compliance with state and territory regulation whim in turn requires compliance with the state and territory regulation which in turn requires compliance with the ARPANSA. Code of Practice (RPS 14). (ARPANSA, 2008)

ii. Nigerian Nuclear Regulatory Authority medical ionizing radiation regulation. The Nigerian basic ionizing radiation regulations 2003 in Part 1 of the radiation protection act talks about dose constraint and dose limit. Dose constraint according to the act means a restriction on the prospective doses to individuals, which may result from a defined source. Dose limit means in relation to persons of a specified class, the limit on effective dose or equivalent dose specified in the fourth schedule to these regulations in relation to a person of that class. Dose record means in relation to a person, a record of the doses received by that person as a result of his exposure to ionizing radiation being the record made and maintained on behalf of the employer by the authorized dosimetric service provider in accordance with regulation 48 of the regulations.

2.3 Dosimetric Quantities commonly used to estimate DRLs

From a practical perspective, the DRL should be expressed as an easily measured patient dose-related quantity for the specified imaging platform, for example, multi-detector computed tomography (MDCT);

i. MDCT examinations - volume computed tomography dose index (CTDIvol mGy) and the dose-length product (DLP, mGy.cm) New CT scanners in accordance with Australian Standards, AS'NZS32002.449, should display the CTDI and/or the DLP on the operator's console after the selection of technique factors and prior to the initiation of x-rays. Average CTDI and total DLP should be available at the end of the scan procedure.
ii. Fluoroscopic examinations - dose area product (DAP, $mGy.cm^2$), screening time (sec).

iii. General Radiographic examinations - either entrance skin dose (ESD, mGy) or the dose area product (DAP, mGy.cm^2)

iv. Mammography – the mean glandular dose (MGD, Gy).

v. Nuclear Medicine-adult reference activity (mBq)

2.3.1Estimating Effective Dose (mSv) as DRL Assessment

Different imaging modalities have different basic dose metrics. To compare these dose metrics and gain some information on the radiation dose delivered and the consequent population statistical risk it is useful to convert the individual DRL dose metrics into approximate effective dose (ED, mSv).

It should be noted that these effective dose conversions are to be used with caution. They should not be applied to an individual but rather are statistical estimates of a dose and risk to a population who may receive that dose.

2.4 International Atomic Energy Agency accepted standards for DRLs in Countries

2.4.1 Australian National DRLS

ARPANSA, in collaboration with other stakeholders has developed the National DRL Service which facilities can use to compare their doses with the National DRLs and from which dose data will be used to develop and update National DRLs due to its significantly higher population dose contribution, the National DRL Service will initially be applied to MDCT. This will be followed by interventional fluoroscopic procedures, nuclear medicine, mammography and general radiography & fluoroscopy. The ARPANSA NDRL project will initially give emphasis to the higher dose modalities. ARPANSA will provide an easy to use tool for all modalities but until these are developed and distributed each

facility is encouraged to undertake paper based local surveys to establish their own FRLs as soon as possible.

Australian national DRLs for adult and pediatric MDCT are now available and are shown in tables 2.1 (ARPANSA, 2014). One of the key issues in the regulations that govern the use of ionizing radiation in medicine is the establishment and use of diagnostic reference levels (Hart *et al.,* 2010). Regulations, 2000, require employers to establish and to undertake appropriate reviews if these are consistently exceeded. The regular review of these diagnostic reference level (DRL) at National, Regional and Local levels provide a feedback loop that ensures good practice. (IRMER, 2010)

Table 2.1**:** Australian Adult (15 + years) MDCT DRLs

Australian Adult (15+ years) MDCT Diagnostic Reference Levels		
Adult Protocol	DLP (mGy.cm)	CTDI vol (mGy)
Head	1000	60
Neck	600	30
Chest	450	15
Abdominopelvic	700	15
Chest, AbdoPelvis	1200	30
Lumbar Spine	900	40

Source: (ARPANSA, 2014)

Table 2.2**:** Australian Child (5 – 14 years) MDCT DRLs

Australian Child (15+ years) MDCT Diagnostic Reference Levels		
Child Protocol	DLP (mGy.cm)	CTDIvol (mGy)
Head	600	35
Chest	110	5
AbdominoPelvic	450	10

Source: (ARPANSA, 2014)

Table 2.3**:** Australian Baby/Infant (0 – 4 years)

Australian Baby (10-15 years) MDCT Diagnostic Reference Levels\		
Child Protocol	DLP (mGy,cm)	CTDI vol (mGy)
Head	470	30
Chest	60	2
Abdomino-Pelvic	170	7

Source: (ARPANSA, 2014)

2.4.2 European Reference Levels

European diagnostic reference levels should be used. The currently available European DRLs for diagnostic radiology are given in Table 2.4. In Table 2.6, however, other acceptable levels used in different member states, expressed in $Gycm^2$, are given. The levels relate to frequent and relatively low-dose exposures. The exposures requiring the most attention, however, are those in pediatrics and high-dose examinations such as CT - scans and interventional radiography. At present there are some European DRLs for exposures to children [EUR96a], which are given in Table 2.5. No European values are as yet available for other groups. Nevertheless, in some Member States dose levels are used for interventional radiography.

For nuclear medicine there are no recommended DRLs at a European level. However, some countries such as the UK and the Netherlands have guidance on optimal values for almost all types of examinations produced by the professional groups and approved by the competent authorities (European commission, 1996)

Table 2.4 Examples of Diagnostic Doses, expressed in entrance surface does per image, for single View, 1996 Criteria Reference Does (EUR96)

Radiograph	1996 Quality Criteria Reference Dose Entrance Surface Dose per single view (mGy)'
Chest Posterior Anterior (PA)	0.3
Chest Lateral (LAT)	1.5
Lumber Spine Anterior posterior(AP)	10
Lumber spine Lateral (LAP)	30
Lumber spine Lumbo-Sacral (LSJ)	40
Breast Cranio-Caudal (CC) with grid	10
Breast Medio-Lateral Oblique (MLO) with grid	10
Breast Medio-Lateral (MLO) with grid	10
Pelvis Anterior Posterior (AP)	10
Skull Posterior Anterior (PA)	5
Skull lateral (LAT)	3
Urinary Tract either as firm or before administration of contrast medium	10
Urinary Tract after administration of contrast medium	10

- Criteria for radiation dose to patient: The entrance surface dose for standard-sized patients is expressed as the absorbed dose in air (mGy) at the point of intersection of the beam axis with the surface of a standard sized patient (70 Kg body weight or 5 cm compressed breast thickness), backscatter radiant included.

Table 2.5 Examples of Diagnostic Reference Doses in standards five years –old patients, expressed in entrance surface does per image, for single View, 1996 Quality Criteria Reference Does (EUR96)

Radiograph	1996 – 5 – years – old patient Quality Criteria Reference Does Entrance Surface Does per SINGLE VIEW (uGy)'
Chest Posterior Anterior (PA)	100
Chest posterior anterior (AP)	100
Cheat Lateral (LAP)	200
Cheat Anterior Posterior (AP NEWBORN)	80
Skull Posterior Anterior/Anterior (PA/AP)	1500
Skull Lateral (LAP)	1000
Pelvis Anterior Posterior (AP)	900
Pelvis Anterior Posterior (AP – infants)	200
Abdomen (AP/PA with vertical/horizontal beam)	1000
Full spine Anterior posterior (AP)	No values as yet available
Segmental Spine (LAT)	No values as yet available
Segmental Spine (LAT)	No values as yet available

❖ Criteria for radiations dose to the patients: The Entrance surface dose for standards-sized patients is expressed as the absorbed dose in air (uGy) at the point of intersection of the beam axis with the surface of a pediatric patient, backscatter radiation included.

Table 2.6 Dose area products for total examinations (NRPB , 96) and (Nor, 96)

Examination	Reference Dose ,Dose Area Product, Total examination ($Gy\ cm^2$)	
	NRPB,1996	Nor 96
Chest	1	1
Pelvis	5	4
Lumber spine	12	10
Urography	40	20
Barium meal	25	25
Barium Enema	60	50

Source: (NRPB,96)

Table 2.7 Fraction of adult administered activity for age groups of children.

Recommended by pediatric Task group of European Association of Nuclear Medicine. (EANM)

Kg	Fraction of Administered. Activity	Kg	Fraction of adult adm. Act.	Kg	Fraction of adult adm. Activity
3	0.1	22	0.50	42	0.78
4	0.14	24	0.53	44	0.80
6	0.19	26	0.56	46	0.82
8	0.23	28	0.58	48	0.85
10	0.27	30	0.62	50	0.88
12	0.32	32	0.65	52-54	0.90
14	0.36	34	0.68	56-58	0.95
16	0.40	36	0.71	60-62	1.00
18	0.44	38	0.73	64-66	
20	0.46	40	0.76	68	

Source: (NRPB,96)

Table 2.8**:** UK and EU MDCT DRLs

Comparison of Head, Chest, and Abdominal CTDose Values with DRLs

Examination	Mean Value	3rd – Quartile Value	United KingdomStudy (3rd – Quartile Value)	European DRL
Head CT				
CTDIw (mGy)	39	47	66	60
DLP(mGy - cm)	544	527	787	1050
Chest CT				
CTDIw (mGy)	9.3	9.5	17	30
DLP(mGy - cm)	348	447	488	650
Abdominal CT				
CTDIw (mGy)	10.4	10.9	19.0	35
DLP(mGy - cm)	549	696	472	780

Note: Data are mean and 3rd quartile values for the examinations performance in the entire patient sample. CTDIw – weighted CT dose index.

Source:(NRPB,96)

Table 2.9: Recommended diagnostic reference doses for general radiography for individual radiographs on adult patients (Hart et al., 2002)

Radiograph	ESD per radiograph (mGy)	DAPper radiograph (Gy cm^2)
Skull AP/PA	3	-
Skull LAP	1.5	-
Chest PA	0.2	0.12
Chest LAP	1	-
Thoracic spine AP	3.5	-
Thoracic spine LAP	10	-
Lumbar spine AP	6	1.6
Lumber Spine LAP	14	3
Lumber Spine LSJ	26	3
Abdomen AP	6	3
Pelvis AP	4	3

Note: Adult is defined as a personal average size (70 to 80 kg)

Source:(NRPB,96)

Table 2.10**:** Recommended diagnostic reference doses for fluoroscopic/interventional examination on adult patients (Hart et al., 2002)

Examination	DAP per exam ($Gy.cm^2$)	Fluoroscopy time per exam (mins)
Barium(or water soluble) swallow	11	2.3
Barium meal	13	2.3
Barium follow through	14	2.2
Barium (or water soluble) enema	31	2.7
Small bowel enema	50	10.7
Biliary drainage/intervention	54	17
Femoral angiogram	33	5
Hickman line	4	2.2
Hysterosalpingogram	4	1
IVU	16	-
MCU	17	2.7
Nephrostogram	13	4.6
Nephrostomy	19	8.8
Retrograde pyelogram	13	3
Sialogram	1.6	1.6
T-tube cholangiogram	10	2
Venogram (leg)	5	2.3
Coronary angiogram	36	5.6
Oesphageal dilation	16	5.5
Pacemaker implant	27	10.7

Table 2.11 Recommended fluoroscopic/interventional diagnostic reference doses for complete examinations on adult patients (Hart *et al.*, 2002)

Examination	Standard age (y)	DAP per exam ($Gy.cm^2$)
MCU	0	0.1
	1	1.0
	5	1.0
	10	2.1
	15	4.7
Barium meal	0	0.7
	1	2.0
	5	2.0
	10	4.5
	15	7.2
Barium swallow	0	0.8
	1	1.5
	5	1.5
	10	2.7
	15	4.6

Source:(NRPB,96)

Table 2.12 Recommended diagnostic reference levels for CT examinations (CTDIvol and DLP) (Shrimpton *et al.,* 2006)

Patient group	Scan region	CTDIvol (mGy)single slice/multi slice	DLP(mGy.cm)single slice/multi slice
Adults	Brain	55/65	760/930
	Abdomen(liver metastases)	13/14	460/470
	Abdomen & pelvis	13/14	510/560
	(Lymphoma staging or follow up)	22/26	760/940
	Chest (lung cancer)	10/13	430/580
	Chest Hi-res	3/7	80/170
Children	Head	30	270
0-1 year old	Thorax	12	200
5 year old	Head	45	470
	Thorax	13	230
10 year old	Head	50	620
	Thorax	20	370

Doses values for adults relate to 16cm diameter CT dosimetry phantom examination of the head and the 32cm diameter CT dosimetry phantom for examinations of the trunk. All dose values for children relate to the 16cm diameter CT dosimetry phantom.

Source: (Shrimpton *et al.,* 2006)

Table 2.13 Recommended diagnostic reference level for mammography for a typical adult patient.

For film screen examinations using a grid, the mean glandular dose (MGD) is 2 mGy based on the 4.2 cm acrylic American College of Radiologists phantom. Additionally for Digital Mammography, the MGD shall be≤ 1 mGy for 2.0 cm PMMA (2.3 cm 50% adipose, 50% glandular breast) and ≥ 4.5mGy for 6.0 cm PMMA (6.0 cm 50% adipose, 50% glandular breast)

(Source: Shrimpton *et al.*, 2006)

2.4.3 French Diagnostic reference levels (French nuclear safety authority (FNSA))

According to French nuclear safety authority (2008), diagnostic reference levels should be clearly defined, easy to measure, give directly an indication of the importance of the dose delivered. It also allows easy correlations with technical parameters of the examination and should be adopted to all types of equipments. DRLs are established for the most frequent and irradiating routine examination for group of standard size patients (70±3kg) and 20cm anterior posterior trunk thickness or for standard phantoms. DRLs are guides for optimization. DRLs should not be exceeded in routine when examinations are performed in accordance with the procedures (good and normal practice). The goal of DRLs is not to deliver doses constantly lower than DRLs because images of poor quality would not provide the diagnostic information.

In France, DRLs parameters are measured in each institution and naturally while local reviews of DRL parameters are undertaking routinely. Comparison is made with national values and necessary actions are taking when they are exceeded consistently.

2.5 Use of Diagnostic Reference levels to reduce patient dose

The use of diagnostic reference levels as an important dose optimization tool is endorsed by many professional and regulatory organizations, including the ICRP, American College of Radiology (ACR), American Association of Physicists in Medicine (AAPM), United Kingdom (U.K.) Health Protection Agency, International Atomic Energy Agency (IAEA), and European Commission (EC). Reference levels are typically set at the 75th percentile of the dose distribution from a survey conducted across a broad user base (large and small facilities, public and private, hospital and out-patient) using a specified dose measurement protocol and phantom. They are established both regionally and nationally, and considerable variations have been seen across both regions and countries (Matthews and Brennan, 2009). Dose surveys should be repeated periodically to establish new reference levels, which can demonstrate changes in both the mean and standard deviation of the dose distribution. (Marcelo and Elizabeth, 2009).

The use of diagnostic reference levels has been shown to reduce the overall dose and the range of doses observed in clinical practice. For example, U.K. national dose surveys demonstrated a 30% decrease in typical radiographic doses from 1984 to 1995 and an average drop of about 50% between 1985 and 2000 (Hart and Wall, 2005 ;Shrimpton*et al*., 2011).. Thus, data points above the 75th percentile are, over time, moved below the 75^{th} percentile – with the net effect of a narrower dose distribution and lower mean does. (Shimpton *et al*., 2011, Hart and wall, 2004)

To promote attainment of an optimum range of values for a specific medical imaging goal, appropriate local review and action is taken when the value observed in practice is consistently outside the selected upper or lower Level. This process helps avoid unnecessary risk for the associated radiation health effects.

2.6 CT Diagnostic Reference Levels from other countries

Diagnostic reference levels must be defined in terms of an easily and reproducibly measured dose metrics using technique parameters that reflect those used in a site's clinical practice. In radiographic and fluoroscopic imaging, typically measured quantities are entrance skin dose for radiography and dose area product for fluoroscopy. Dose can be measured directly with TLD or derived from exposure measurements. Some Authors survey typical technique, factors and model for dose metric of interest. (Babalola, 2004 and Damijan *et al.,* 2006).

In CT, published diagnostic reference levels use CTDI-based metrics such as CTDIw, CTDlvol, and DLP. Normalized CTDI values (CTDI per mAs) can be used by multiplying them by typical technique factors, or CTDI values can be measured at the typical clinical technique factors. Tables 2.10, 2.11 and 2.12 below provide a summary of CT reference levels from a variety of national dose surveys. (Godwin and Racheal, 2010)

2.6.1 Definitions and examples

Definitions of the general medical imaging task, more specific medical imaging task, and specified medical imaging protocol are below, along with examples of quantities and their application to diagnostic reference levels. The term general medical imaging task refers to an imaging task for a general clinical purpose, with minimum specification of other factors, e.g. a posterior anterior (PA) chest radiograph with the clinical purpose and technique factors unspecified. Examples of quantities and their application to improve a regional, national or local distribution of observed values for a general medical imaging task are:

a) Entrance surface air kerma (in air, no backscatter) or entrance surface dose (in specified material, with backscatter) in mGy, for a given radiographic projection
b) Dose area product (DAP) in mGy cm^2 for a given type of fluoroscopic examination that has a well-defined anatomical region of clinical study example is barium enema.
c) Administered activity (A) in mBq for a given nuclear medicine imaging task using a given radiopharmaceutical (e.g. lung perfusion with Tc-99m MAA).

The term more specific medical imaging task refers to an imaging task for a clearly defined clinical purpose, but allows for differences among medical facilities in other technical and clinical details, example is PA chest radiograph with the clinical purpose and the general technique (such as high kVp) specified, but the detailed technique factors unspecified. Examples of quantities and their application to promote attainment of a narrower range of values that represent good practice for a more specific medical imaging task are:

a) Entrance surface air kerma (in air, no backscatter) or entrance surface dose in specified material with backscatter in mGy, for a specific radiographic imaging task.

The clinical purpose is defined, but the x-ray equipment, technique factors, and image quality criteria may vary among facilities;

b) Dose length product (DLP) in mGy. cm for a given type of computed tomography (CT) examination that has a well-defined anatomical region of clinical study (e.g. routine abdominal CT scan), with specified clinical objective, image quality criteria and technical factors. The x-ray equipment (the CT system) may vary among facilities.

c) Dose area product (DAP) in mGy cm^2 for a specific fluoroscopic examination. The clinical purpose is clearly defined, but the type of equipment, technique factors and patient characteristics may differ within or among facilities. The relative tissue dose distribution is expected to be minimally variable, such that a proportional change in DAP corresponds to a nearly proportional change in absorbed dose for each of the irradiated tissues.

The term specified medical imaging protocol refers to a clinical protocol with a fully defined set of specifications that is followed, or serves as a nominal baseline, at a single facility (or several allied facilities), for example a protocol for PA chest radiograph that specifies the clinical purpose, the technical conduct of the procedure, the image quality criteria, any unique patient characteristics, and other appropriate factors. Examples of quantities and their application to promote attainment of an optimum range of values for a specified medical imaging protocol are:

i. Milliampere second (mAs) for a specific CT protocol. The clinical purpose, type of equipment, technical factors and patient characteristics are defined.

ii. Administered activity (A) in MBq for a specific imaging protocol for single photon emission computed tomography (SPECT). The clinical purpose, type of equipment, technical factors and patient characteristics are defined.

2.6.2 CT Diagnostic Reference Levels from the ACR CT Accreditation Program

Beginning in 2002, the American College of Radiology (ACR) CT Accreditation Program has required sites undergoing the accreditation process to measure and report CTDIw and CTDIvol for the head and body CTDI phantoms. The typical acquisition parameters for a site's adult head , pediatric abdomen , and adult abdomen examinations were used to calculate CTDIw and CTDIvol. For the pediatric exam, sites were instructed to assume the size and weight of a typical 5-year-old child, and doses were measured using the 16-cm phantom. The average and standard deviation of these doses were calculated by year. Summary data for CTDIvol are shown in table 2.12 below.In every case except adult abdomen examination in 2003, both the average dose and the standard deviation fell for each consecutive year. Thus, the establishment of CT reference levels in the United States appears to have helped reduce both the mean dose and the range of doses for these common CT examinations.

Although dose reduction was observed for adult head CT examinations, feedback from sites undergoing accreditation indicated that sites were systematically reducing dose to below the 60 mGy level, even though complaints with regard to head image quality at this dose level were common. The purpose of reference levels is to decrease dose levels only when doing so does not compromise' image quality or patient care. Changes in technology (multi-detector-row CT) and practice (3-5 mm image widths) have occurred since the U.K. dose survey that gave rise to the 60 mGy level for the adult head. (ARPANSA, 2014)

2.6.3 CT Diagnostic Reference Levels for other CT Applications

Because the practice of CT encompasses many more examination types than routine head and body examinations, reference levels for many common CT examinations are important for continuing dose optimization efforts in CT. To this end, several national surveys have

begun to assess a broader range of examination types. Additionally, the ACR has begun a project to automatically collect CTDIvol data directly from the DICOM header, thus allowing considerably faster accumulation of data sufficient to establish reference levels for additional examination types. This information will extend the value of the diagnostic reference level concept to the majority of CT applications, enabling individual CT users and the community at large to answer the question, "What doses are typical and what doses are too much (Marcelo and Elisabeth, 2009; Johan and Indrastuti,2012)

Table 2.14Adult Diagnostic Reference Levels for CTDlw (mGy) and DLP (mGy.cm)in some countries (ARPANSA,2014).

Adult Diagnostic Reference Levels for CTDlw (mGy) and DLP (mGy.cm)

	Head		Abdomen		Abdomen & Pelvis			
	Whole Exam		Whole Exam		Pelvis		Whole Exam	
	CTDIw	DLP	CTDlw	DLP	CTDlw	DLP	CTDlw	DLP
EC 1999	60	1050	35	900	-	-	35	780
ACR 2002	602	-	35	-	-	-	-	-
UK 2003	-	930	20	470	-	-	20	560
Germany 2003	60	1050	25	770	-	-	24	1500
Switzerland 2004	60	800	20	710	30	540	-	-
Taiwan 2007	72	850	31	680	28	520	-	-

Key: EC = European Commission; ACR = American College of Radiology; UK = United Kingdom.

Source: Shrimpton *et al.*, 2009

Table 2.15Adult Diagnostic Reference Levels for CTDlw (mGy) and DLP (mGy.cm)

Adult Diagnostic Reference Levels for CTDlw (mGy) and DLP (mGy.cm)

	Head		Abdomen		Abdomen & Pelvis			
	Whole Exam		Whole Exam		Pelvis		Whole Exam	
	CTDlvol	DLP	CTDlvol	DLP	CTDlvol	DLP	CTDlvol	DLP
Sweden 2002	75	1200	25	-	-	-	-	-
UK 2003	65 – 100	930	14	470	-	-	14	560
Netherlands 2008	-	-	-	-	-	-	15	700
EC 2004	60	-	25	-	-	-	15	700
ACR 2008	75	-	25	-	-	-	-	-

EC = European Commission; ACR = College of Radiology; UK = United Kingdom

Source: Shrimpton *et al.*, 2009

Table 2.16 CTDlvol (mGy) statistics from the first 3 years of the ACR CT Accreditation Program

CTDlvol (mGy) statistics from the first 3 years of the ACR CT Accreditation Program

	2002	2003	2004	2002	2003	2004	2002	2003	2004
	Adult Head			adult Abdomen			Pediatric Abdomen		
Mean	66.7	58.5	55.8	18.7	19.2	17.0	17.2	15.9	14.0
Std. Dev.	23.5	17.5	15.7	8.0	8.7	7.6	9.7	8.6	7.0
75%	76.8	63.9	60.0	22.6	23.4	21.1	9.7	20.5	18.4
90% tile	99	82.2	74.0	29.5	30.6	25.8	20.6	25.6	23.4

2.7 Fluoroscopically-guided Interventional Procedures

For fluoroscopically-guided interventional procedures, diagnostic reference levels, in principle, could be used to promote the management of patient doses with regard to avoiding unnecessary stochastic radiation risks. However, the observed distribution of patient doses is very wide, even for a specified protocol, because the duration and complexity of the fluoroscopic exposure for each conduct of a procedure is strongly dependent on the individual clinical circumstances. A potential approach is to take into consideration not only the usual clinical and technical factors, but also the relative "complexity" of the procedure. More than one quantity (multiple diagnostic reference levels) may be needed to evaluate patient dose and stochastic risk adequately(Mahesh, 2001).Diagnostic reference levels are not applicable to the management of deterministic radiation risks (radiation-induced skin injuries) from fluoroscopically-guided interventional procedures. In this case, the objective is to avoid deterministic effects in individual patients undergoing justified, but long and complex procedures. The need here is to monitor in real time whether the threshold doses for deterministic effects are being approached or exceeded for the actual procedure as conducted on a particular patient. The relevant risk quantity is absorbed dose in the skin at the site of maximum cumulative skin dose. A helpful approach is to select values for maximum cumulative absorbed dose in the skin at which various clinical actions regarding the patient's record or care (related to potential radiation-induced skin injuries) are taken (ICRP, 2000). Then, during actual procedures, appropriate quantities that can help indicate the maximum cumulative absorbed dose in the skin is monitored.

Table 2.17 Diagnostic Reference Levels and Achievable Doses for Adult and Pediatric x-ray Examinations (incident air kerma, free-in-air)

Examination	DRL (mGy)	AD (mGy)
Adult PA chest (23cm), without grid	0.15	0.11
Pediatric PA chest (12.5cm), without grid	0.06	0.04
Pediatric PA chest (12.5cm), with grid	0.12	0.07
Adult AP abdomen (22cm)	3.4	2.4
Adult AP lumbosacral spine (22cm)	4.2	2.8

Source: (Shrimpton *et al.*, 2006)

DRLs and Absorbed dose are provided for abdominal fluoroscopy in Table 2.18. For fluoroscopy, this practice parameter bases DRLs and Ads on a measurement of air kerma at the skin plane (with some backscatter due to the geometry) to a standard phantom using the x-ray technique factors the facility would typically select for an average size adult patient. Published reference levels are currently not available for pediatric patients.

The phantoms and details of measurements are provided in NCRP Report 172. In Table 2.18 22cm, PA abdomen was modeled by phantom measurements with a grid.

Table 2.18: Diagnostic Reference Levels and Achievable Doses for Under Table

Adult (22cm PA Abdomen) Fluoroscopy Imaging

Phantom: Adult PA Abdomen with grid	DRL	AD
Upper GI fluoroscopy, without oral contrast media	54 mGy min^{-1}	40 mGy min^{-1}
Upper GI fluoroscopy, with oral contrast	80 mGy min^{-1}	72 mGy min^{-1}
Phantom: Adult PA Abdomen with grid	DRL	AD
Fluorography image, without contrast		
Film	3.9 mGy	2.5 mGy
Digital	1.5 mGy	0.9 mGy
fluorography image, with contrast		
Film	27.5 mGy	18.7 mGy
Digital	9.9 mGy	5.3 MGy

Source: Shrimpton *et al.*, 2009

2.7.1 Computed Tomography

The DRLs and Ads for CT are based on the volume CT dose index ($CTDI_{vol}$). The International Electrotechnical Commission (IEC) has specifically defined the $CTDI_{100}$, weighted $CTDI_w$, and $CTDI_{vol}$ (IEC,2003). For the values reported below, the 16cm diameter phantom was used for all head and pediatric abdomen CT examinations, and the 32 cm diameter phantom was used for all adult body CT examinations. (Tsai and Tsung, 2007).

Table 2.19: Diagnostic Reference Levels and Achievable Doses for Adult and Pediatric CT ($CTDI_{vol}$)

	Patient Lateral Dimension	CTDI Phantom Diameter (cm)	DRL (mGy)	AD (mGy)
Adult head	16	16	75	57
Adult abdomen-pelvis	38	32	25	17
Adult Chest	35	32	21	14
Pediatric 5 years old abdomen-pelvis	20	16	20	14

The recommended CT DRLs were derived from analysis of the data gathered from first 3 years of the ACR CT Accreditation Program (Shrimpton*et al.*, 2003), 2005 CT National Evaluation of X-Ray Trends (NEXT) data and NCRP Report 172. The LAT dimensions are for average patients of the specified age (Tsai and Tsung, 2007).A recent publication from six pediatric hospitals is based on actual patient data and suggests a DRL for a 20cm LAT 5 year old abdomen-pelvis of 14 mGy and an AD of 11 mGy. Only patients of these sizes should be compared against these values (Hart*et al.*,2011).

2.8 Legal Implementation and Practical Application of DRLs

As stated previously, a DRL is a level set for a standard procedure, for groups of standard-sized patients or a standard phantom and not for individual exposures and individual patients. Taking this into account, if this level is consistently exceeded a review of procedures and/or equipment should be made and corrective action should be taken as

appropriate (IAEA,1994).However, exceeding this level does not automatically mean that an examination is inadequately performed and meeting this level does not automatically mean good practice, as there may be poor image quality(IAEA, 1994). As procedures for examinations are not identical, each procedure needs its own DRL as follows:

i. DRLs should be set by Member States taking into account individual national or regional circumstances such as the availability of equipment and training. However, as such circumstances do not differ dramatically between the Member States of the European Union; harmonized levels might be feasible and are certainly preferable. If Member States wish, in the first instance the proposed DRLs published by the EU in 'European Guidelines on Quality Criteria for Diagnostic Radiographic Images' [EUR96] can be used for radio-diagnosticpurposes.
ii. The values should be selected by professional medical bodies and reviewed at intervals that represent a compromise between the necessary stability and the long-term changes in observed dose distributions. They should be adequately adapted to new techniques or methods.
iii. In nuclear medicine, it does not seem feasible at present to set harmonized levels as administered activities differ widely between different countries. However, if the radiopharmaceutical used is the same, it is worth considering why in some Member States for some examinations higher administered activities are used than in other Member States, while for other examinations it is the other way round.
iv. In principle, DRLs are applicable for standard procedures in all areas of diagnostic radiology, both in radiodiagnostic and nuclear medicine. They are, however, particularly useful in those areas where a considerable reduction in individual or collective doses may be achieved or where a reduction in absorbed dose means a relatively high reduction in risk:

(a) frequent examinations, including health screening;

(b) high-dose examinations such as CT and procedures which require long fluoroscopy times, such as for interventional radiology; and

(c) Examinations with more radiosensitive patients, such as children.

However, it should be recognized that it is rather more difficult to establish DRLs for CT, interventional radiology and groups of children than it is for more frequent, less complex exposures.

Therefore priority could be given to the more simple and frequent examinations.

(d) After the DRLs have been established, the patient dose either in standard phantoms or groups of standard-sized patients should be assessed on equipment in every room of every radiological facility periodically, with the long-term aim of annual assessments, and after every major change or service. These measured doses should be compared with the pre -established DRLs.

(e) There are two different methods for applying DRLs: using a phantom or using patients.

The use of a phantom has some advantages. Normally one or two exposures for each view, for each examination type and for each item of radiological equipment are sufficient. However, using a phantom is only possible if:

i. the DRLs are set for a phantom and that specific (type of) phantom is available for all radiological facilities, or

ii. Conversion factors from the phantom to patients are available.

(f) For some examinations the number of patients available in a relatively short period is insufficient. Moreover, patients can differ widely in size and shape, so in

fact there are only a few 'standard-sized patients'. The report quotes as an example DRLs developed for standard-sized patients with 20 cm AP trunk thickness and 70 kg weight [EUR96]. [EUR96] recommends that measurements be performed on standard-sized patients or patients close to standard size, preferably with an average weight, that is 70±10 kg. For mammography, a standard phantom should be used.

(g) Because of a shortage of standard-sized patients some countries take all patients available in the measurement period and take the average of the dose results as the outcome for a standard-sized patient. This will give a reasonable idea of the dose, provided that the number of patients is not too small: say, a minimum of 10 patients. As people's size and shape also differ between populations, a typical range of patient per country can be assessed. For the use of harmonized DRLs, correction factors should be assessed and applied.

(h) If the measured doses on a sample of standard-sized patients or on a standard phantom for a standard procedure consistently exceed the relevant DRL, a local review of the procedures and the equipment should be performed.

(i) These DRL-related reviews will cause, in most cases, a reduction of the doses in the upper end of the tail of the curve giving the number of examinations and their doses. So, if for example, national authorities or professional bodies set the DRL at the 75th percentile or some other percentile of the dose curve in diagnostic radiology for a particular examination, this value should decrease over time. Moreover, both in diagnostic radiology and nuclear medicine new techniques and improved procedures could influence dose distribution or administered activity in either direction.

(j) As mentioned before, meeting the DRL does not always mean that good practice is performed. Quality assurance including quality control should be maintained even if the DRL is not exceeded and particularly so if the doses are far below the DRL.

(k) Moreover, dose is not the only aspect: constantly checking image quality and a periodical clinical audit process will optimize the system.

(l) DRLs are also an important tool for clinical audit, which can provide a basis for a retrospective evaluation and for recommendations to improve procedures.

2.9.1 Procedures for Establishing DRLs in Diagnostic Radiology

(i) In accordance with the European commission, 1996, DRLs should be established both for diagnostic radiology and for nuclear medicine, and if they are consistently exceeded investigation and appropriate corrective action should be taken. Therefore, in diagnostic radiology this level should be higher than the median or mean value of the measured patient doses or doses in a phantom. Given that the curve giving the number of examinations and their doses is usually skewed with a long tail, the level of the 75th percentile seems appropriate. The use of this percentile is a pragmatic first approach to identifying those situations in most urgent need of investigation.

(ii) DRLs for diagnostic radiology should be based on doses measured in various types of hospitals, clinics and practices and not only in well-equipped hospitals. Examples of DRLs which have already been used for several years in various Member States are given in Table 2.13. These values represent the 75th percentile entrance surface doses measured in surveys and trials carried out in 1991/2 in different Member States [EUR96]. Table 2.14, gives DRLs expressed in dose area products (DAPs).If Member States wish to establish their own national DRLs, measurements have to be performed. Entrance surface doses, dose area products or other dose related

parameters can be used. Appendix I of [EUR96], [Nor96] and [NRP92] give methods of dose measurement to check compliance with the criteria and provide guidance on sampling of hospitals.

(iii) As mentioned before, because patients and the information required differ widely, DRLs are only applicable to standard procedures, standard phantoms or groups of standard-sized patients, and for specific groups of children distinguished by age, size and weight.

(iv) DRLs can be assessed using entrance surface doses, measured with a TLD fixed on the patient's body, or the DAP ($Gycm^2$).

The DAP is more practical because

(i) the whole examination is recorded;

(ii) the position of the patient in the beam is less important than it would be with a TLD, so the measurement does not interfere with the examination of the patient and

(iii) there is no need to disturb the patient with the measurements.

there are also some disadvantages in using the DAP. As the absorbed organ dose needs to be measured, there should be a fixed relationship between the DAP and the absorbed dose. However, this is sometimes not the case, especially in pediatrics, and when fluoroscopy is used as in cardiology and interventional radiology. In pediatrics, where small areas are exposed, the DAP can be low while the absorbed dose is high. On the other hand, when a large area is exposed, the DAP can be high but the absorbed dose low. Furthermore, in fluoroscopy the field size is often changed during the procedure.However, suitable devices to overcome these problems are not widely available, but DAPmeters are, and use of DAP

concerning DRLs is recommended. Nevertheless ,the disadvantages should be recognized and other, additional measurements, e.g. skin dose measurements, should be performed in the case of non-standard pediatric or fluoroscopic procedures (Shrimpton *et al.,* 2009).

i. DRLs are particularly useful for more common examinations, or examinations which may involve high doses or are frequently performed, such as chest posterior anterior (PA) and lateral (LAT), dental radiography, lumbar spine anterior posterior (AP), lateral (LA T) and the lumbo-sacral joint (LSJ), which give relatively high doses and which are frequently performed;

ii. mammography: the breast is, relatively a highly radiosensitive organ and in screening programme, mammography is used on healthy persons;

iii. barium enema, which is a complex examination requiring several views and fluoroscopy;

iv. coronary angiography and some interventional radiological procedures such as Percutaneous Transluminal Coronary Angioplasty (PTCA), which require long fluoroscopy times and (therefore) give high doses;

v. Types of CT-examinations giving high doses, such as Brain General, Face and Sinuses, Chest General, Abdomen General, Lumbar Spine and Pelvis General.

vi. When setting DRLs for procedures performed with digital systems it is important to remember that the level of image quality can be selected by the user, or automatically set by the x-ray system. In either case,

a. the selected level of image quality must be justified by clinical requirements, otherwise the patient dose will be increased without clinical justification;

b. the x-ray system and the image processing software must be optimized. If not, the patient dose will be increased without a better outcome;

c.as digital images are very easy to obtain, the practitioner should be aware of the patient dose per image and should limit the number of images to what is strictly necessary for the diagnosis of a particular patient.

vii When performing fluoroscopy, one has to be aware that the automatic brightness control may have been adjusted to an increased level due to deterioration of the image chain, meaning that patient doses from fluoroscopy may be abnormally high.If examinations are performed for which DRLs are not available, it is recommended to use the mean number of images and the mean total fluoroscopic time as temporary DRLs.

viii Last but not least, human factors are involved. Doses can be unnecessarily high due to inattention, indifference or too much work pressure, although they may sometimes also be due to individual reluctance to accept generally-accepted standard procedures. DRLs can encourage changes in working procedures by showing what is possible in other departments gives an activity uptake comparable to that for adults but for children aged under 10 tends to result in a low count density, e.g. due to relatively larger organ mass or a shorter retention time. The European Association of Nuclear Medicine's Task Group on Pediatrics (EANM90), using nomograms for surface area, has produced a list of tractions of adult activity (Table 3.3) which give the same count density as that for an adult patient, although the effective dose is higher. These fractions are suitable for most nuclear medicine examinations. Both the first two methods require a minimum activity of 1/l0th of the adult value, otherwise imaging times may be very long in children and it might be difficult to keep them still (Table 3.4).

2.10 THEORETICAL REVIEW

2.10.1 Radiation

Radiation refers to the propagation of waves and particles through space and includes both electromagnetic radiations, atomic and sub-atomic particle radiation. Electromagnetic radiation has a broad continuous spectrum of energy that includes visible light, radio waves, micro waves, x-rays, gamma rays, infrared and ultraviolet radiation. All EM radiation travel in the speed of light. Particle radiation includes alpha and beta particles, neutrons, protons and heavy ions. The speed and energy of particle radiation depends on the source of radiation and any subsequent interaction of particle with matter (Bushong, 1993).

2.10.2 Types of radiation

There are basically two types of radiation:

1. Ionization radiation.
2. Non ionization radiation

2.10.3 Ionizing radiation

Ionizing radiation has enough energy to remove electron from an atom. Types of ionizing radiations (see figure 2.1) includes:

i. Alpha radiation (α) consist of a fast moving helium nucleus and is stopped by a sheet of paper.
ii. Beta radiation (β) consist of electrons, is halted by an aluminum plate.
iii. X-radiation consists of high energy photon but less than that of gamma radiation passes through dense material.

iv. Neutron (n) radiation consists of free neutrons that are blocked using light elements like hydrogen, which slow and or capture them.

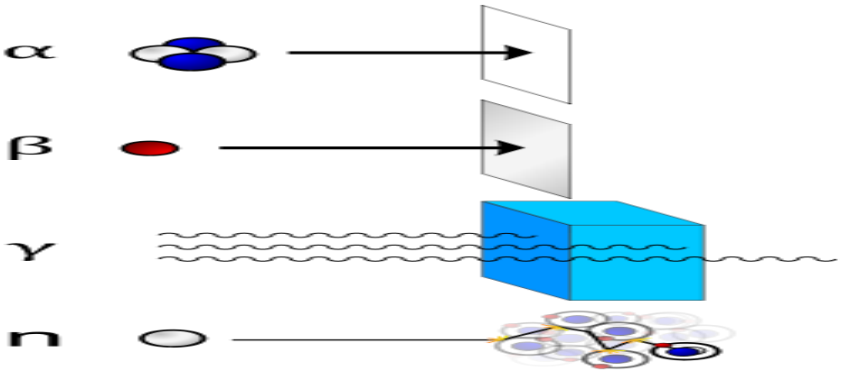


Figure 2.1: Penetrating power of types of ionizing radiation.

Source: Curry *et al.*, (1995)

2.10.4 Non ionizing radiation

This refers to any type of electromagnetic radiation that does not carry enough energy per quantum to ionize molecules or atom that is to completely remove an electron from an atom or molecule. Instead of producing charged ions when passing through matter, it only have sufficient energy for excitation (movement of an electron to higher energy state). Types of non-ionizing radiation includes: visible light, infrared light, microwave, radio-wave (Bushong, 1993).

2.10.5 Source of radiation

There are two main sources of radiations

i. Natural sources: Radon gas is a natural source of which is about 50% of the total of natural sources. It comes from uranium buried in rocks and in the soil. Uranium has a half-life of millions of years. Radon from the ground spreads through the air. Its concentration level in air is low but in a closed space such as house it is much higher

and radiation protection is needed. Another source of radiation is due to Cosmic ray from space, stars, sun when they interact with atmospheric atoms. This gives an exposure of about 20 μSV annually to people on the ground. Gamma radiation is also obtained from radioactive nuclide in the soil, rocks and building materials. Similarly, the main natural sources of radiation are radon, cosmic rays, gamma radiation from rocks and soil, radioactive nuclides in food and drink (Curry *et al*., 1995).

ii. Artificial sources: Patients are exposed to radiation in x-ray routine examinations when radiographs are taken for injuries and other pathological conditions. These medical examinations produce radiation doses per year of about 350 μSV. Similarly dose is obtained in medical treatment such as radiotherapy where patients may have cancers. Fallout in radiation from the atmosphere takes place when nuclear weapons are tested. Fallout occured in Russia at Chernobyl nuclear station when the reactor went out of control. Milk and animal food from a large area of farms had high doses of radiation at first but test and research literature published in the UK show that it is now small such as 0.1 μSV. An artificial source of radiation includes x-rays, fallout and discharge from nuclear stations (Curry *et al.*, 1995).

2.10.6 Uses of radiation

Radiation is used for different purposes which includes;

i. Medical application

Hospital, Doctors (Such as radiologist, oncologist, cardiologist, dentist) and radiographers use a variety of radiation from different sources to diagnose, monitor and treat a wide assortment of metabolic processes and disease conditions in humans. In fact, diagnostic x-rays or radiation therapy have been administered to about 7 out of every 10 Americans (UNSCEAR, 2000). As a result, medical procedures using

radiation have saved thousands of lives through the detection and treatment of various disease conditions (UNSCEAR, 2000). X-ray and other forms of radiation also have a variety of therapeutic uses when used in this way, they are most often intended to kill cancer tissue, reduce the size of tumour or reduce pain, for example, radioactive iodine (Iodine – 131) is frequently used to treat thyroid cancer, a disease condition that strikes about 11,000 Americans every year (UNSCEAR, 2000).

X-ray machines have also been connected to computers in machines called computerized axial tomography (CAT) or computed tomography (CT) scanners. This imaging modality enables cross-sectional studies and scans of anatomical structures and can pick minute pathologies. UNSCEAR, 2000, estimated that approximately 10 million nuclear medicine procedures are done in hospitals and radiology centers in the United States each year (Curry *et al.*, 1995).

ii Academic application

Universities, colleges, high schools and other academic and scientific institutions use nuclear materials and other forms of radiation from different sources for course work, laboratory demonstrations, experimental research and a variety of health physics applications. Radiation from different sources enable scientists to label substances that pass through plants, animals or our world. This allows researchers to study such things as the paths that different types of air and water pollution take through the environment. Researchers also use low energy radioactive sources in gas chromatography to identity the components of petroleum products, smog and cigarette smoke, and even complex proteins and enzymes (UNSCEAR, 2000). Archeologists also use radioactive substances to determine the ages of fossils and other objects through a process called carbon dating.(Curry *et al*., 1995).

ii Industrial application

There are many uses of radiation in the industry for example food, medical equipment and other substances are exposed to certain types of radiation to kill germs without harming the substance that is disinfected. Medical equipments such as bandages, hypodermic syringes and surgical instruments are sterilized without being exposed to toxic chemicals or extreme heat. Similarly, radiation is used to remove toxic pollutants such as exhaust gases from coal fire powered station and industry (Caroll, 2014).

The Agricultural industry makes use of radiation to improve food production and packaging plant seeds for example seeds can be exposed to radiation to produce improved varieties. Engineers also use gauges containing radioactive substance to measure the thickness of paper products, field levels in oil and chemical tanks and the moisture and density of soils and materials at construction sites. (UNSCEAR, 2000).

iv Nuclear application

Electricity is produced by nuclear fission via splitting the atom. As our country becomes a nation of electric users, we need a reliable, abundant and affordable source of electricity. In America, Nuclear power plant is the second largest source of electricity (after coal powered plants) producing approximately 21% of the nation's electricity. (UNSCEAR, 2000).

2.10.7 Discovery of x-rays

X-rays were accidentally discovered in 1895 by Professor Wilhelm Conrad Roentgen who was experimenting with a cathode ray tube (Harrison, 1993). Roentgen was working in his laboratory at Wurzburg University in Germany. He has darkened his laboratory and completely enclosed his tube with a black paper so that he could better visualize the effects

of the cathode rays in the tube because of a black paper enclosing the tube, but the barium platinocyanide fluoresced regardless of its distance from the tube. (Harrison,1993). Because the cathode rays Roentgen was studying could not travel more than a few centimeters in air, he concluded that the source of the glow of the plate he noted was another kind of unknown rays. He called these unknown rays, x-rays (Harrison, 1993). Roentgen started placing different objects between the tube and the fluorescent plate. This discovery of x-ray, its characteristics and application paved the way for new field in medicine (Harrison, 1993).

2.10.8 X-rays and its Characteristics

As with other forms of ionizing radiation, x-rays are high energy electromagnetic wave that pass through the body during medical procedure and indicate relative densities on photosensitive plate. Essentially bones are denser and pass less x-rays than soft tissues and muscles. X-rays also cause biochemical changes in living cells. A high energy x-ray photons deposit its energy by liberating its electrons from atoms and molecules. X-rays are produced artificially in x-ray generator. In the x-ray tube, electrons are produced by heating metal filament by thermionic emission. The electrons produced areaccelerated towards the positive metal target by a large electric field produced by a high voltage applied between the cathode and anode. The focusing cup concentrates the electrons onto a target which is usually made of a metal such as tungsten and x-rays are produced (Harrison, 1993). X-ray may have many properties in common with light, however, the unique properties of x-rays are what make them invaluable in diagnostic imaging. Some of these characteristics are:

i. X-rays are able to penetrate materials that absorb or reflect light.

ii. When x-rays are absorbed by a certain material, they may produce light.

iii. Like light, x-rays can produce an image on photosensitive film.

iv. X-rays can ionize the atoms they pass through and so they can cause more damage to cells of the human body than light. Light interacts mainly by excitation, therefore, causes less damage to cells. (Bushong,1993).

2.10.9 Theory of x-ray beam production

There are so many processes involved in x-ray production. These include; Compton scattering, Auger electron interaction, electron capture, internal conversion and beta interaction.

In the x-ray tube, the cathode (negative electrode) is held at very high potential difference. The electrons as a result are accelerated from the cathode to the anode and gain a very high kinetic energy. The electrons are allowed to hit theanode target and energy and x-ray photons are produced. (Bushong, 1993) The electrons travel with a kinetic energy given by:

$$K = {}^{1}/_{2}\, mv^{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{equation 2.1}$$

Where m is the rest mass of the electron and v is the velocity (Bushong, 1993).

When the projectile electrons travel from the cathode and hit the atoms of the heavy metal anode, they interact with these atoms and transfer their kinetic energy to the target atoms. The projectile electrons interact with either the orbital electrons or electric field of the target atoms. The interactions results in the conversion ofthe kinetic energy of the electron into thermal energy (heat) or electromagnetic energy (x-rays). (Bushong, 1993).

The accelerated electron interacts with the anode via any of the following processes:

1. Excitation

2. Ionization

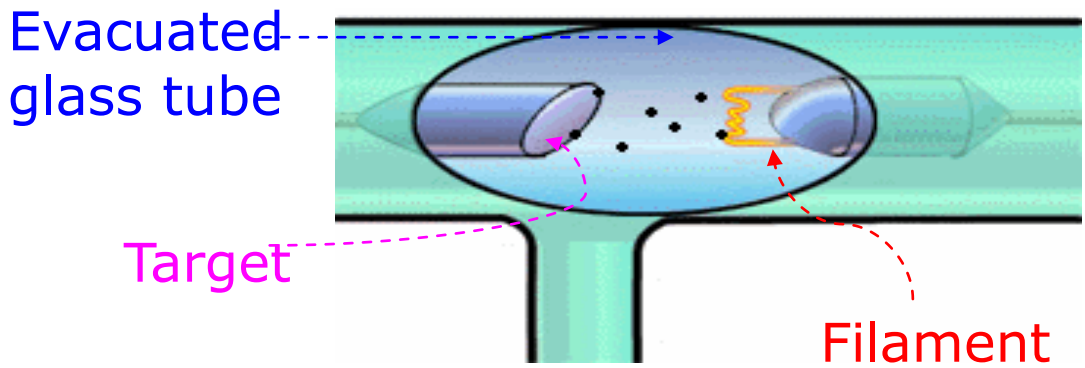


Figure 2.2: Schematic diagram of x-ray tube and its Production.

Source: Bushong, 1993

2.11 X-rays spectrum and beam characteristics

2.11.1 X-rays spectrum

X-ray spectrum consists of a continuous display of energies overlapped by a number of discrete lines. The continuous spectrum is in form of a graph and represents Bremsstrahlung x-rays which have energies ranging from zero to a maximum value corresponding to the applied tube voltage. The discrete lines represent characteristic x-rays which has precise fixed energies and are produced by ionization of bound electrons. These energies are characteristics of the difference between binding energies of the particular elements. (Bushong, 2003).

2.11.2 X-ray beam characteristics

X-ray beam can be described by its quality and or quantity. Each of these characteristics is discussed separately.

2.11.3 X-ray beam quantity

The x-ray beam quantity is the x-ray intensity (number of photons per unit area per unit time) or the radiation exposure and is measured by the change in any of the following factors; milliampere seconds, kVps, distance and filtration.

Milliampere seconds: (mAs) is the amount of charges accelerated towards the anode in an x-ray tube. It can also be defined as the product of x-ray tube current and the time of exposure. If the current is doubled, twice as many electrons will flow from the cathode to the target, and hence twice as much x-ray photon will be produced (Bushong, 1993). Thus, x-ray quantity is directly proportional to the mAs.

Thus,

$$I \; \alpha \; mAs \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ equation 2.2}$$

Where I is the x-ray intensity that is produced when a current mAs, is applied to the tube.

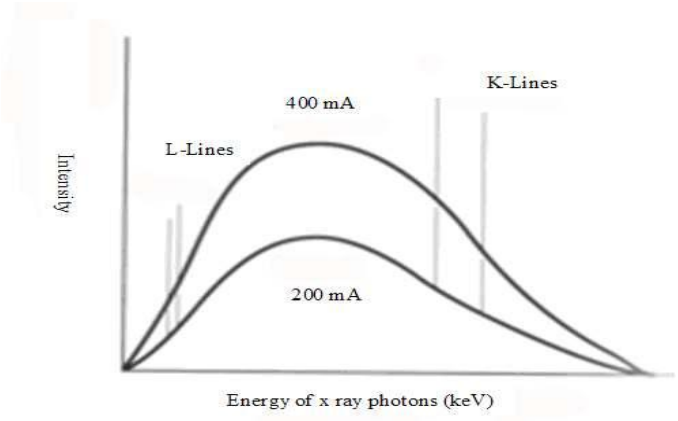


Figure 2.3: Effect of tube current on x-ray spectrum

Source: Curry *et al.*, 1995

Applied Voltage (kVp): The increase in applied voltage will increase the probability of bremsstrauhlung interaction and hence more x-ray photon will be produce. It was found that X-ray quantity is approximately proportional to the square of the applied voltage (Bushong, 1993).

Thus:

$$I\alpha(kVp)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ equation 2.3}$$

Where I is the intensity of the beam produced when kVp, voltage is applied on the tube.

Any change in the potential difference will affect both the amplitude and the position of X-ray spectrum. The area under the curve increase with the square of the factor by which kVp is increased and the relative distribution of emitted X-ray photons shifts to the (higher energies) (Bushong, 1993). Thus for the same mAs increasing the applied voltage will increase X-ray beam quantity.

Distance: the intensity of X-rays is inversely proportional to the square of distance from the target (Bushong, 1993) thus,

$$I\alpha\left(\frac{1}{d}\right)^2 \quad \text{……..... equation 2.4}$$

Where I is the intensity of x-rays and is the distance from the target (Bushong, 1993)

Filtration**:** Any material that lies in the path of x-ray beam is called a filter. There are two types of filtration; inherent and added filtration. The x-ray tube housing for example is an inherent filter material. Any added material to the tube is an added filtration. It reduces the x-ray quantity by selectively removing low energy x-ray photons that do not add any information to the diagnostic image and hence improving the x-ray beam quality (Bushong, 1993).

Thus the total effects of filtration on x-ray beam:

i. Change in the x-ray spectrum shape
ii. The Peak of the spectrum shifts towards higher energies
iii. The maximum energies remain unchanged
iv. The minimum energy shifts towards the higher energies.

2.11.4 X-ray beam quality

The X-ray quality is the measure of the penetrating ability of x-ray beam and it is measured by the half value layer (HVL) of the beam into half of its original value. The larger the HVL, the higher the beam quality. The following factors affect the X-ray beam quality;

Applied voltage (kVp): the kVp controls the speed of the accelerated electrons and therefore control the energy of the produced x-rays and the half value layer (HVL) (Bushong, 1993)

Target Material: The atomic number of the target material affects both the number and effective energy of the x-rays. When the atomic number of the target is increased, the spectrum is shifted to the right (Bushong, 1993).The increase of total filtration will increase the beam quality by removing low energy photons.

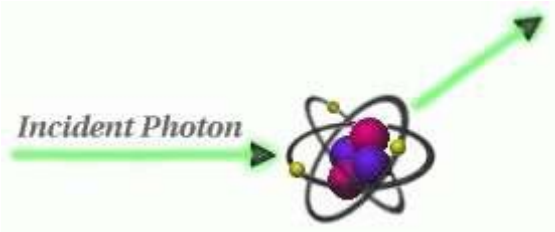
2.12 Interaction of x-ray with Matter

X-ray photon may interact with matter via any of the following five interactive processes:

2.12.1 Classical scattering

In this interaction, the incident photon suffers changes in its direction not in wave length. This kind of interaction is sometimes called coherent scattering and there are two types of coherent scattering. Thomson scattering involves one electron in the interaction while in Ray Leigh scattering the interaction happens with the whole atom. This kind of interaction does not involve energy loss and hence no ionization of the atom and only a very small percentage of the radiation undergo coherent or classical scattering. (Curry *et al.*, 1995)

λScattered



Photon λ

Figure 2.4: Schematic diagram of Classical Scattering

Source: Curry *et al*., 1995

2.12.2 Compton scattering

Also called inelastic or non-classical scattering. It is the predominant interaction of x-ray and gamma ray photons in diagnostic energy range with soft tissue. In this interaction, a high energy photon strikes a free electron in the target and ejects it; the photon changes its direction and loses some of its energy as a kinetic energy given to the ejected electron. The scattered photons produce noise to the image and cannot be completely removed by the use of grids. The scattered radiation increases the dose to patients and staff and distorts diagnostic information. Compton scattering not only predominates in diagnostic energy range above 26keV in soft tissue but also continues to predominate well beyond diagnostic energies to approximately 30MeV.

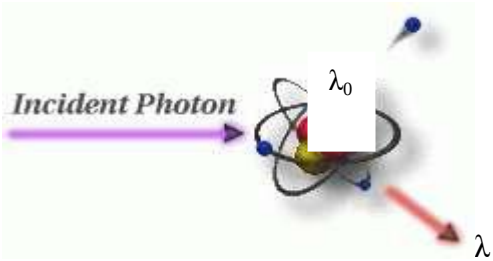


Figure 2.5: Schematic diagram of Compton scattering.

Source: Curry *et al*., 1995.

2.12.3 Photoelectric effect

In this interaction the incident photon ejects an electron from the atom by giving its energy which leaves the atom in an ionized state with an electron vacancy that is filled immediately by an electron from a higher energy level accompanied by an emission of characteristic radiation. The kinetic energy of the ejected electron is the difference between the binding energy and the incident photon energy. Following a photoelectric interaction, the atom is ionized, with an inner shell electron vacancy. This vacancy will be filled by an electron from a shell with lower binding energy. This creates another vacancy, which, in turn is filled by an electron from an even lower binding energy shell. Thus, an electron cascade from outer to inner shells occurs. The difference in binding energies is released as either characteristic-rays or Augerelectrons. The characteristic x-rays emission decreases asthe atomic number ofthe absorber decreases.

λ_0

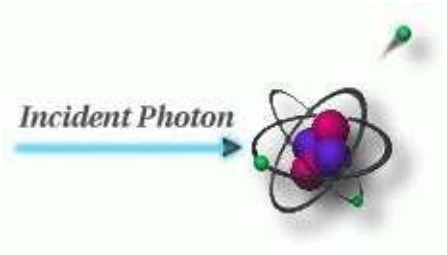


Figure 2.6: Schematic diagram of photoelectric effect

Source: Curry *et al*., 1995

2.12.4 Pair production

Pair production can only occur when the energies of x-rays and gamma rays exceeds 1.02MeV. In pair production, an x-ray or gamma ray interacts with the electric field of the nucleus of an atom. The photon's energy is transformed into an electron-positron pair .In this interaction a photonwith a high energy interacts with the nucleus where the proton disappears and in its place an electron positron pair appears for this interaction to take place, the energy of the incident photon must be at least 1.02MeV.The rest mass equivalent of each electron is 0.511MeV, and this threshold for this reaction is 1.02MeV. Photon energy in excess of this threshold is imparted to theelectron(also referred to as negatron or beta minus particle) and positron as kinetic energy. The electron and positron lose their kinetic energy via excitationand ionization. Because of its high energy, this interaction is not important in diagnostic radiology.

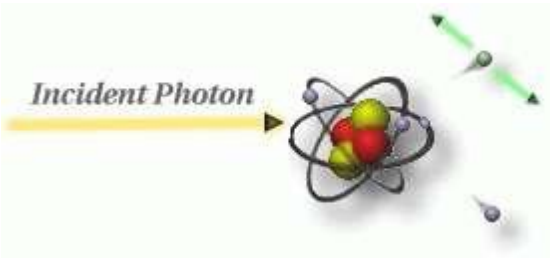


Figure 2.7: Schematic diagram of Pair Production

Source: Curry *et al.*, 1995

2.12.5 Photodisintegration

In this interaction, the incident photon has energy greater than 10MeV and hence, it interacts directly with the nucleus and split it in parts with emission of neutrons. Because of the high photon energy required from this interaction this interaction does not occur in diagnostic radiology.

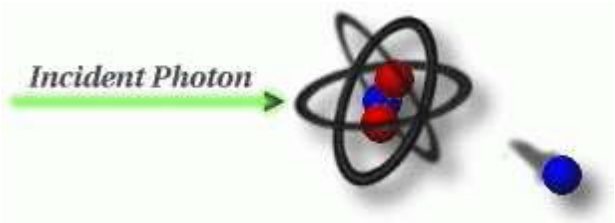


Figure 2.8: Schematic diagram of Photodisintegration

Source: Curry*et al.*, 1995

2.12.6 Calculation of Entrance Skin Dose

The first set of skin dose calculation was published by Birtch*et al.* in 1974. A more simple equation of skin dose was then published by Edmond in 1984. Edmonds used the data published by Birtch and proved that these radiation doses can be reduced to a simple equation that depends on kVp, mAs, filtration and SSD. Edmonds noted that skin dose is proportional to (kVp) $^{1.74}$ and as such, skin dose may be given by:

$$\text{Skin dose (µGy)} = \frac{836\ (kVP)^{1.74}\ (MAs)}{(SSD)^2}\left(\frac{1}{T} + 0.114\right) BSf \left(\frac{\mu en}{\rho}\right)_{air}^{tissue} \quad \text{.....equation 2.4}$$

where, kVp is applied tube potential, mAs is the product of tube current and exposure time, T is the patients thickness and BSF is the back scatter factor. The second trace of skin dose can be found in the literature published by Tung and Tsai, 1999. similar to the approach used by Edmonds. (Edmond 2014). Tung and Tsai studied the relationship between entrance skin dose and Aluminum filtration. These two relations allowed Tung and Tsai to propose the following equation for a three phase generator:

ESD (μ Gy) = $C\left(\frac{kVp}{FSD}\right)^2\left(\frac{mAs}{mmAL}\right)$……. equation 2.5

Where ESD is the entrance skin dose, kVp is the applied tube potential, mAs is applied mAs (Tube current multiplied by the exposure time), FSD is the focus to skin distance and C is the proportionality constant or machine dependent constant and it depends on the x-ray machine and is about 2.775 for all manufacturers and x-ray machines (Tung and Tsai, 1999).

Tong and Tsai also suggested the use of free air exposure (as obtained from National Council on Radiation Protection data and convert it into entrance skin dose by multiplying it by the ratio of the mean energy absorption coefficient of tissue to that of air and backscattering factor. This second formula as suggested by Tung and Tsai, 1999 was

ESD = FAE x 0.00877 x$\left(\frac{\left(\frac{\mu en}{\rho}\right)tissue}{\left(\frac{\mu en}{\rho}\right)air}\right)xBSF$…… equation 2.6

Where ESD (mGy) is the entrance skin dose FAE is the free air exposure in mR, the 0.00877(mGy/mR) is the factor used to convert the FAE into free air dose in mGy, $\left(\frac{\left(\frac{\mu en}{\rho}\right)tissue}{\left(\frac{\mu en}{\rho}\right)air}\right)$ is the ratio of mean energy absorption co-efficient of tissue and air and is about 1.06 for all diagnostic x-ray energies and BSF is the backscatter factor.

Tong and Tsai compared the performance of the two equations with that obtained using TLD and found that the first equation is quite accurate and that of wall equation performed well compared to TLD measurements.

2.12.7 Effect of Radiation on the Human Body

The human body is composed of a large number of individual cells. These cells can be split broadly into two categories, namely:

1. Somatic cells
2. Germ cells

The germ cells are those that are responsible for reproduction of offspring, and constitute the sperm in males, and the ova in females. All other cells fall under the classification of somatic cells.The genetic information that characterizes any individual is contained within the chromosomes. Somatic cells contain 46 chromosomes (23 chromosomes, occurring in pairs), and germ cells contain 23 chromosomes (23 chromosomes occurring once), so that when a sperm and an ovum come together, they produce a composite with the full 46 chromosomes. All cells in the body contain exactly the same genetic information; when cells divide, the chromosomes are reproduced exactly, so that the new cells resulting from cellular division exactly the same genetic information as in the original cell (UNSCEAR, 1993).

The chromosomes, in turn, are composed of linear sequences of genes. Genes are the basic units of heredity, and mammalian cells contain between 60000 and 70000 genes. The chromosomes are composed principally from deoxyribonucleic acid, which is usually shorted to ‘DNA’. A molecule of DNA contains around 10 million atoms, and it consists of two chains that are entwined around each other (the famous ‘double helix’). The two

chains are held together by various cross-connections (termed ‘hydrogen bonds’) between the two chains. The genetic information held in the DNA molecule is defined by the sequence in which various groups of atoms occur on the molecule(Christian, 2011).

The main effect of this radiation is to cause ionization of the atoms in the absorbing medium. Thus, when cells are irradiated, it is likely that ionization of one or more of the atoms on some of the DNA molecules will occur. This can lead to a number of consequences for the affected molecule. These effects include:

i. breakage of the chains of molecules comprising the DNA, and

ii. breakage of the links between chains.

In many cases, the cell is able to repair the damage, but not always. When the damage cannot be repaired, the affected cell is left with altered or damaged genetic information, compared with the unaffected cells. All descendants of that cell will contain altered or damaged information as well, because cellular division results in exact replication of the genetic information in the original cell (Christian, 2011).

The direct attack of radiation on the structure of DNA is not the only means by which radiation can affect cells. The majority of the human body (about 70%) is made up of water, and the ionizing effects of radiation on water can lead to an indirect attack on DNA. The effect of radiation on water (via a series of chemical reactions) is to produce a liquid, similar to water in composition, called hydrogen peroxide. Hydrogen peroxide is, in contrast to water, a chemically active compound, and it is capable of reacting with DNA to damage cells and the genetic information contained therein. Cells can therefore be subject to an indirect attack due to the action of radiation on body water, as well as from the direct effects of ionization at the site of the DNA.

Therefore, if germ cells (sperm and ova) suffer damage to the genetic information and they are subsequently involved in germination with other germ cells (i.e. affected sperm cells uniting with an ovum), the offspring will carry cells containing the damaged information. Similarly, somatic cells will divide to increase the number of cells in the body with damaged information. The root cause of cancer is damage to certain genes that make cells unable to stop dividing. Cancer cells are almost like normal cells but for its rapid proliferation (Christian, 2011).

2.13 Models of radiation damage

Potential biological effects depend on how much and how fast a radiation dose is received. Radiation dose can be grouped into two categories, acute and chronic dose.

2.13.1 Acute dose

An acute radiation dose is defined as a large dose (0.1Gy or greater , to the whole body) delivered during a short period of time. If large enough, it may result in effects which are observable within a period of hours to weeks.

Acute dose can cause a pattern of clearly identifiable symptoms (syndromes). These conditions are referred to in general as Acute Radiation Syndrome. Radiation sickness symptoms are apparent following acute doses ≥1Gy. Acute whole body doses of ≥4.50Gy may result in statistical expectation that 50% of the population exposed will die within 60 days without medical attention.(Shrimpton *et al.,* 1986 and Thulani *et al.,* 2009).

2.13.2 Chronic dose

A chronic dose is relatively small amount of radiation received over a long period of time. The body is better equipped to tolerate a chronic dose than an acute dose.

The body has time to repair damage because a smaller percentage of the cells need repair at any given time. The body also has time to replace dead or non-functioning cells with new, healthy cells (Shrimpton *et al,.*1986, Wall and Shrimpton, 1995).

2.13.3 Classifying radiation effects

The effects of radiation are usually classified into two categories, depending on the intensity of the radiation and the time period of exposure. These classifications are genetic and somatic effects. These categories are referred to as stochastic effects and deterministic effects.

a) Somatic versus Genetic Effects

Somatic effects appear in the exposed individual and is divided into two classes based on the rate which the dose was received. Prompt somatic effects are those that occur soon after an acute dose (typically 10rad or greater to the whole body in a short period of time) . Examples include temporary hair loss after a dose of 400rad to the scalp. Delayed somatic effects are those that may occur years after the radiation doses are received. Example includes increased potential for cancer and cataracts. Genetic or heritable effects appear in the future generations of the exposed person as a result of radiation damage on the reproductive cells. Prenatal radiation exposure of embryo/fetus is considered to be at the most radiosensitive stage of human development, particularly in the first 20 weeks of pregnancy. Limits are established to protect the embryo/fetus from any potential effects which may occur from a significant amount of radiation. Potential effects associated with prenatal radiation doses include: growth retardation, small head/ brain size, mental retardation and childhood cancer (BSS9).

i. Stochastic effects

Stochastic effects are usually associated with exposures to low levels of radiation exposure. The term stochastic literally means 'random', the implication being that low levels of radiation exposure are not certain to produce an effect. The induction of cancer and genetic defects are two of the most familiar consequences attributed to stochastic effects. The description of stochastic effects is usually controversial (owing to the difficulties in separating the effects of low-level radiation exposure from the effects of other carcinogens, e.g. tobacco smoke and non-radioactive species), but the currently accepted theories lead to the following conclusions about stochastic effects:

There is no threshold level of radiation exposure below which we can say with certainty that cancer or genetic effects will not occur. It is probabilistic. The biological effects of high levels of radiation exposure are fairly well known, but the effects of low level radiation are difficult to determine. Since deterministic effects do not occur with chronic dose, in order to assess the risk of this exposure, we must look to other types of effects (Wallbroad*et al.,* 2011).

Doubling the radiation dose doubles the probability that a cancer or genetic effect will occur. Taken together, radiation experts refer to these two conclusions as the 'linear-no-threshold' hypothesis. This hypothesis is questioned from time to time; however, it provides a pragmatic means of estimating radiation risks, and is consistent with the (limited) data that are available (Christian, 2011).

ii. Deterministic effects

Deterministic effects are associated with much higher levels of radiation exposure. Deterministic effects have two characteristic features:

-Severity increases with increase dose

-There is a threshold radiation dose, below which the deterministic effects are not observed; there are a variety of deterministic effects that can be observed after an acute exposure to radiation. These include (in order of increasing severity):

(a)Hemopoietic syndrome – This is the effects of radiation on blood-forming tissues, normally indicated by changes in blood cell counts. Dose of <1Gy characterized by damage to the erythrocytes, lymphocytes, thrombocytes and to mature sperms. Symptoms include aneamia and temporary loss of sterility. Dose >1Gy can cause damage to cells that divide at the most rapid pace such as bone marrow, spleen, lymphatic tissue. Symptoms include internal bleeding, fatigue, bacterial infections and fever.

(b) Gastrointestinal syndrome – (>10Gy) an effect signaling the destruction of the gastrointestinal epithelium and cells that divide rapidly (the lining of the gastrointestinal tract). Symptoms include nausea, vomiting, diarrhea, dehydration, electrolytic imbalance, loss of digestion ability(constipation), bleeding and ulcers.

(c) Central nervous system syndrome – (>50 Gy)is an effect seen at very high radiation doses in which the central nervous system undergoes irreparable damage. Symptoms includes; loss of coordination, confusion, coma, convulsions and shock. Death is within hours and days.

The usual symptoms following an acute radiation dose include nausea, vomiting and general fatigue. In the case of the hemopoietic syndrome, medical intervention may be capable of saving the victim. With the gastrointestinal syndrome, the most likely outcome is death within several weeks. Anyone suffering the central nervous syndrome

will die within a few hours to a few days of exposure (Christian, 2011).Other effects of acute radiation dose includes, 2 to 3Gy to the skin can result in the reddening of the skin (erythema), similar to a mild sunburn and may result in hair loss due to damage to hair follicles. 1.25 to 2.0Gy can result to damage to the ovaries, prolonged or permanent suppression of menstruation in about 50 % of women 6Gy to testicles can result in permanent sterility.0.5Gy to the thyroid gland can result to benign (non-cancerous) tumors.

2.14 Radiation units

Exposure is a dosimetric quantity for ionizing electromagnetic radiation, based on its ability to produce ionization in air. It is the total charge of the ions of one sign produced in air when all the electrons liberated by photons per unit mass of air are completely stopped in air.

Exposure (X) = $\frac{dQ}{dm}$ …… equation 2.7

Unit is Coulomb per kilogram (Ckg^{-1}) or Roentgen (R).

$1R = 2.58 \times 10^{-4}\ Ckg^{-1}$……..equation 2.8

2.15Radiation dose to tissue or organ

Expressing the size of a radiation dose is most conveniently done by specifying the amount of energy deposited by the incident radiation. The basic measures of radiation dose is called absorbed dose (Serro*et al.,* 1992;Sato *et al.,* 1995).

2.15.1 Absorbed dose

Absorbed dose is the amount of energy absorbed in the body, divided by the mass of the body volume irradiated. Usually the interaction of radiation with matter involves a transfer of energy from the radiation to the matter. Ultimately, the energy transferred either to tissue or to a radiation shield is dissipated as heat. The radiation dose depends on the intensity and energy of the radiation, the exposure time, the area exposed and the depth of energy deposition.

Absorbed Dose (D) $=\frac{dE}{dm}$…….equation 2.9

The unit is J/kg or Gray (Gy) formally rad.

1Gy = 100 rad…….equation 2.10

It is possible to calculate the absorbed dose in a material if the exposure is known.

D (Gy) = f x (Ckg^{-1})…….equation 2.11

Where f is the conversion coefficient depending on the medium (Sato *et al.,* 1995).

2.15.2 Equivalent dose

The absorbed dose does not give an accurate indication of the damage that radiation can do. An absorbed dose of 0.1Gy of alpha radiation, for example, is more harmful than an absorbed dose of 0.1Gy of beta, x-ray or gamma radiation. To reflect the damage done in biological systems from different types of radiation, the equivalent dose is used.

$H_{T,R} = w_T D_{T,R}$ ..... equation 2.12

Where $H_{T,R}$ is the equivalent dose in tissue, T and W_R is the radiation weighting factor (Sato et al., 1995).

The unit is sievert (Sv)

1Sv = 100rem…… equation 2.13

2.15.3 Effective dose

A given equivalent dose will in general produce different effects in different parts of the body. A dose to the hand is, for example, considerably less serious than the same dose to blood forming organs. In general, cells which undergo frequent cell division, and organs and tissues in which cells are replaced slowly, exhibit high radiation sensitivity. This is why different tissues show different sensitivity to radiation. The thyroid, for example, is much less sensitive than bone marrow. In order to take these effects into account, equivalent doses in different tissues is weighted with a factor that depends on radiation sensitivity. The resulting expression called the effective dose is given by:

$E = \sum(w_T H_T)$…… 2.14

Where w_T is the tissue weighting factor (Sato *et al.,* 1995).

In assessing effective doses, the calculated or measured effective dose is usually compared with dose limits. Dose limits are acceptable values, and are prescribed by a body known as the International Commission on Radiological Protection (Marcelo and Elisabeth, 2009). For members of the public, the dose limit is 1mSv/yr (0.001 Sievert per year), and for all occupational workers, the dose limit is prescribed as 20 mSv/yr average over a period of

5 consecutive years. These dose limits exclude background radiation dose (Sato *et al.*, 1995).

2.16 Radiation dosimetry

All human beings are exposed to ionizing radiation from natural and manmade (artificial) sources. This property of ionizing radiation is employed in their detection and measurement. In order to determine the dose, that is the quantity of x-rays; various methods can be employed, which are all based on the fundamental properties of radiation. Measurement can be performed in two ways. The dose rate at a given moment may be measured or a summing of all the separate doses administered during a certain time (integrated) may be made to determine the total dose. A dose meter can be arranged to measure the dose rate directly or measure the dose integration.

Some of the methods to measure the dose are;

i. Chemical dosimetry
ii. Dosimetry using ionization chamber
iii. Dosimetry using solid state detectors, example thermo luminescent dosimetry. (Ogunseyinde, 2002).
iv. Scintillation dosimetry
v. Biological dosimetry.

2.16.1 Thermoluminescent detectors in dosimetry.

Thermoluminiscent dosimeters are excellent personnel and environmental dosimeters. However, they contain storage phosphors in which a fraction of the electrons, raised to excited state by ionizing radiation, become trapped in excited states. When this trapped electrons are released, either by heating or by exposure to light, they fall

to lower energy states with the emission of light. The amount of light emitted can be measured and indicates the radiation dose received by the phosphor material. The most commonly used TLD material for personnel dosimetry is lithium fluoride (LiF). LiFTLDs have a wide dose response range of 100μSv to 5Sv but usable up to 1000 Sv. These dosimeters are used over a long time interval (upto 1 to 3 months if necessary) before being returned for analysis. The energy response is 0.766 to 5 MeV for x-ray and gamma- ray radiation. Another advantage of LiF TLDs is that their effective atomic number is close to that of the tissue and so are tissue equivalent; therefore the dose of LiF chip is close to that of the tissue dose over a wide energy range. TLDs do not provide a permanent record, because heating the chip to remove the exposure removes the deposited energy (Young *et al.*, 2005).

Thermo luminescent dosimeter badges contain thermo luminescent crystals that absorb and store energy when exposed to radiation and emit light when heated above 100 to 200 degree centigrade. The light output is proportional to the radiation dose. Thedose is read by heating the TLD crystal in a reader which is a device equipped to detect the emitted light. TLD responds quantitatively to x-rays, gamma rays, beta rays, electrons and protons over a range that extends to about 0.1mGy to 100Gy.Some TLDs such as LiF phosphors area approximately tissue equivalent with effective atomic number of 8.1 compared to that of tissue 7.4. Their response is almost energy independent from about 100keV to 1.3keV gamma rays with sensitivity below 100keV. The variety of materials used in TLDs and their different physical forms allows the determination of different radiation quantities over a wide range of absorbed dose. This makes TL dosimeters useful in radiation protection where dose levels of micro grays are monitored as well as radiotherapy where doses of several grays are measured (Christian, 2011). The major advantages of TL detectors are their small

physical size and that no cables or auxiliary equipment is required during the dose assessment. TLDs are sensitive, reusable with only a gradual change in efficiency and calibration and therefore more economical , often more nearly tissue equivalent, can measure deep and shallow doses and are less subject to fading with time. TL dosimeters are insensitive to most of the environmental agents such as humidity, pressure, atmospheric composition. Their evaluation is easily automated and can be used for many forms of radiation (Hanan, 2007). However, no TLDs can satisfy the above requirements, some are best used at low energy range while others at high energy range. Their sensitivity could also vary thus the problem of selecting TLD depends on the task they are used for. (Hanan, 2007).

When a charged particle passes through a thermoluminiscent material the interaction of its charge with the atoms of the materials causes ejection of electrons from the atoms (ionization) leaving holes in atomic structure (a deficit of electrons).The ejected electrons and holes are free to wander about in the lattice and the most of them recombine in a very short interval of time. In this condition the materials has an excess of energy since charge has been separated by radiation.(Hanan, 2007).

Raising the temperature of the material may allow the electrons and holes to escape from traps, and on recombination they give up their excess energy as light. (Tung and Tsai, 1999)

The thermoluminiscent materials are placed in a metal pan which is heated electrically. In order to prevent the photomultiplier tube responding to the thermal radiation from the pan and the thermoluminiscent materials, filter, which is opaque to infra-red radiation but transparent to the thermoluminiscent light, is placed between the sample and the photomultiplier tube. The final output of the system depends on the overall gain. If the

photomultiplier output is plotted and a function of the temperature of the irradiated thermoluminiscent material the resulting graph is known as a glow curve. The glow curve of a particular material may show a number of peaks; those at low temperature are due to shallow traps which require only a small amount of energy to release the trapped electron or holes and those at high temperature are due to deep traps. Either the peaks in glow curve or total amount of light emitted during the heating cycle may be used as an indication of the dose received by the material. The latter is the most common procedure, the heating being arranged so that pan is taken through a temperature cycle automatically and an integrating circuit is used to sum the output of the photomultiplier tube.(Hanan, 2007; Tung and Tsai, 1999).

After passing through the temperature cycle required for read-out the thermoluminiscent materials is ready for re-use, since the traps have been emptied. In practice, if the material is to be reused, it underwent a process known as annealing. (Tung and Tsai, 1999)

2.16.2 Patient Specific Dosimetry in establishing DRLs

Because the diagnostic reference levels are derived from standard phantom measurements and are used as benchmarks for comparing X-ray dose estimates from a given facility, they should not be used as a substitute for estimating specific doses delivered to a patient. For example, $CTDI_{100}$, $CTDI_{w}$, and $CTDI_{vol}$ are estimates of dose delivered to phantoms of a specified size and material as a result of the X-ray production of the CT scanner in question. CTDI doses do not indicate the dose to an individual patient (Hart*et al.*,2011). To address this need, the American Association of Physicist in Medicine has developed a better estimate of the patient dose during CT examinations of the trunk of the body called size specific dose estimate (SSDE) that corrects for changes in patient dose as a function of the patient's size (Boone *et al.*,2011).

On occasion, the need may arise to estimate the dose delivered to an individual patient because of a specific situation (pregnancy, prolonged fluoroscopy, multiple examinations). In these situations it is recommended that the physician consider executing a formal written medical physics consultation with the Qualified Medical Physicists. Using the specific x-ray parameters of the diagnostic examination, the Qualified Medical Physicist can render an estimate of the specific dose to a given location in the patient, such as the location of the embryo or fetus, the patient's midline, or the patient's skin (Agba*et al.,* 2002). The consultation request should be signed by the requesting physician. The Qualified Medical Physicist's report should be signed by the Qualified Medical Physicist and should be incorporated into the patient's medical record. DRLs or Ads should not be used for patient dose estimates. An estimate of the dose to a patient is sometimes needed to assess the potential risk associated with a high dose examination involving ionizing radiation. Deterministic radiation risks are typically the primary concern due to the size of the patient and the relatively large skin doses that occur. Since stochastic effects may not develop until decades after the examination, older, seriously ill adults may not survive long enough for a stochastic effect to develop. In contrast, pediatric patients are at greater stochastic risk due to longer remaining lifespans and their greater sensitivity to ionizing radiation. Finally, both stochastic and deterministic effects are a potential risk for larger adolescent patients who receive relatively large skin doses and who have a longer life expectancy than adults (NCRP,2010).

Diagnostic x-ray examinations play an important role in the health care of the population in Nigeria and Worldwide. This examination may involve significant irradiation of the patient and probably represent the largest man-made source of radiation exposure for the population (Hanan, 2008). The radiation exposure received during x-ray examinations is

known to increase the risk of malignancy as well as above a certain dose, the probability of the skin damage and cataract.

In today's diagnostic radiology, there is a growing concern about radiation exposure. (ICRP, 2000). Intensive studies in the field of patient dose were conducted in the United Kingdom and these studies eventually lead to the introduction of the European Union Council directive which made it compulsory that patients dose be measured in every hospital and doses should be compared to reference dose levels establishedbythe competent Authorities involved.

2.16.3 Radiation Safety in Medical Imaging

Radiologists, radiographers, medical physicists, registered radiologist assistants, and all supervising physicians have a responsibility for safety in their workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel that work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection and application of dose limits) and the principles of proper management of radiation dose to patients (justification, optimization and the use of dose reference levels) NCRP,2010.Nationally developed guidelines, such as the ACR's Appropriateness Criteria, should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure. Facilities should have and adhere to policies and procedures that require varying ionizing radiation examination protocols (plain radiography, Mammography, fluoroscopy, interventional radiology, CT) to take into account patient body habitus (such as patient dimensions, weight, or body mass index) to

optimize the relationship between minimal radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used whenever appropriate. If such technology is not available, appropriate manual techniques should be used (Jeska*et al*., 2014).

Advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, radiographers, referring providers, medical physicists, and radiologists). Radiation exposures or other dose indices should be measured and patient radiation dose estimated for representative examinations and types of patients should be evaluated by a Qualified Medical Physicist in accordance with the applicable ACR technical standards. Regular auditing of patient dose indices should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry, the NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference or Radiation Control Program Director's National Evaluation of X-ray Trends. (ACR Resolution 17 adopted in 2006 – revised in 2009, 2013, Resolution 52) NCRP,2010.

2.16.4 Quality Control and Improvement, Safety, Infection Control, and Patient Education

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control Implementation, Safety, Infection Control, and patient Education.Performance evaluation, quality control, acceptance testing, written survey reports and follow-up procedures should be in accordance with the appropriate ACR Medical Physics Technical Standards. The Qualified Medical Physicist's annual survey report should include estimates of radiation dose for representative examinations and types of patients (adults,

and pediatric) as applicable. The Qualified Medical physicist should also compare these values with current DRLs and provide recommendations for improvement if the dose estimates exceed the DRLs. (Abdullahi*et al*.,2015).

2.15.5 Dose estimation

Radiation-induced effects are divided conventionally into deterministic and stochastic effects. The likelihood of these effects in any individual patient cannot be predicted unless that patient's radiation history is known. This is the principal reason for recording patient radiation dose. Monitoring and recording patient dose data can also be valuable for both quality-assurance purposes and for improving patient safety. Feedback to the operator may help to optimize radiation doses (ICRP,2017)

2.17 Empirical Review

2.17.1 Diagnostic reference levels in Nigeria, Africa and other countries

Jibiri and Olowookere, (2016), conducted a study on patient dose audit of the most frequent radiographic examinations and the proposed local DRLs in Southwestern Nigeria: imperative for dose optimization. Entrance skin doses (ESD) were measured in twelve healthcare centers consisting of 15 radiological units using thermoluminiscent dosimeters (TLDs). Seven radiological procedures such as chest posterior anterior (PA), abdomen anterior posterior (AP), pelvic AP, lumbar spine AP, skull, knee and hand (AP) were included in the study. Findings ranges from 1.78 to 3.01mGy, 2.71mGy to 2.84mGy ,2.11mGy to 3.79 mGy, 3.93mGy to 8.79mGy, 1.06mGy to1.73 mGy and 1.10 to 1.44 mGy for chest, pelvis, lumbar spine, skull, knee and hand respectively. Large variations were found within x-ray units studied even within the same centers. The values of the determined DRLs were compared with established DRLs in UK,US, Slovenia, Italy, Brazil. The study concluded that the relative higher doses found in the study are attributable to higher tube load (mAs) used and indicative of the need for dose optimization in Nigerian radiological practice. A similar study was carried out in Lagos state, southwestern part of Nigeria by Micheal *et al*.,(2016) on the determination of reference dose levels for chest, abdomen and lumbar spine among selected x-ray centers in Lagos state. The used a non invasive unifors Thinx Rad kiloVoltage peak meter on the couch at a source to image distance of 100cm and an erect bucky of 180cm. Their result showed mean entrance skin dose of 0.603,2.57 and 2.57mGy for chest, plain abdomen and lumbar spine respectively, while the DRLs were 0.93,2.74 and 2.47mGy for chest, plain abdomen and lumbar spine respectively. Their study established DRLs for Southwest Nigeria. Diagnostic reference levels for chest was higher than the international recommended values while that of plain abdomen and Lumbar spine were within

acceptable range. A study on the determination of CT DRLs was conducted in North central Nigeria by Muhammad *et al.,* (2016). The objective of their study was to estimate dose levels for common CT examinations in north central Nigeria. They considered CT examination of the head, chest and abdomen for a four month duration using four CT centers. They recorded data on CT dose based on a minimum of 10 averaged- sized patients for each facility to estimate the DRLs enrolling 226 patients. Result established DRLs of 60mGy and 1024mGy.cm for head scans and 15mGy, 407 mGy.cm for chest scans and 15mGy and 757mGy.cm for abdominal scans. The study provided comparative dose values and template by which CT practice in this part of Nigeria can be evaluated. Hyacienth *et al.,* (2015) conducted a study on increasing radiation doses from computed tomography versus DRLs: how compliant are we? The aim of their study was to assess the radiation dose received in a clinical real life setting by patients visiting selected radiological centers in Enugu, southeast Nigeria for computed tomography scans of the head and thus assess compliance to DRLs. The study design was a prospective cross-sectional survey design, 98 patients made of 60 males and 38 females with age range of 3 to 65 years. Measurement was carried out using TLD-100 chips, their mean absorbed dose was 4.3 mSv and the mean effective dose of 2.24 mSv . In children the mean absorbed dose was 5.6 mSv and mean effective 2.9 mSv and the doses were higher than that of the adults. The annual collective dose was 224.4 person – mSv and the annual per caput dose is 5.9×10^{-7} mSv. Their study also calculated mean organ effective dose of 0.14 mSv,0.884 mSv, 0.147 mSv, 0.354 mSv and 0.147 mSv for the brain, eye lenses, thyroid gland, red bone marrow and breast respectively. The overall mean effective dose was in compliance with the recommended DRLs. The study showed positive correlation with the tube current and the number of images obtained but negatively correlated with the scan time, patients head AP dimension and age. Radiation risks from CT can be reduced

through justification of procedure and dose optimization. The establishment and use of DRLs is essential for proper use and audit of ionizing radiation in medicine as suggested by Godwin and Racheal, (2014). Their study showed that Nigeria does not yet have a guideline for establishing and setting DRL. The European Commission reference dose levels were applied to routine computed tomography examinations in Nigeria's major hospitals. The aim of their study was to determine the dose absorbed during CT examinations at University College Hospital, Ibadan, Nigeria and to provide a cover template for dose optimization. Data was obtained from a GE Bright speed multi-detector CT scanner. The dose characteristics and estimates were derived from computed tomography dose index (CTDI vol), and dose length product (DLP) with the effective dose (E) calculated using software developed by IMPACT group with National Radiological protection Board-5250 conversion coefficient data for a random sampling of 1 per 10 typical CT patients. Their results showed the mean values of CTDI vol in mGy were 73.5 ± 4.2 for head, 22.7 ± 6.7 for chest, 37.9 ± 5.6 for abdomen, 28.2 ± 8.3 for abdomen pelvis 41.4 ± 4.2 for lumbar spine examinations. The corresponding mean values of DLP in mGy cm were 1198, 1189, 1902, 2548, 1372 and 1562 respectively. The calculated E values in mSv for the above examination were 2.8, 11.8, 22.5, 39.6, 4.6 and 29.0 respectively. All values exceeded recommended European commission regional DRLs except the CTDI vol for chest, cervical and abdomen –pelvis doses were higher than the European Commission recommended guidelines necessitating a need for optimization of CT practice and the requirement for a CT dose survey in Nigeria. In another study by Abdullahi *et al., (*2015), on DRLs for Adult brain CT scans in a tertiary health care center in Nigeria . They surveyed the need to establish DRL for adult brain CT scan. The study was conducted on forty patients and their result showed CTDI vol of 38.08mGy which is below 60mGy reference value for European Commission. The DLP of 1477.42mGy.cm was obtained and

it is also below 1050mGy.cm as recommended by European Commission. However, their study indicated that corrective measures are required to eliminate unnecessary radiation that does not contribute to the overall profile of patients. Another study by Joseph *et al.*,(2014)on the rationale for implementing DRLS as a quality assurance tool in medical radiography in Nigeria. They stated that there has been a number of approach to DRLs used for medical imaging in Nigeria, and to facilitate standardization and ensure optimization, specific protocols were reviewed systematically to give detailed inter and intra hospital variations. The aim of the study was to provide protocols for setting DRLs as a quality assurance tool in medical radiography. The paper stated the paucity of information on DRLs in Nigeria and hence suggested that establishing DRLs for radiological examinations is the way forward. Nzotta and Joseph, (2016) conducted a study on the need to establish DRLs for radiological examinations in Nigeria, their study was a systematic review of literatures on existing DRLs and the methodologies of establishing them. The combined search identifies 90 articles and their result showed that there is no comprehensive DRLs for Nigeria yet, however, they concluded that there is need to establish local, regional and national DRLs in Nigeria as a tool for optimizing Radiation protection in Nigeria. A research on French DRLs in diagnostic radiology, computed tomography and nuclear medicine: 2004-2008 review was conducted by Roch and Aubert, (2013). The French Nuclear Safety and Radiation Protection Institute conducted an analysis which critically surveyed the representativeness of current DRLs in terms of relevant examinations, dosimetric quantities, numerical values and patient morphologies. Since 2004, the involvement of professionals has increased, especially in nuclear medicine, followed by CT and then interventional radiology. Analyses show some discordance between regulatory examinations and clinical practice. On the basis of the findings, FIRNS formulates recommendations to update regulatory DRL with current and

relevant examination lists, dosimetric quantities and numerical values. In another study on Establishment of CT DRLs in selected procedures in South India by Saravanakumar *et al.*,(2016), a pilot study was carried out to investigate the most frequent CT examinations. CT centers were asked to complete a booklet to allow the recording of CT parameters for each of the3 CT examinations during a one year period. CTDIvol and DLP were obtained and recorded on a minimum of 50 average – sized patients in each category. Seventy fifth (75^{th}) percentile value were recorded as the proposed DRLs. 47mGy and 1041mGy.cm for head CT, 10mGy and 445mGy.cm for chest CT and 12mGy and 550 mGy.cm for abdomen respectively. Their values were lower than their national DRLs and comparable to other international established studies. The study concluded that the differences in CT doses between CT scanners departments as well as identical scanners suggest a large potential for optimization of examination. Janbabanezhad *et al.*,(2015), conducted a study on dose assessment in CT examination and Establishment of DRLs in Mazandaran, Iran. The study was aimed at evaluating the radiation dose to patients from CT examination in Mazandaran, Iran. The methodology enrolled patient related data on CT examinations including brain, sinus, chest, abdomen and pelvis. The CTDIw range were 15.6-73mGy,3.8-25.8mGy,4.5-16.3mGy and 7-16.3 mGy for brain,sinus, chest, abdomen and pelvis respectively and DLP range of 197-981mGy.cm,n41.8-184mGycm,131-342.3mGycm and 283.6- 486 mGycm for brain,sinus, chest, abdomen and pelvis respectively. Results of this study demonstrated large scales of dose for the same examination among different centers. For all examination, their values were lower than international reference doses.

The goal of any DRL is to control the level of optimization of the procedure (NRPB,1990; NCRP, 2012 and ICRP, 2017). The United States and United Kingdom were the first to adopt DRLs for patient's medical exposures (Wall and Shrimpton, 1998). After these

National initiatives, International recommendations from societies for Radiological protection were published. The International Commission on Radiological protection suggests the use of investigation levels for medical exposures as a starting point in the identification of incorrect practices. (ICRP, 1991). In addition, publication 73 (5), the commission recommends that DRLs be used to optimize patients doses. They can serve as a quality assurance tool for diagnostic radiology, providing a trigger for local review, if consistently exceeded. (ICRP, 1996).

In Europe, dose values associated with DRLs were published in a set of three recommendations. European guidelines on quality criteria for diagnostic radiographic images in adult and pediatric patients (EC guidelines, 1996) and for computed tomography in adult patients. (EC guidelines, 1999). These publications recommended using 75^{th} percentile (third quartile values) of the distribution of mean doses observed for a particular examination to establish national DRLs. The distribution of doses was obtained on a large scale surveys carried out in representative samples of health services distributed in some European countries. In Brazil, DRLs in medical radiology were established by regulation of the Brazilian Ministry of Health in 1998. Although not mentioned in the document, the national regulation adopts the same DRL values published by the International Atomic Energy Agency in safety series number 115 (IAEA, 2002). It is important to point out that reference levels must be established considering the national or regional reality and take into account the equipment and human resources available. (IAEA, 2002).

There is a need to establish DRLs due to lack of large scale dose surveys in Brazil, this study provides a survey of ESD values delivered to patients subjected to the most frequent radiological examinations. Chest, skull, sinuses, spine (cervical, thoracic and lumbar), carried out in a representative sample of clinics and hospitals in the most populous Brazilian state. Sao Paulo (39.2) million inhabitants in 2004, 22% of the country's

population . DRLs were inferred from a distribution of mean ESD values of standard size patients for each type of radiograph considered. Furthermore, information about health services (Distribution of equipment and annual number of radiological examinations) and about the exposure parameters used in the examinations (tube potential in kilovolts (kV)) exposure setting in milli Ampere – seconds (mAs), source image distance are also analyzed allowing an overview of the medical exposures. In Brazil, especially in the state of Sao Paulo there have been a number of approaches to reference levels used in radiology examinations. Typically reference levels are used as investigation levels and quality assurance tool. But there are exceptions where the approach uses achievable levels indicative of more optimum conditions, mentions dose constraints, or incorporates a dose limits or suspension level. However, authorized bodies may require implementation of the concept of a diagnostic reference level.

The International Atomic Energy Agency has explored the feasibility of establishing International procedures. (Olarinoye and Sharifat,2008). Researchers in various studies have presented reference levels or radiation doses for cardiovascular procedures (Hart*et al.*,2012). US – specific reference levels are not currently available for any interventional radiology procedures because of paucity of dose data. The only large series of radiation dose data in the United States is the Radiation doses in International Radiology procedures (RAD - IR) study which was directed by one of the investigators of this study (Hart *et al.*, 2012).

Normally, patients undergoing radiological examination such as conventional x-ray, dental x-ray, computed tomography, fluoroscopy and mammography would expect that the radiation dose imparted in different hospitals will be within a narrower range. However, a large number of national and multinational surveys indicate that this is not so (Jenia and Medan, 2015). Variations by a factor of 20 or more were reported initially by national

surveys in the United Kingdom for Radiologic examinations and these were even higher in European surveys (Jenia and Medan, 2015). Jenia and Medan (2015), conducted a study on DRLs they conceptually reviewed the difference between dose limits and DRLs, How to set DRLs, they highlighted the features of DRLs, and raised some research questions like what if the typical doses in my facility exceeds National DRLs, achievable doses and diagnostic reference ranges. They concluded that DRLs are a useful tool for continuous improvement of clinical practice and a trigger to identify those facilities using unusually high doses in a specified radiological procedures for which optimization actions are needed. Jenia and Medan, (2015) reported in a study on diagnostic reference levels that in contrast to occupational dose limits, diagnostic reference levels should not apply to individual patients because one patient's body mass and habitus may require a higher dose than those of a standard patient.

A study on the implementation of DRLs to Australian radiology practice reported by Wallace, (2010) revealed that presently, there is no national surveillance of the increasing ionizing radiation dose to the population from diagnostic imaging procedures. As the number of procedures undertaken is increasing, it is expected that the population dose will also increase. A substantial component of that contribution is from multi detector computed tomography (MDCT) systems. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA, 2010) estimated that the growth in MDCT scans based on medical benefits scheduled data, is increasing at approximately 9% per annum. With over two million MDCT scans performed in 2009. The caput effective dose (mS*v*) from this modality is expected to be one key issue in the regulations that govern the use of ionizing radiation in medicine and the establishment of DRLs. (Hart *et al.,* 2002 and Young *et al.,* 2005).

A multi-disciplinary working party with representatives from all the professional bodies involved in diagnostic medical exposures was convened by the department of health in 2000 to provide broad policy guidance of ionizing radiation medical exposure regulations requirement and to formally adopt national DRLs. An employer may decide to adopt national DRLs or to set higher or lower DRLs depending on the medical imaging equipment of the health care establishment. Local DRLs higher than those set nationally would need to be justified. This flexibility enables professionals to provide input at a local level to the DRL setting process. The regular review of these DRLs at national, regional and local levels provides a feedback loop that ensures good practice. Ionizing radiation medical exposure regulation (IRMER, 2000) approaching 1.2 mSv per annum. If current dose detriment models are accurate, the risk of induction of carcinogenic detriment from current MDCT scanning patterns is a significant public health issue that requires a concerted and ongoing response. (Wallace, 2010). For the application of ionizing radiation in medicine the International Commission on Radiological protection (ICRP, 2010) recommends the conservative philosophy of justification and optimization via the establishment of DRLs to limit the over exposure of patients and decrease the overall population burden.

The Australian government has commissioned ARPANSA to survey, calculate and construct representative national DRLs for diagnostic imaging modalities that use ionizing radiation. However, this will be achieved in close consultation with the professional organizations that represent the professionals responsible for the use of ionizing radiation in diagnostic imaging. (Wallace, 2010), Johan and Indrastuti, (2002) conducted a study on an attempt to establish national DRLs for head CT-scan examinations in Indonesia. They reached a resolution that CT scanners are becoming more and more popular imaging modality amongst medical practitioners as their tools for diagnostic practices. Yet, since

CT scanners employ ionizing x-ray beam as the source of imaging light, protection against its damaging effects to patients are minimum. The study involved three departments of radiology in three major cities in Melang, Indonesia. One hundred patients, fifty males and fifty females were recruited for the study. The patients were referred by physicians to undergo non-contrast CT head examination in each hospital. The effective dose of each patient was calculated using the CT Dosimetry Version 1.0.4 dose calculator software. There results revealed that the effective doses received by patients were in range 1.25-2.51mSv for male patients and 1.14-2.39 mS*v* for female patients. They proposed 2.0 mS*v*thresholds as the local DRLs for CT head examinations in hospitals in greater Melang district. However, they suggested that further research is required to extend the area of coverage in order to establish a national DRLs. (Johan and Indrastuti, 2012).

In a study of radiation safety concerns and DRLs for computed tomography scanners in Tamil Nadu by Roshan and Paul, (2010). They stated that radiation safety in computed tomography scanners is of concern due to its widespread use in the field of radiological imaging. Their study intends to evaluate radiation doses imparted to patients undergoing thorax abdomen and pelvic CT examinations and formulate regional DRLs in Tamil Nadu, South India. In-site CT dose measurement was performed in 127 CT scanners in Tamil Nadu for a period of 2years as a part of the Atomic Energy Regulatory Board (AERB). Out of 127 CT scanners, 13 were conventional; 53 single slice helical CT scanners; 44 multislice CT scanners and 17 refurbished scanners. CT dose index was measured using a 32 cm polymethyl methacrylate body phantom in each CT scanner. DLP for different anatomical regions was generated using CTDI values. The regional DRLs for thorax, abdomen and pelvis examinations were 557, 521 and 294 mGy cm respectively. The mean effective dose was estimated using the DLP values and was found to be 8.04, 6.69 and 4.79 mSv for thorax, abdomen and pelvic CT examinations respectively. The

establishment of DRLs in this study is the first step towards optimization of CT doses in the Indian context. (Roshan and Paul, 2010).

Over the years, reductions in patient doses have been achieved through advances in technology and changes in clinical practice. In the United Kingdom in particular, repeated National dose surveys by the UK National Health Protection Agency (HPA) have shown a significant lowering of patient dose for individual procedure types. (Hart *et al.*, 2002 and Hart *et al.*, 2007). However, while some dose reduction measures have a positive effect on image quality, others degrade contrast or increase noise. Thus, it is important not just to reduce doses but to optimize each imaging technique, maximize its efficiency and determine the right balance between patient dose and image quality this can be monitored using DRLs (Roshan*et al.*, 2007). Once an x-ray examination is definitely justified, the principle of optimization implies that during the examination, the margin of good over harm is maximized by giving attention to all aspects of radiographic examination process (ICRP, 2007).

The most reliable dosimetric quantities commonly used in diagnostic radiology to give an indication of the typical dose that is being delivered to an average adult patient are the patient ESD including backscatter for simple x-ray projections and the dose area product (DAP) for complex examinations. (Wall and Shrimpton, 1995). The ESD, in particular, is recommended as the most appropriate dosimetric quantity for simple x-ray projections since it meets the three basic conditions set out by IAEA and CEC in their document quality criteria for the most common radiographic images. In addition, the measurement of ESD permits easy comparison with published diagnostic guidance or reference levels. (Wall, 1995, EC, 1997 and IAEA, 2002).

A study conducted by Thulani *et al.*, (2009) on patient dose audit for patients undergoing six common radiography examinations: Potential DRLs, they established a base line for potential DRLs in South African examinations. The study involved chest x-ray posterior anterior, chest lateral, pelvis, abdomen, lumbar and thoracic spines. Entrance air kerma were calculated based on x-ray tube output of the unit used and the exposure parameters used for actual examinations. They established DRLs based on third quartile of the entrance surface air kerma values from the individual rooms. The following DRLs were established 0.1 mG*y* for chest PA, 0.22 mG*y* for lateral chest x-ray, 2.98 mG*y* for pelvis AP, 4.19 mG*y* for abdomen AP, 5.30 mG*y* for lumbar spine. The established DRLs were lower compared with previously published DRLs from other countries. (Thulani *et al.*, 2009). There is growing evidence that comparison of dose values with DRLs has led to decrease patient doses (Wilbroad, 2008).

2.16.2 DRLs for Radiographic examinations in Nigeria and other countries

A study by Gholami *et al.*,(2017) on DRLs for routine x-ray examination in Lorestan province, Iran examined a total of 2382 patients dose. Entrance surface air kerma (ESAK) was measured using thermoluminiscent dosimeters according to the x-ray tube output, optimized exposure parameters and body thickness for each technique. The parameters such as, 1st quartile, mean, median, 3rd quartile, minimum, maximum and standard deviation of each ESAK values are reported and compared to National Radiation Protection Board (NRPB) guidance levels. The results showed that the ESAKs values in the lumbar spines and chest x-ray examinations were 30% above the guidance levels, However the pelvis, skull and abdomen (AP) examinations were below reported NRPB values. Periodic quality control and monitoring of the technical performance of radiographers might effectively improve the image quality and eventually reduce the dose received by patients. A study was carried out by Gaetano et al., (2005) on local DRLs in

standard x-ray examinations. ESD distributions were determined for 10 standard projections comprising of Abdomen,chest, skull, lumbar spine Lumbo- sacral joint lateral projection, pelvis, abdomen, skull PA and Lateral and urinary tract. Value obtained includes 3.9 for lateral skull to 34.3mGy for AP abdomen and 3.9mGy (PA skull) ESD were compared with data previously published and with Italian DRLs. Values obtained were 2.1 to 34.3mGy for skull lateral and plain Abdomen respectively for individual adults and 2.1 to 6.6 mGy for PA skull and urinary tract respectively across the mean values of radiological departments. Their study concluded that Local DRLs can be proposed to obtain a more fully optimized radiation protection of patients. A research work on National collection of local DRLs in Norway and the role of optimization of x-ray examinations was carried out by Eva Goske *et al.*,(2015). They considered 40 health care centers representing 104 individual clinics which involved conventional x-ray and mammography and nine CT examinations. The response rate from the clinics was 69% and 539 individual reported local DRLs in total. Large variations in Local DRLs were observed between different clinics for all examination types ranging from a factor of 3.3 to 61 for conventional coronary angiography and lumbar spine, respectively. Local DRLs exceeded the current national DRLs which were observed for all examination types except for conventional coronary angiography. The 75^{th} percentile of the collected local DRLs indicates the need for a downward revision of the national DRLs by 20 to 60%. Hart et al.,2009 conducted a study on National reference doses for common radiographic, fluoroscopic and dental x-ray examination in the UK. They analyzed the data collected from 316 hospitals over a five year period. The information supplied amounted to a total of 23,000 ESD measurements and 57000 dose area product measurements for single radiographs. In addition, patient dose data for dental x-ray examinations were included for the first time in the series of yearly reviews. The article presents a summary of key outputs

from the National Patients Dose Data Base (NPDD) national reference doses . These are based on the third quartile values of the dose distributions for 30 types of diagnostic x-ray examinations and 8 types of interventional procedures on adults and four types of x-ray examination on children. The reference doses are 16% lower than the corresponding values in the previous 2000 reviews and are typically less than half the values of UK national reference doses that were derived in 1980s. The study concluded that no clear evidence could be found for the use of digital imaging equipment having a significant effect on dose. A study titled assessment of ESD and image quality and DRLs for chest x-rays in North Eastern Nigeria was carried out by Joseph *et al.,* (2014). Sixty Thermoluminiscent dosimeters were used to determine the ESD received by the patients. European guidelines 1999 criteria was used to analyze the image quality. Findings showed that the dose obtained were 0.50 mGy and 0.54 mGy respectively. The results were higher compared to other established DRLs. The image quality criteria were good with a score of 60% and above. They concluded that, there is need to optimize radiological examination in most hospitals in Nigeria. A study attempted to establish DRLs for chest, skull and lumbar spine, the study was conducted in two hospitals. The aim of the study was to assess the patient's dose for chest PA, Chest Lateral, skull AP and lumbar spine AP projection. ESD and effective doses were obtained using Dose Cal software. Result of 140 patients studied in Hospital A were 0.20mGy,0.47mGy, 1.25mGy and 1.61mGy respectively while that of hospital B were 0.10mGy,0.28mGy,0.66mGy and 2.44mGy for similar examination respectively. The results were lower than the established recommended doses however there was need for personnel training and national guidance on good practice for optimization of patient doses(Kouther *et al.,* 2015). Ujah et al., (2012) did a work on comparative study of patients radiation levels with standard DRLs in federal medical center and Bishop Murray hospital in Makurdi. In their work, TLD technique was used

with phantoms to measure the amount of radiation received by patients during routine PA chest x-ray examination in the hospitals under study. The average skin dose measured were 0.15mGy and 4.207mGy for Federal medical center and Bishop Murray hospital respectively. Compared to international recommended doses, the dose value for Federal medical center was within standard level while that of Bishop Murray hospital was above ICRP recommended standard. Mohammed *et al.,* (2014), conducted a study on radiation dose measurements during hysterosalpingography. The study was carried out in three radiology departments, a total of 50 patients were studied from three hospitals. Patient dose measurements were performed using unifors dosimeters. Result showed that the patient dose were 20.1mGy,28.9mGy and 13.6mGy. Results were higher compared to established standard doses. DRLs for digital mammography was systematically reviewed by Moayyad *et al .,* (2014). The study aims to review literatures on existing DRLs in mammography procedures and methodologies for establishing them. To this end, a systematic search through medline, cinahl, web of science, Scopus and google scholar was conducted using search terms. DRLs in mammography. The search resulted in 1539 articles of which 22 were included after a screening process. Relevant data were summarized and analyzed. Differences were found in the methods utilized to establish DRLs including test subject types, protocols followed, conversion factors employed, breast compression thickness and percentile values adopted. They concluded that an international accepted protocol is valuable so that comparison can be made.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research Design

The study is a prospective cross sectional study which involves taking dose metrics from patients who came for radiology examination. Radiation dose metrics estimated were entrance skin dose (ESD) in mGy from thermoluminiscent dosimeters(TLDs) for routine radiographic examinations, contrast examination, dental examination and mammography examinations. Dose area product (DAP) mGy.cm2from DAP meter for fluoroscopy examination. Computed tomography dose index (CTDI) and dose length product (DLP) were obtained directly from the CT machine.

3.2 Location of the study

The study was conducted in the Radiology departments of two University Teaching Hospitals located in North Eastern part of Nigeria. They include Abubakar Tafawa Balewa University Teaching Hospital Bauchi State and Federal Teaching Hospital Gombe State. The data in this study were collected from October 2015 to January 2017. The centers were chosen because they met the eligibility criteria for the study (having all the imaging modalities for the study).

3.3 Target Population

The population of this study includes adult standard sized patients referred to the various Radiology departments of the study centers by physicians for conventional x-ray, dental x-ray, computed tomography, fluoroscopy and mammography. However, only patients who consented and met the eligibility criteria were included. Thirty (30) patients were enrolled

for thirty nine (39) different radiological examinations. The total population 1080 patients were enlisted for the study.

3.4 Sampling Technique

Convenient sampling technique was used to recruit the patients who participated in the study. Adult patients were enrolled based on their eligibility status and consent as they come for diagnostic radiology procedures in the radiology department of the hospital.

3.5 Sample Size

Sample size was determined in accordance with the standard guidelines by International Commission on Radiological protection (ICRP), 2017 recommending at least 20 standard sized patients for each radiological examination surveys in a facility when establishing DRLs for radiological examinations (ICRP,2017).Several established studies recommended at least 20 standard sized adult patientsfor each procedure in setting DRLs (European Commission, 1996; Hart *et al.*, 2012; Saravanakumar, 2014; Foley *et al.*, 2014; ARPANSA, 2014 and ICRP, 2006). However, the larger the sample size, the more representation ofthe population from which it was taken (Willis, 2014). Therefore, thirty(30) patients were enrolled for each conventional x-ray, dental x-ray, and fluoroscopy and computed tomography procedure in the study.

3.6 Ethical Clearance

In line with Helsinki declaration (1964), ethical approval was obtained from the research ethics committee of the Faculty of Health Science and Technology, Nnamdi Azikiwe University Nnewi Campus and from each hospital under study (See Appendix A to D). Informed consent form interpreted in Hausa language was filled by each (volunteer,

Patient) participant in compliance with the Human Research Ethics Guidelines for patients who donot understand English Language.

3.7 Inclusion criteria

i. Only adult male and female patients from 18 years and above referred for conventional x-ray, dental x-ray, mammography, fluoroscopy and CT examinations in each hospital under study
ii. Subjects weighing 70±10kg.
iii. Data were acquired from imaging machines that have quality control and quality assurance program in place.

3.8 Exclusion Criteria

i. Patients who are critically sick and or whose weight could not be measured and patients that could not meet the inclusion criteria.

3.9 Materials

The following were the equipment's and research tools in this research work(See appendix J for specifications).

a. Machines and their specifications: (See appendix R,S,T,U)
    i. Conventional x-ray machine: The machine used were products of Variant medical system manufactured in China and United states for hospital A and B respectively both manufactured 2009. Maximum and minimum kVp and mAs for the machines are 40-150 and 0.5-630 for hospital A and 40-200 and 0.5-400 for hospital B respectively and inherent filtration of 1.5mmAL and 0.8mmAL for hospital A and B respectively.

ii. Dental x-ray machine: The model for both hospitals was PC-2500 and PC-1000 for hospitals A and B respectively. They were manufactured in 2000 by Philips (Hospital A) and in 2002 by Fort Iwayne USA (Hospital B). They have a kVp and mAs range of 50-90 and 0-7 for hospital A and 70-90 and 0-6 hospital B.

iii. Computed tomography machine: Both machines were manufactured by Neurosoft medical systems Philips in the year 2010 and 2013 for hospitals A and B respectively. They have kVp and mAs range of 30-120 and 30-500 for hospital A and 40-140 and 22-400 for hospital B respectively. All the equipment's were multislice design with rotating gantry, anode target of tungsten-Rhenium alloy and ring detectors.

iv. Fluoroscopy machine: The equipment is an over couch type manufactured by Philips in February 2010. The inherent filter is 2.5mmAl with kVp and mAs range of 40-150 and 0.5-850. Fluoroscopy machine used was for hospital A. Hospital B has no fluoroscopy machine.

v. Mammography machine: for hospital A the machine is manufactured by Planmed OY, Helsinki Finland in April 2008 while that of hospital B was manufactured by Halogic Inco-operation USA in July 2012. There kVp and mAs range are 20-35 and 10-500 for hospital A and 20-40 and 10-400 for hospital B respectively. The inherent filtration for both hospitals was 30µM Molybdenum, 0.5mmAl, 25µM Rhodium.

b. Thermoluminescent dosimeters (TLD): LiF (TLD–100) chips (calibrated) annealed. Manufactured in 2008 by radiologic STU TR 4 incorporation USA. It is 3.2x3.2 cm round.The Thermoluminiscent dosimeter chips were obtained from the Radiation Safety Adviser (RSA), Nigerian Nuclear regulatory Authority (NNRA), Abuja, Nigeria.

Figure 3.1 TLD Chips used for the study

c. Dose Area Product (DAP) meters used for the study was 7.2 Kermax Plus Tino, Chicago (calibrated):The DAP meter measured the radiation dose to air, times the area of the x-ray field expressed in gray-cm^2 (Gy-cm^2). The reading from the DAP meter can be changed by altering the x-ray technique factors (kVp, mA, or time), varying the area of the field, or both. If the chamber area is larger than that of the collimators, as the collimators are opened or closed the charge collected will also increase or decrease in proportion to the area of the field. The DAP meter was placed at the center of the collimator of the x-ray tube housing.

d. ZT WHO standard scale and height meter with error level of ±0.05. It was manufactured by Halogic incorporation United States of America in the year 2008.
e. Survey meter Rad Eye 1500 was used to record the background radiation. It was manufactured by Toshiba in the year 2009 in China
f. Measurement tape was used to measure the anterior posterior thickness of each and the focus to film distance (FFD).
g. Transparent Cello tape
h. IAEA Dose survey form adopted from IAEA technical report series number 457. See appendix I.

3.10 Methods of Data Collection

The following information were collected patients age, gender, sex, weight, height, Body mass index, focus to film distance and technical parameters. Data were entered by the researcher assisted by two senior Radiographers in each facility and then checked by a medical physicist. The information obtained for the study includes:

(i) Age to make sure that only adult patients of 18 to 80 years were recruited in the study.
(ii) Gender of the patients.
(iii) Patients body region examined
(iv) Technical Parameters such as tube potential (kVp), tube current (mAs), scan length, Field of view, angle of rotation, focus to film distance, anterior posterior thickness and fluoroscopy time for each examination and procedure where applicable.
(v) Weight(kg), height(m) and body mass index BMI (kg/m^2)

(vi) Type of Radiological equipment used, Machine parameters, model type, manufacturer, year and country specific to each radiological modality such as Computed Tomography (CT), fluoroscopy, mammography, conventional Radiography and dental Radiography were documented.

(vii) Dose measurements for each procedure or examination were recorded from the various machines.

3.10.1 Dose Metrics

The following dose parameters were obtained for different radiological imaging modalities according to the protocol of Institute of Physics and Engineering in medicine (IPEM) guidance, 2012.

(i) General and dental radiography examinations: kVp, mAs, entrance skin dose (ESD) in mGy from TLDs and Dose area product (DAP) in $mGy.cm^2$.

(ii) Mammography: The mean glandular dose (MGD) in mGy obtained from TLD readings, kVp and mAs.

(iii) Fluoroscopy: Dose area product (DAP) in $mGy.cm^2$, screening time (seconds), kVp and mAs

(iv) Computed tomography: Volumetric computed tomography dose index (CTDI vol) in mGy and the Dose length products DLP in mGy.cm

3.10.2. Examination Procedure

A total 1080 patients were considered in this study, 30 patients each were enrolled for 36 Radiological procedures comprising of 14 common radiographic examination, including dental x-ray examination, 12 contrast radiographic

examination, 4 mammography examination and 6 computed tomography examinations.

i. Radiography (Dental and conventional):For each general and dental examination considered in this study, the TLD chips were placed on the patients at the center of the x-ray beams central axis where the radiation strikes the patients skin. For dental x-ray, peri-apical view was considered, for mammography Medio lateral oblique and cranio-caudal views were considered. The patient breast was positioned on the support paddle, compression is then applied the machines uses automatic exposure control, it therefore provides the exposure factors to be used automatically namely kVp, mAs, Anode/filter combination according to the breast granularity and thickness. The machine also provides the compressed breast thickness before exposure was made. The parameters were recorded for each patient and the compressed breast thickness is measured using flexible meter rule. The TLD chip was placed at the upper inner quadrant of the breast before ‘any compression was made for both the CC and MLO views of both breasts. Two (2) TLD chips were used for each patient. The TLD exposure were labeled for proper identification and kept in black nylon away from radiation

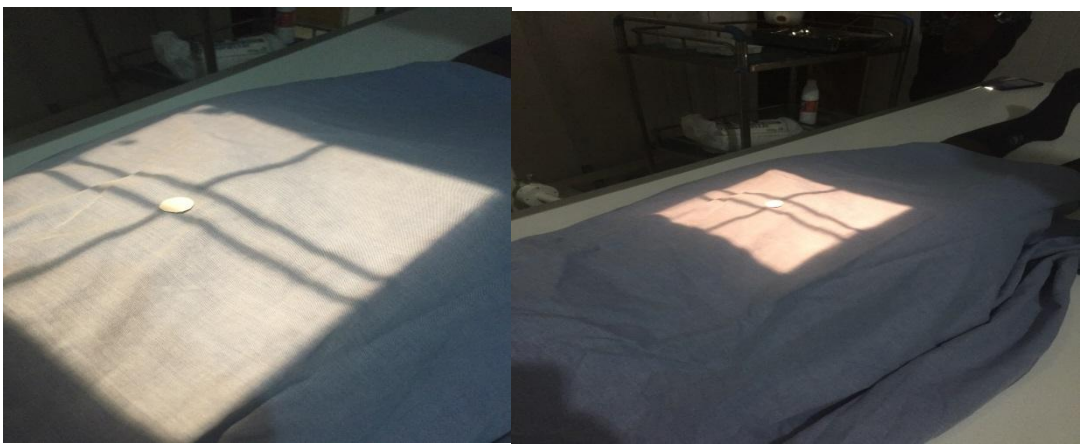


Figure 3.2: Set-up for measuring ESD

i. Fluoroscopy: DAP meter in the fluoroscopy room was placed 2cm below the x-ray collimator beam to measure the dose area products in mGy cm^2 forfluoroscopy procedures while TLD chips were placed at the centering point where the x-ray beam intercepts with the patient's body. The examinations carried out using fluoroscopy machine were Hysterosalpingography, intravenous urography, retrograde urethrography, micturating cystouretrography, barium enema, barium meal and barium swallow.

   The radiographic contract procedure were carried out according to the following standard protocol;

   a. Hysterosalpingography: The TLD chips were placed on the patient's pelvis 5cm above the symphysis pubis for Conventional x-ray procedures while DAP meter was placed just beyond the collimators for each fluoroscopy HSG examination, at the point where the central beam intercepts the Patient's centering point.

   b. Intravenous urography: venous access via the median ante-cubital vein was carried out, the cannula/needle was inserted to allow injection to be given rapidly. Sixty(60) mls of urografin was injected then anterior posterior abdomen views and coned down view of the renal area anterior posterior films are taken with patient lying supine based on the timing series immediate, 5minutes, 15 minutes, 30 minutes, bladder view and post micturition respectively. The TLD chips were placed at the umbilicus exactly at the center of the beam where the x-ray strikes the patient's body region of interest for IVU exposures.

   c. Retrograte urethrography: The TLD chips were placed at point 5cm above the the symphysis pubis where the x-ray beam strikes the patient's body region of interest for every exposure.

d. Micturating cystourethrogram: The TLD chips was placed 2.5 cm above the symphysis pubis at the center of the beam where the x-ray strikes the patient's body region of interest for every exposure.

e. Barium swallow: The TLD chips was placed at the 3rd to 4th cervical bone region at the center of the beam where the x-ray strikes the patient's body region of interest for every exposure.

f. Barium meal : The TLD chips were placed at the center of the beam where the x-ray strikes the patient's body region of interest for every exposure.

g. Barium enema: The TLD chips were placed at the center of the beam where the x-ray strikes the patient's body for every exposure.

ii. Computed Tomography (CT): As scans are done for different procedures head CT, chest CT, Abdominal CT and pelvic CT. Computed Tomography Dose Index (CTDI vol.) and Dose Length Product DLP were obtained from the monitor of the machine directly. Scan parameters such as tube current (mAs) , tube voltage (kV) , slice thickness, pitch, scan length, number of slices scan mode and field of view (FOV) were also displayed on the monitor.

Figure 3.3: Set up for patient positioning during head computed tomography

3.10.3 Procedure for recording weight and height

The patients that consented for the study were asked to stand erect in anatomical position and without shoes on the WHO ZT scale for weight and height. Measurements for weight and height were done in all the centers. Body mass index were obtained by dividing weight by square of height (kg)/height^2 (m^2). However, the scale was always on zero before taking measurements to ensure accuracy

Figure 3.4: Set up for measuring weight and Height

3.10.4 Dosimetric Measurements

Thermoluminiscent dosimeters and Dose area Product meters were used for dose measurement for conventional x-ray, dental x-ray, and mammography and fluoroscopy examinations. The TLDs were annealed and read after each exposure at the Center for Energy Research and Training Zaria, Kaduna State, Nigeria. The TLDs were annealed before taking the next measurements. The annealing was done at a high temperature of 98 degree centigrade; this process essentially zeroed the Thermo luminescent material by releasing all trapped electrons before the TLD is used. About ten percent (10%) of the

TLD chips used were set aside as controls in the various centers to help record background radiation. The control TLD chips are kept in a black nylon away from exposure to irradiation (both primary and secondary beam).Dose area product readings were taken directly from the DAP meters. After collection of the TLD and DAP readings, the collective values were recorded for each examination. The mean and third quartile (75^{th} percentile)values were obtained from the total received.

3.10.5 Thermoluminescent dosimeter dose Algorithms

a. Glow curve analyzer which determines the quality of the glow curve. See appendix K for dose curve profile of TLD-100 (LiF-TLD).
b. Glow curve deconvulation which segregates the glow curve into their individual glow peaks
c. Chain of custody and health physics record system, which updates and maintains dose data
d. The peak value of the glow curves produced (plate 1) were automatically converted to dose using the formula:

$$\text{Dose} = \frac{Q \times ECC}{RSF} \quad \text{.....Equation 3.1}$$

Where

Q = Charge (the glow peak value, in nano -columb).

ECC = Element correction coefficient = 3749

RCF = Reader calibration factor = 0.0171

3.10.6 Processing of the TLD

The TLD reader used in this study is the Harshaw Model 4500. It has a hardware comprising the following system.

1. The model 4500 Harshaw TLD reader which contains data processing electronic, a sample drawer assembly, a precision light measurement system, a detector heating system, a light voltage power supply, data storage facilities and photo multiplier tubes.
2. A video display unit (VDU) for the display of data graphics, operating instruction and messages.
3. Keyboard that provides the interactive central interface with the TLD reader Harshaw model 4500.
4. A set of floppy disk for backup.

The model 4500 Reader is capable of reading a number of forms of thermo luminescence dosimeters, such as the whole body and the environmental dosimeter.

The Harshaw Model 4500 Manual TLD Reader with WINREMS is a state-of-art; tabletop instrument used for thermo luminescence dosimetry (TLD) measurement of a wide variety of TL materials in many forms and sizes. This model incorporates two Photomultiplier Tubes in a sliding housing, with both planchet and hot gas (nitrogen or air) heating methods. The TL element may be heated by hot gas or by a planchet. Hot gas is used for whole body and Environmental TL cards and extremity Dosimeters (Chipstrates and Ringlets), while the planchet is used for theunmounted TL elements: chips, disks, rods, and powders.The system consists of two major components: the TLD Reader and the Windows Radiation Evaluation and Management System (WinREMS) software resident on a personal computer (PC), which is connected to the Reader via a serial communications port.

a. WinREMS Application software

The data architecture of the system includes both a host computer in the Reader and a Windows based PC connected through an RS-232-C serial communication port. The dosimetric functions divided between the Reader and the HarshawWinREMS (Windows Radiation Evaluation and Management) software on the PC. All dosimetric data storage, instrument control, and operator inputs are performed on the PC, transport subsystem control, gas and vacuum controls, and signal acquisition and conditioning are performed in the Reader.

3.11 Data Analysis

Data was obtained and saved on a computer Microsoft excel spread sheet and categorized for each examination and imaging modality respectively. It was independently checked by a statistician and two senior radiographers. Statistical Package for Social Sciences version 21.0 was used to analyze the mean and standard deviation of the anthropometric variables, technical parameters and radiation dose received. Seventy fifth (75^{th}) percentile or (3^{rd} quartile) value of the total mean of the examinations and or procedures were obtained at 95% confidence interval. Using Kolmogorov- Smirnov to test for normality of data distribution it was verified that, for 95% of confidence level, there was a normal distribution. Therefore, we used a parametric test that was suitable for the set of data and analysis. Pearson's correlation was used to determine the relationship between radiation dose and weight at statistical significance of $p<0.05$.

3.11.1 Dose Determination for mammography

After the TLD chips were read by the TLD reader, of the value gotten by the control chips reading was subtracted from the value of the actual TLD chips to get the value of the Entrance Surface Dose (ESD).

To get the Mean glandular Dose the conversion factors derived by Dance *et al*., (2000) was used to calculate the MGD.

The MGD was calculated using this formula:

$MGD = K \times g \times C \times s$……Equation 3.2

Where K = Entrance Surface Dose

g= ESD to MGD conversion factor on the assumption that the entire breast has a glandularity 50%.

C = Conversion factor for difference in breast composition other than 50% grandularity.

s = is the conversion factor for different x-ray spectrum which can be due to different anode/filter combination e.g. Mo/Mo, Mo/Rh.

3.12 Deriving Diagnostic Reference Dose Levels

Diagnostic reference levels will be taken from the third quartile (75^{th} percentile) readings of the distribution of mean doses from different radiological examination values obtained.

3.12.1 Step 1

Mean TLD values, DAP values, CTDIvol and DLP values derived from eachexamination and procedure were recorded. The mean summarizes all the data, it is calculated by adding all the values and dividing the sum by the number of observations. This was achieved by using Statistical Package for Social Sciences version 21.0.

3.12.2 Step 2

The DRLs was set at approximately the level of 75th percentile (3rd quartile) of the average of dose distribution applied on radiological procedures. The 75thpercentile (3rd quartile) is chosen as the appropriate investigation level on the grounds that if 75% of the units can operate satisfactorily below this dose level, the remaining 25% should be made aware of their potentially less than optimal performance. They should then be encouraged to work on their radiographic technique to bring their dose in line with the majority (European Commission, 1999).

3.12.3 Step 3

Comparison of the established DRL values obtained in this study with the data from other countries where DRLs have been established.

3.12.4 Step 4

Test for normality of data was done using Kolmogorov Smirnov to determine whether the data is normally distributed or not. Pearson's correlation was used to determine the relationship between dose and anthropotechnical parameters while students T-test was used to compare the mean radiation dose between the two hospitals.

CHAPTER FOUR

RESULTS

4.1 Mean and standard deviation of anthropometric and technical parameters for all the patients

Table 4.1 a and **b** below shows patients total mean value for anthropometric parameters(age (years), weight (kg), height (m), body mass index (kg/m^2), focus to skin distance (FSD), anterior posterior (AP) thickness (cm) and compressed breast thickness (CBT) in (cm) for mammography)and technical parameters (Tube potential kVp and tube current mAs). The mean and standard deviation of the age weight, height, BMI,AP thickness, CBT, FSD, kVp and mAs for the whole patient population are 38.10±93, 60.00±1.0, 1.65±0.10, 24.32±3.30, 17.12±0.13, 19.88±0.11, 98.34±3.00, 60.11±1.00 and 30.1±0.1. The mean weight recorded in this study was 60.01±9.0kg while the mean patient age was 38.10±9.3 years (Table 4.1b)

Table 4.1a Total mean and standard deviation of anthropometric and technical parameters for radiographic and dental examination.

Examination	Age (years)	Weight (kg)	Height (m^2)	BMI (kg/m^2)	Thickness (cm)	FSD (cm)	kVp	mAs
Chest x-ray PA	37.18±13	66.25±6	1.67±0	26.32±16	14.15±2.6	129.50±16	61.86±4	14.23±2
Chest x-ray Lateral	41.63±12	66.67±6.4	1.64±0.	25.18±7.	18.93±3.0	119.17±20	84.40±5.	34.09±7
Hand Dorsi Palmar	41.17±13	68.56±6.3	1.74±0	23.23±2	1.07±0.25	86.33±7.5	53.70±8	2.33±0.3
Hand DP Oblique	40.82±15	68.60±6.1	1.74±0	23.21±2	1.03±0.14	92.00±9.9	58.00±5.	2.38±0.5
Abdominal x-Ray	43.06±15	68.20±6.1	1.75±0.	22.72±24	20.67±3.8	94.00±4.7	81.02±7.	39.32±7
Pelvic x-Ray	47.70±18	69.12±6.5	1.76±0.	22.23±3.	17.15±3.1	80.00±9.4	77.00±5.	37.22±7.
Skull x-Ray PA	45.07±17	67.87±6.2	1.70±0	24.73±6	13.78±3.3	88.42±12	72.09±9	29.43±9
Skull Lateral	43.43±15.	66.26±2.9	1.75±0	22.86±2	10.57±1.4	87.10±3.8	66.00±7	34.75±3
Knee AP	37.89±13	66.87±5.4	1.75±0	21.59±3	4.66±0.95	89.25±12	54.59±4	4.43±3.6
Knee Lateral	40.67±15	68.70±6.8	1.75±0	22.70±3	22.45±0.8	47.65±5.6	60.08±6	3.60±0.5
Elbow AP	36.23±12	65.23±6.1	1.65±0	23.48±3	4.17±0.89	82.67±11	54.00±7	3.43±0.5
Elbow Lateral	34.58±11	65.24±6.1	1.68±0	23.51±3	4.05±0.67	84.67±9.9	52.43±6	3.23±0.5
Dorsi Plantar Foot	38.42±13	65.60±6.0	1.62±0	24.48±3	3.14±0.7	95.00±6.9	54.17±3	11.37±2
DP Oblique Foot	38.93±13	67.10±6.2	1.64±0	24.89±2	3.14±0.72	98.34±3.7	54.01±3	11.26±2
Shoulder AP	42.27±16	66.19±6.2	1.65±0	24.32±3	5.99±1.01	88.67±9.2	58.82±3	5.57±0.7
Lateral Shoulder	42.49±17	66.18±6.2	1.65±0	24.31±3	5.83±1.07	86.17±11	59.11±3	4.69±0.9
Wrist AP	41.22±13	67.26±6.2	1.71±0	23.06±2	2.35±0.62	73.17±6.4	54.35±4	3.09±0.4
Lateral Wrist	40.23±11	67.27±6.2	1.71±0	23.06±2	12.75±4.0	73.17±6.4	55.67±3	3.70±0.4
AP Dorsal Spine	48.30±9.6	64.30±5.5	1.64±0	22.41±3	19.88±2.9	86.00±4.9	67.08±5	34.42±3
Lat. Dorsal Spine	48.30±9.6	64.12±5.5	1.65±0	22.27±3	26.65±3.4	95.67±5.0	75.00±6	36.42±3
AP C/Spine	42.15±13	65.40±5.8	1.63±0	23.56±3	5.48±0.72	105.00±5	60.34±3	21.87±2
Lateral C/ Spine	42.15±13	65.40±5.8	1.63±0	23.56±3	5.32±0.62	105.00±5.	60.34±3	21.87±2
AP Lumbosacral	46.20±11	68.30±5.5	1.64±0	22.41±3	19.13±1.4	92.00±9.9	61.83±2	31.50±2
Lateral LSS	46.20±11	84.93±5.4	1.65±0	22.13±3	24.83±4.2	91.33±10	68.33±8	33.33±5
Dental x-Ray	42.04±11	65.30±5.8	1.65±0	23.36±3	2.07±0.25	73.50±4.0	47.49±4	11.47±1

Key:DP- Dorsi-plantar, AP-Anterior posterior, PA- Posterior anterior, C/S- Cervical spine, LSS-lumbosacral spine,

Table 4.1b Total mean and standard deviation of anthropometric and technical parameters for contrast Radiographic examination, computed tomography (CT) and mammography examination

Examination	Age (years)	Weight (kg)	Height (m^2)	BMI (kg/m^2)	Thickness (cm)	FSD (cm)	kVp	mAs
Contrast Study								
IVU	39.04±7.7	66.82±6	1.66±0	37.99±8	18.12±2.8	126.17±21	80.00±4	40.62±7
HSG	27.55±3.6	67.39±6	1.73±0	22.77±2	14.70±3.7	97.00±4.6	37.78±7	16.21±5
RUG	47.70±16	69.12±6	1.76±0	22.23±3	17.15±3.1	80.00±9.4	77.00±5	37.22±7
Barium Enema	39.04±7.7	65.93±5	1.64±0	38.64±8	18.12±2.8	128.17±18	80.00±4	40.62±7
Barium Swallow	39.04±7.7	65.93±5	1.66±0	38.64±8	18.12±2.8	126.17±21	72.83±4	37.08±4
Barium Meal	36.43±11	66.45±6	1.66±4	27.57±0	14.75±2.7	121.33±17	76.48±6	27.04±8
CT								
Head	42.56±19	66.26±6	1.67±0	30.32±2	57.25±12	48±575.80	120±0.10	99.00±2
Chest	47.06±17	66.21±6	1.68±0	23.36±3	20.94±4.4	107.06±5	162.60±3	98.25±3
Abdomen	51.00±17	66.46±6	1.64±0	42.68±5	19.92±5.5	91.90±4.7	123.20±1	98.42±1
Total Mean					**88.34±3.0**			
Mammography								
Cranio- Caudal	50.89±7.9	62.55±8	1.63±0	23.04±3	20.0±0.40	60.00±0.0	80.20±0	20.63±1
MLO	49.14±8.9	63.55±5	1.61±0	23.64±3	19.9±0.42	59.33±1.7	80.35±2	20.83±1
Total Mean	**38.10±9.3**	**60.01±9**	**1.65±0**	**24.32±3**	**17.12±0.1**	**19.88± 0.1**	**60.11±1**	**30.1±0.1**

Key:
IVU- Intravenous urography, HSG- Hysterosalpingography,
RUG- Retrograte-urethrography,BMI- Body mass index, FSD- focus to skin distance,
kVp- kilo volt peak, mAs- milli ampere seconds, CT- Computed tomography.

4.2 Mean and standard deviation of entrance skin doses (mGy) received by patients during radiographic examinations, dental x-ray, contrast examination, mammography and computed tomography examination.

Table 4.2a shows the mean and standard deviation of entrance skin doses (mGy) received by patients during radiographic examinations in both hospitals and the established diagnostic reference levels in mGy.

The total mean dose and standard deviation of the radiographic examinations for the hospitals were 0.45±0.36, 0.82±0.44, 0.77±0.41, 0.69±0.73, 0.40±0.25, 0.46±0.34, 0.50±0.24, 0.63±0.37, 0.45±0.21, 0.41±0.23, 0.86±0.32, 0.92±0.35, 0.64±0.26, 0.99±0.11, 1.43±0.10,0.39±0.25,0.63±0.44,0.38±0.21,0.69±0.38,0.83±0.31,0.60±0.30,0.25±0.20,0.56±0.37 and 0.29±0.37 all mGy for posterior anterior chest x-ray, lateral chest, posterior anterior skull, lateral skull, anterior posterior shoulder, lateral shoulder, dorsi plantar foot, dorsi plantar oblique foot, anterior posterior dorsal spine, lateral dorsal spine, anterior posterior cervical spine, lateral cervical spine, anterior posterior lumbosacral spine, lateral lumbosacral spine, anterior posterior wrist, lateral wrist, anterior posterior knee, lateral knee, abdominal x-ray, pelvic x-ray, hand dorsi palmar oblique, hand dorsi palmar and dental x-ray (peri-apical view) respectively.

Table 4.2a Mean dosesand 75th percentile (DRLs) for radiographic examination

Examination	Mean ESD (mGy) Hospital A	Mean ESD (mGy) Hospital B	Mean ESD(mGy) Both	DRL(mGy)
PA chest x-ray	0.34±0.05	0.55±0.43	0.45±0.36	0.59
Chest x-ray lateral	0.78±0.07	0.87±0.49	0.82±0.44	1.02
PA skull x-ray	0.79±0.32	0.74±0.50	0.77±0.41	1.02
Lateral skull	0.77±0.32	0.61±0.45	0.69±0.73	1.01
AP elbow	0.44±0.05	0.36±0.17	0.40±0.25	0.57
Lateral elbow	0.56±0.06	0.36±0.29	0.46±0.34	0.77
AP shoulder	0.29±0.03	0.71±0.27	0.50±0.24	0.71
Lateral shoulder	0.59±0.06	0.66±0.40	0.63±0.37	0.83
Dorsi plantar foot	0.34±0.03	0.56±0.24	0.45±0.21	0.58
Dorsi plantar oblique foot	0.36±0.03	0.45±0.25	0.41±0.23	0.61
AP dorsal spine	0.87±0.33	0.86±0.318	0.86±0.32	1.03
Lateral dorsal spine	0.97±0.50	0.87±0.20	0.92±0.35	1.09
AP cervical spine	0.37±0.18	0.53±0.26		0.62
Lateral cervical spine	0.73±0.25	0.54±0.27	0.64±0.26	0.79
AP L/S spine	0.99±0.11	0.98±0.45	0.99±0.11	1.22
Lateral L/S spine	1.43±0.10	1.28±0.33	1.43±0.10	1.59
AP wrist	0.46±0.16	0.42±0.24	0.39±0.25	0.52
Lateral wrist	0.58±0.20	0.42±0.30	0.63±0.44	0.87
AP Knee x-ray	0.36±0.18	0.80±0.42	0.38±0.21	0.50
Lateral knee x-ray	0.58±0.35	0.40±0.24	0.69±0.38	0.91
Abdominal x-ray	0.87±0.46	0.43±0.35	0.83±0.31	1.01
Pelvic x-ray AP	0.62±0.05	0.80±0.34	0.60±0.30	0.82
Hand dorsi palmar oblique	0.21±0.03	0.58±0.28	0.25±0.20	0.59
Hand dorsi palmar	0.49±0.07	0.30±0.21	0.56±0.37	0.58
Dental x-ray (periapical view)	0.41±0.11	0.27±0.24	0.29±0.37	0.46

Key- ESD- Entrance skin dose, L/S- Lumbo sacral spine.

Table 4.2b shows the mean and standard deviation of doses received and the diagnostic reference levels in the hospitals for contrast radiographic examination in mGy and mG.cm^2

The mean and standard deviation of entrance skin dose in hospital A for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 2.17±1.94mGy, 1.41±0.66mGy, 1.66±0.44mGy,10.63±1.05 mGy,1.62±0.35mGy and 1.18±0.65mGy respectively. The mean and standard deviation of entrance skin dose in hospital B for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 4.61±4.58 mGy, 2.30±1.45mGy, 2.61±1.31mGy,2.62±1.31,2.62±1.45 and 1.82±1.19 respectively. The total mean and standard deviation of entrance skin dose for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 4.89±3.26mGy, 1.44±0.55mGy, 2.14±0.88mGy, 11.95±1.90mGy, 2.12±0.90mGy and 1.50±0.92mGy respectively.The mean and standard deviation for dose area product in mGy.cm^2 for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 9.25±1.31, 2.97±0.55, 7.33±1.85, 16.26v3.23, 7.62±2.01 and 5.91±1.24.

Table 4.2b Mean doses received and 75th percentile (DRLs) for contrast radiographic examination

Examination	Mean ESD (mGy) Hospital A	Mean ESD (mGy) Hospital B	Mean ESD (mGy) Both	DAP ($mGy.cm^2$)	DRL mGy	$mGy.cm^2$
IVU	2.17±1.94	4.61±4.58	4.89±3.26	9.25±1.31	6.68	10.66
HSG	1.41±0.66	2.30±1.45	1.44±0.55	2.97±0.55	2.31	3.67
Barium meal	1.66±0.44	2.61±1.31	2.14±0.88	7.33±1.85	2.66	8.98
Barium enema	10.63±1.05	2.62±1.31	11.95±1.90	16.26±3.23	12.78	20.64
Barium swallow	1.62±0.35	2.62±1.45	2.12±0.90	7.62±2.01	2.73	6.56
RUG	1.18±0.65	1.82±1.19	1.50±0.92	5.91±1.24	2.05	7.55

Key- IVU- Intravenous urography, HSG- Hysterosalpingography,

RUG- Retrograte-urethrography, ESD- Entrance skin dose, DAP-Dose area product

Table 4.2c shows mean and standard deviation of the entrance skin dose, mean glandular dose and diagnostic reference levels for mammography examination. The mean entrance skin dose for cranio-caudal and Medio lateral oblique are 0.50±9.48mGy and 0.70 ±0.74mGy for Hospital A, 0.31±0.05mGy and 0.69±0.11mGy for hospital B. The total mean and standard deviation for both hospitals were 0.48±0.69mGy and 0.68±0.40mGy for cranio-caudal and Medio lateral oblique respectively. The mean glandular dose for cranio-caudal and Medio lateral oblique are 0.31±0.05 and 0.69±0.11. The diagnostic reference level for cranio-caudal and Medio lateral oblique are 0.63mGy and 1.04mGy.

Table 4.2c Mean glandular dose (MGD) received and 75th percentile (DRLs) for mammography examination

Examination	Mean ESD (mGy) Hospital A	Mean ESD (mGy) Hospital B	Mean ESD (mGy) Both	MGD (mGy)	DRL (mGy)
Cranio-caudal	0.50±0.48	0.31±0.05	0.48±0.69	0.31±0.05	0.63
Medio lateral oblique	0.70±0.74	0.69±0.11	0.68±0.40	0.69±0.11	1.04

Key-ESD- Entrance skin dose, MGD- Mean glandular dose

Table 4.2d shows mean and standard deviation of computed tomography dose index (CTDI) and diagnostic reference level for computed tomography for head, chest and abdomen.

The mean CTDI for hospital A is 57.26±12.50mGy, 13.94±4.48mGy and 13.92±5.57mGy for head CT, chest CT and CT Abdomen respectively. The mean CTDI for hospital B is 44.08±9.95 mGy, 10.64±4.78mGy and 10.92±5.57mGy for head CT, chest CT and CT Abdomen respectively. The total mean CTDI for hospitals is 57.25±2.50 mGy, 12.58±4.20mGy and 12.24±4.28mGy for head, chest and Abdomen respectively. The mean and standard deviation of dose length product are 958.52±6.3, 659.10±1.30 and 1290.07±1.71 for CT head, CT chest and CT abdomen respectively.

Table 4.2d Mean doses received and 75 percentile (DRLs) for computed tomography examination

Examination	Mean CTDI (mGy) Hospital A	Mean CTDI (mGy) Hospital B	Mean CTDI (mGy) Both	DLP (mGy.cm)	DRL (mGy)
CT Head	57.26±12.50	44.08±9.95	57.251±2.50	958.52±6.3	67.90
CT Chest	13.94±4.48	10.64±4.78	12.58±4.20	659.10±1.30	18.38
CT Abdomen	13.92±5.57	10.92±5.57	12.24±4.28	1290.07±1.71	19.20

Key-CT- Computed tomography, CTDIvol- Volumetric computed tomography dose index, Dose length product

4.3 Relationship between doses received by patients during radiographic examination and their anthropometric variables

Table 4.3ashows the relationship between doses received by patients during radiographic examination and their anthropometric variables. Detail result from the table shows that, during chest PA x-ray radiological examination, the result indicated that there was a positive no significant relationship ($p>0.05$) between the height and weight of the patients with Entrance skin dose (ESD) received, however, AP thickness showed a negative no significant relationship ($p>0.05$) with Entrance skin dose (ESD) received, while BMI showed a negative significant relationship ($p<0.05$) of the doses received by the patients during radiological examination. The entrance skin dose for lateral chest x-ray showed a positive no significant correlation between AP Thickness, height and BMI and showed a negative no significant correlation.

Table 4.3a Relationship between mean doses received by patients and anthropometric parameters for radiographic examination.

Dose Versus	Thickness (cm)		Weight (kg)		Height (m^2)		BMI (kg/m^2)	
Examination	r	p	r	p	r	p	r	p
Chest x-ray PA/AP	-0.030,	0.876	0.006,	0.974	0.106,	0.577	-0.152,0.422	
Chest x-ray lateral	0.002,	0.991	-0.218,0.248		0.194,0.303		0.325, 0.080	
Hand Dorsi palmar	-0.171,0.366		-0.122,0.522		0.005,0.977		-0.222,0.283	
Hand Dorsi palmar oblique	0.342,0.065		0.215,0.254		-0.194,0.304		0.344,0.063	
Abdominal x-ray AP	0.303,0.104		0.134,0.481		-0.033,0.862		0.058,0.761	
Pelvic x-ray AP	-0.006,0.975		-0.074,0.697		-0.474**,0.008		0.961,0.830	
Skull x-ray PA/AP	-0.272,0.153		0.288,0.123		0.200,0.290		-0.157,0.408	
Lateral skull	0.156,0.409		-0.316,0.089		0.115,0.444		-0.202,0.285	
Knee AP	0.131,0.489		-0.008,0.966		-0.163,0.389		0.053,0.783	
Knee Lateral	0.511**,0.004		-0.224,0.235		0.312,0.093		-0.421*0.021	
Elbow AP	-0.259,0.167		-0.20, 0.917		0.002,0.992		0.011,0.954	
Elbow Lateral	0.059,0.756		0.060, 0.755		-0.614**,0.00		0.537**,0.002	
Shoulder AP	0.303,0.103		0.016, 0.933		-0.173,0.361		0.201,0.288	
Shoulder Lateral	0.100,0.599		-0.109, 0.566		-0.250,0.182		0.244,0.194	
Dorsi plantar foot	0.221,0.240		-0.333,0.073		0.373*,0.042		-0.241,0.199	
Dorsi plantar oblique foot	-0.501**,0.05		0.122,0.519		0.470**,0.009		-0.428*,0.018	
AP Dorsal spine	-0.130,0.493		0.353,0.056		-0.113,0.551		0.026,0.891	
Lateral dorsal spine	-0.205,0.277		0.060, 0.753		-0.050,0.793		0.074,0.697	
AP Cervical spine	-0.436*,0.016		-0.044,0.818		0.250,0.182		-0.209,0.269	
Lateral Cervical spine	0.230,0.222		0.017,0.931		-0.157,0.408		0.153,0.420	
AP Lumbosacral	-0.236,0.209		-0.374*,0.042		-0.547**,0.002		0.222,0.239	
Lateral Lumbosacral	0.150,0.428		-0.094,0.620		-0.323,0.082		0.187,0.324	
AP Wrist	0.037,0.846		0.256,0.172		0.011,0.953		-0.109,0.567	
Lateral Wrist	0.153,0.418		0.282,0.130		0.337,0.068		0.635,0.572	
Dental x-ray Periapical	0.196,0.299		-0.243,0.196		0.136,0.474		-0.194,0.303	

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 4.3b shows the relationship between doses received by patients and anthropometric parameters for mammography examination. There was no statistical significant relationship ($p>0.05$) between the dose and compressed breast thickness, weight, height and BMI.

Table 4.9 shows the relationship between doses received by patients and anthropometric parameters for computed tomography examination. There was no statistical significant ($p>0.05$) relationship between computed tomography dose index with thickness, weight, and height BMI head CT and abdominal CT. However, Chest CT show statistical significant relationship ($p<0.05$) with weight and height.

4.3b Relationship between mean glandular dose received by patients and anthropometric parameters for mammography examination

Dose versus	CBT (cm)		Weight (kg)		Height(m^2)		BMI (kg/m^2)	
Examination	r	p	r	p	r	p	r	p
Cranio caudal	0.134	0.479	-0.197	0.297	0.255	0.174	-0.220	0.242
Medio lateral oblique	-0.197	0.297	-0.219	0.244	0.324	0077	-0.352	0.057

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Key-CBT- Compressed breast thickness

Table 4.3c shows the relationship between mean doses and anthropometric parameters for computed tomography examination. There was no statistical significant ($p>0.05$) relationship between computed tomography dose index with thickness, weight, height and BMI for head CT and abdominal CT. However, Chest CT show statistical significant relationship ($p<0.05$) with weight and height.

Table 4.3c Relationship between mean dose (CTDI vol) and anthropometric parameters for computed tomography examination.

Dose versus Examination	FOV (cm)		Weight (kg)		Height (m^2)		BMI (kg/m^2)	
	r	p	r	p	r	p	r	p
Head CT	0.051	0.791	-0.149	0.392	0.013	0.943	0.012	0.947
Chest CT	0.123	0.231	-0.365*	0.019	-0.330*	0.035	-0.213	0.182
Abdomen CT	0.534	0.622	-0.236	0.160	-0.033	0.844	-0.041	0.812

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Key-FOV- Field of view, CT- Computed tomography, BMI- Body mass index

Table 4.3d shows the relationship between doses and anthropometric parameters for contrast radiographic examination. There was statistical significant relationship between dose area product (DAP) and weight in intravenous urography (IVU). During hysterosalpingography procedure there was statistical significant relationship ($p<0.05$) between weight, height and DAP. There was no statistical significant relationship ($p>0.05$) between entrance skin dose and AP thickness, weight, height and BMI in intravenous urography, hysterosalpingography, retrograde urethrography, Barium meal, barium enema and barium swallow respectively.

Table 4.3d (i) Relationship between mean doses and anthropometric parameters for contrast radiographic examination

Intravenous Urography				
	ESD Vs Anthrop. variables		DAP Vs Anthrop. Variables	
Anthropometric variables	R-val	P-val	R-val	P-val
APThickness	-.217	.250	.276	.140
Weight	.031	.870	.366*	.047
Height	.154	.415	-.107	.573
BMI	.051	.791	.334	.071
Hysterosalpingography				
APThickness	0.239	0.203	0.081	0.669
Weight	-0.081	0.669	0.360	0.051
Height	0.091	0.633	-0.531**	0.003
BMI	-0.276	0.140	0.509**	0.004
Retrograte Urethrography				
APThickness	-.012	.950	-.027	.886
Weight	-.050	.793	.218	.247
Height	.006	.480	-.161	.396
BMI	-.096	.615	.333	.073

Table 4.3d (ii) Relationship between mean doses and anthropometric parameters for contrast radiographic examination

Barium Meal				
	ESD Vs Anthrop. Variables		DAP Vs Anthrop. variables	
Anthropometric variables	R-val	P-val	R-val	P-val
APThickness	-0.150	0.427	-0.144	0.447
Weight	0.152	0.423	-0.188	0.320
Height	-0.078	0.683	0.215	0.255
BMI	0.127	0.504	-0.015	0.936
Barium Enema				
APThickness	-0.150	0.427	-0.144	0.447
Weight	0.152	0.423	-0.188	0.320
Height	-0.078	0.683	0.215	0.255
BMI	0.127	0.504	-0.015	0.936
Barium Swallow				
FSD	0.241	0.199	0.146	0.441
APThickness	0.112	0.555	-0.036	0.850
Weight	0.121	0.524	0.164	0.386
Height	0.029	0.879	-0.182	0.335
BMI	0.079	0.676	0.139	0.463

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

4.4 Relationship between mean doses received and technical parameters for radiographic examination

Table 4.4a shows the relationship between mean doses received during and technical parameters for radiographic examination. The result indicated that when the mean dose of Entrance skin dose (ESD) and technical variables (FSD, KVp and mAs) of various radiological examinations of (Chest x-ray PA/AP, Chest x-ray Lateral, Hand dorsi Palmar, Abdominal x-ray, Pelvic x-ray, Hand dorsi, Hand dorsi Palmar Oblique, Cranio Caudal View, Medio Lateral Oblique (MLO), Dental x-ray, when correlated they all showed no statistical significant differences ($P>0.05$), but in PA Chest x-ray there was a positive significant correlation ($P<0.05$) between Focus to skin distance (FSD) and Entrance skin dose (ESD), while kVp relationship with Entrance skin dose (ESD), showed a negative significant correlation ($P<0.05$) as shown in the table 4.4a below.

Table 4.4a-Relationship between doses received by patients during radiographic examination and technical parameters

Examination	Technical Parameters	ESD vs Technical parameters	
		R-value	p-value
Chest x-ray PA/AP	FSD	0.469	0.009*
	kVp	-0.249	0.185
	mAs	0.265	0.157
Chest x-ray lateral	FSD	-0.282	0.131
	kVp	-0.099	0.603
	mAs	-0.288	0.123
Hand dorsi palmar	FSD	-0.138	0.466
	kVp	-0.288	0.123
	mAs	-0.266	0.156
Abdominal x-ray	FSD	0.091	0.634
	kVp	-0.087	0.646
	mAs	0.056	0.769
Pelvic x-ray	FSD	-0.301	0.107
	kVp	-0.149	0.433
	mAs	-0.308	0.098
Hand dorsi palmar oblique	FSD	0.167	0.377
	kVp	-0.458	0.011
	mAs	-0.051	0.789
cranio caudal view mammography	FSD	0.003	0.989
	kVp	0.139	0.464
	mAs	-0.081	0.669
Mammagraphy medio lateral oblique	FSD	0.012	0.021
	kVp	-0.199	0.292
	mAs	0.187	0.322
Dental x-ray	FSD	-0.079	0.677
	kVp	-0.217	0.250
	mAs	0.013	0.945

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 4.4b shows the relationship between doses received by patients during radiographic examination and technical parameters. Result showed statistical significant relationship ($p<0.05$) between ESD and tube current (mAs) for AP knee with ESD and tube potential (kVp) for AP shoulder. The is no statistical significant relationship ($p>0.05$) between technical parameters and ESD for skull x-ray AP and lateral, knee AP and lateral, elbow AP and lateral, Shoulder AP and lateral and dorsi- plantar foot.

Table 4.4b- Relationship between doses received by patients during radiographic examination and technical parameters

Examination	Technical Parameters	ESD vs Technical Parameters	
		R-value	p-value
AP/PA skull x-ray	FSD	-0.340	0.066
	kVp	0.317	0.088
	mAs	0.014	0.943
Lateral skull	FSD	0.090	0.635
	kVp	0.053	0.783
	mAs	-0.160	0.398
AP knee	FSD	0.085	0.656
	kVp	0.138	0.466
	mAs	-0.479	0.007
Knee lateral	FSD	-0.232	0.217
	kVp	-0.187	0.322
	mAs	-0.245	0.192
Lateral elbow	FSD	-0.093	0.627
	kVp	-0.534**	0.002
	mAs	-0.100	0.599
Lateral shoulder	FSD	0.310	0.096
	kVp	0.200	0.290
	mAs	0.095	0.617
AP elbow	FSD	0.114	0.549
	kVp	-0.320	0.085
	mAs	0.125	0.510
Dorsi plantar foot	FSD	0.358	0.052
	kVp	-0.064	0.736
	mAs	0.010	0.959
AP shoulder	FSD	0.150	0.427
	kVp	-0.533	0.002
	mAs	-0.095	0.619

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).kVp- kilo volt peak, mAs- milli ampere seconds, FSD- Focus to skin distance, AP- Anterior posterior.

Table 4.4c shows the relationship between doses received by patients during radiographic examination and technical parameters. Result showed no statistical significant relationship ($p>0.05$) between ESD and technical parameters (FSD, kVp and mAs) for AP dorsal spine, lateral dorsal spine, AP cervical spine, lateral cervical spine dorsi-plantar oblique foot AP wrist and lateral wrist respectively.

Table 4.4c- Relationship between doses received by patients during radiographic examination and technical parameters

Examination	Technical Parameters	ESD vs Technical Parameters	
		R-value	p-value
AP dorsal spine	FSD	0.063	0.742
	kVp	0.053	0.781
	mAs	-0.281	0.133
Lateral Dorsal spine	FSD	0.072	0.707
	kVp	0.361	0.050
	mAs	-0.075	0.694
AP Cervical spine	FSD	0.201	0.287
	kVp	0.009	0.962
	mAs	0.175	0.354
Lateral cervical spine	FSD	-0.004	0.985
	kVp	0.132	0.487
	mAs	0.080	0.676
Dorsi plantar oblique foot	FSD	0.070	0.563
	kVp	-0.062	0.742
	mAs	-0.048	0.798
AP Wrist	FSD	0.039	0.837
	kVp	-0.335	0.071
	mAs	-0.356	0.054
Lateral wrist	FSD	-0.107	0.574
	kVp	-0.029	0.880
	mAs	0.030	0.875

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Key-kVp- kilo volt peak, mAs- milli ampere seconds, FSD- Focus to skin distance, AP- Anterior posterior.

Table 4.4d shows the relationship between doses received by patients during contrast radiographic examination and technical parameters. Result from IVU examination show that there was statistical significant relationship ($p<0.05$) between FSD and ESD, mAs and DAP while kVp and mAs show no statistical significant relationship ($p>0.05$) with ESD. During HSG examination there was statistical significant relationship ($p<0.05$) between tube current (mAs) and DAP. For RUG examination, ESD and technical parameters (kVp, mAs and FSD) show no statistical significant relationship ($p>0.05$). There was statistical significant relationship ($p<0.05$) between FSD, tube potential (kVp) and DAP. Barium enema show statistical significant relationship ($p<0.05$). Between DAP, ESD and FSD while kVp and mAs show no significant relationship with ESD and DAP. There is statistical significant relationship ($p<0.05$) between kVp, mAs and FSD while DAP showed that there is no significant relationship ($p>0.05$). Similarly, for barium swallow and enema examination, kVp and mAs show statistical significant relationship ($P<0.05$) with ESD while DAP show no statistical significance ($p>0.05$) with kVp, mAs and FSD.

Table 4.4d Relationship between doses received by patients during contrast radiographic examination and technical parameters

Examination	Technical Parameters	ESD Vs Technical Parameters		DAP Vs Technical Parameters	
		R-value	p-value		
IVU	FSD	0.534	0.002	0.077	0.686
	kVp	-0.317	0.088	-0.209	0.268
	mAs	-0.067	0.726	-0.469**	0.009
HSG	FSD	0.171	0.367	-0.096	0.613
	kVp	0.250	0.183	-0.071	0.708
	mAs	0.012	0.949	-0.132	0.488
RUG	FSD	-0.235	0.211	0.671	0.000
	kVp	-0.153	0.420	0.485	0.007
	mAs	0.213	0.259	-0.010	0.956
BA ENEMA	FSD	0.386	0.035	0.390*	0.033
	kVp	-0.086	0.650	-0.199	0.292
	mAs	-0.013	0.944	0.230	0.222
BA SWALLOW	FSD	0.174	0.357	-0.137	0.470
	kVp	0.448	0.013	-0.110	0.562
	mAs	0.678	0.000	-0.056	0.769
BA MEAL	FSD	0.139	0.465	0.185	0.327
	kVp	-0.532	0.002	-0.162	0.393
	mAs	-0.437	0.016	-0.246	0.191

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significantat the 0.05 level (2-tailed).

Key-IVU- Intravenous urography, HSG- Hysterosalpingography, RUG-Retrograteurethrography, ESD- Entrance skin dose, DAP-Dose area product, kVp- kilo volt peak, mAs- milli ampere seconds, FSD- Focus to skin distance, BA- Barium

4.5 Comparison of mean radiation dose and technical parameters in the hospitals studied during radiological examination.

Table 4.5a, shows the T-test comparison of radiation dose and technical parameters in the two hospitals studied during radiological examination. Detail result from the table shows that when the mean doses (Entrance skin dose) and technical variables (KVp and mAs) of AP elbow, Lateral Shoulder, Dorsi plantar foot, AP Dorsal Spine,Lateral Dorsal Spine, AP Cervical Spine, Lateral Cervical Spine, and Lateral Elbowof patients at Hospitals were compared, the show no statistical significant differences ($P>0.05$) in the radiological dose and technical variables patients received in the both hospitals.

Table 4.5a (i) Comparison of patient's radiation dose and technical parameters for radiographic examination between hospital A and Hospital B

Examination	Parameters	Mean±Std (Hospital A)	Mean±Std (Hospital B)	P-value	T-value
Chest x-ray PA/AP	kVp	59.17±0.78	64.56±4.53	0.25	0.533
	mAs	11.85±0.41	16.61±3.29	0.06	0.652
	ESD	0.34±0.05	0.55±0.43	0.75	0.988
Chest x-ray Lateral	kVp	82.80±10.00	86.00±2.00	0.25	0.543
	mAs	38.50±10.00	29.67±10.00	0.06	1.081
	ESD	0.78±0.10	0.87±0.10	0.06	1.102
Hand Dorsi Palmar (PA)	kVp	53.76±10.00	53.63±5.00	0.08	0.020
	mAs	1.980±1.00	2.68±01.00	0.06	0.857
	ESD	0.210±0.11	0.27±0.08	0.06	0.390
Hand Dorsi Palmar Oblique	kVp	57.33±10.00	58.66±5.00	0.08	0.206
	MAs	2.58±1.05	2.17±1.05	0.85	0.489
	ESD	0.69±0.20	0.43±0.30	0.06	1.249
AP Elbow	kVp	55.33±1.00	52.66±10.53	0.75	0.437
	mAs	2.98±1.00	3.55±1.53	0.25	0.538
	ESD	0.44±0.010	0.36±0.10	0.06	0.980
Lateral elbow	KVp	50.00±5.00	54.87±4.00	0.06	1.317
	mAs	2.95±1.00	3.51±2.00	0.08	0.434
	ESD	0.56±0.10	0.36±0.20	0.06	1.549
AP shoulder	KVp	58.53±2.97	59.10±7.00	0.25	0.130
	mAs	3.97±1.00	7.17±2.00	0.06	2.479
	ESD	0.29±0.10	0.71±0.20*	0.03	3.253
AP/PA Skull x-ray	KVp	68.17±10.00	76.00±3.00	0.25	1.299
	mAs	31.00±10.00	27.86±7.00	0.06	0.446
	ESD	0.79±0.10	0.74±0.20	0.06	0.387
Lateral Skull	KVp	68.00±6.00	64.00±10.00	0.08	0.594
	mAs	33.83±10.00	35.66±10.00	0.06	0.224
	ESD	0.77±0.12	0.61±0.30	0.06	0.858
Lateral shoulder	KVp	60.15±2.00	58.06±10.00	0.08	0.355
	mAs	4.73±1.05	4.65±1.00	0.85	0.095
	ESD	0.59±0.10	0.66±0.20	0.06	0.542
Dorsi plantar foot	KVp	56.09±2.57	52.56±10.00	0.75	0.593
	mAs	8.85±1.00	13.88±3.00	0.25	2.755
	ESD	0.24±0.10	0.56±0.23	0.06	1.344

Table 4.5a (ii) Comparison of patient's radiation dose and technical parameters for radiographic examination between hospital A and Hospital B

Examination	Parameters	Mean±Std (Hospital A)	Mean±Std (Hospital B)	P value	T-value
DPO foot	KVp	55.12±2.51	52.57±10.00	0.08	0.428
	mAs	8.63±2.00	13.88±5.00	0.06	1.689
	ESD	0.36±0.10	0.45±0.10	0.25	0.697
AP Wrist	KVp	57.40±3.10	54.43±2.00	0.06	1.393
	mAs	3.91±0.90	4.33±1.00	0.75	0.347
	ESD	0.46±0.10	0.42±0.10	0.25	0.490
Lateral Wrist	KVp	59.83±5.10	59.00±7.00	0.06	0.166
	mAs	3.96±1.00	5.00±1.00	0.06	1.274
	ESD	0.58±0.09	0.42±0.20	0.08	1.264
AP D/S	KVp	61.83±2.97	72.33±2.00	0.06	5.079
	mAs	31.50±10.00	37.33±10.00	0.06	0.714
	ESD	0.87±0.10	0.86±0.20	0.08	0.077
Lateral D/S	KVp	68.33±5.03	81.67±10.00	0.85	2.064
	mAs	33.33±10.00	39.50±10.00	0.06	0.756
	ESD	0.97±0.10	0.87±0.20	0.75	0.775
AP C/S	KVp	56.02±4.53	64.30±10.00	0.25	1.305
	mAs	21.43±10.00	22.30±10.00	0.06	0.107
	ESD	0.37±0.10	0.53±0.20	0.06	1.239
Lateral C/S	KVp	56.03±5.52	64.30±4.00	0.08	2.098
	mAs	21.43±10.00	22.30±10.00	0.06	0.107
	ESD	0.76±0.15	0.54±0.10	0.08	2.119
AP Knee	KVp	57.50±6.00	51.67±5.00	0.06	1.293
	mAs	2.76±1.12	5.41±2.00	0.25	1.996
	ESD	0.36±0.20	0.40±0.20	0.06	0.245
Knee Lateral	KVp	58.83±8.00	61.33±10.00	0.75	0.338
	mAs	3.12±1.47	3.75±1.00	0.25	0.615
	ESD	0.610±.25	0.80±0.10	0.06	1.194
Abdomen (AP)	KVp	71.83±10.00	84.03±3.00	0.06	2.660
	mAs	32.84±10.00	46.80±10.00	0.06	1.954
	ESD	0.87±0.200	0.80±0.10	0.08	3.817
Pelvic (AP)	KVp	74.66±10.00	79.33±10.00	0.06	0.572
	mAs	34.83±10.00	39.60±10.00	0.25	0.584
	ESD	0.62±0.20	0.58±0.30	0.06	0.192
Dental x-ray	KVp	45.30±4.00	49.67±4.00	0.75	1.338
Peri- apical view	mAs	11.43±5.10	11.50±4.00	0.08	0.019
	ESD	0.41±0.20	0.27±0.10	0.09	1.084

Key - DPO-Dorsi plantar oblique, C/S- Cervical Spine, AP- Anterior Posterior, D/S- Dorsal Spine

Table 4.5b shows the T-test comparison of radiation dose and some technical parameters in the hospitals studied during contrast radiographic examination. Mean Entrance skin dose for IVU, HSG, RUG, barium enema, barium swallow and barium meal show no statistical significant relationship ($p>0.05$) with technical parameters. However, ESD and DAP show statistical significant relationship for barium enema while mAs and kVp shows statistical significant relationship between barium swallow and barium meal.

Table 4.5b Comparison of patient's mean radiation dose and technical parameters for contrast radiographic examination for hospital A and Hospital B

Examination	Parameters	Mean±Std (Hospital A)	Mean±Std (Hospital B)	P-value	T-value
IVU	KVp	78.50±9.16	81.50±10.00	0.06	0.383
	mAs	32.00±10.00	49.23±10.00	0.07	2.110
	ESD	3.17±1.02	6.61±2.00	0.15	2.654
	DAP	9.25±0.00	10.26±2.00	0.25	0.875
HSG	KVp	66.90±5.00	76.63±4.00	0.06	2.632
	mAs	25.67±10.00	40.80±10.00	0.07	1.853
	ESD	1.41±0.91	2.30±0.88	0.09	1.207
	DAP	2.97±0.00	3.44±0.40	0.11	2.035
RUG	KVp	74.67±3.00	79.33±10.00	0.08	0.773
	mAs	34.83±10.00	39.60±10.00	0.06	0.584
	ESD	1.18±1.00	1.82±0.80	0.06	0.866
	DAP	5.91±0.00	7.14±1.00	0.06	2.130
Barium enema	KVp	78.50±10.00	86.00±2.00	0.07	1.274
	mAs	32.00±10.00	29.67±10.00	0.06	0.285
	ESD	10.63±4.00	2.62±0.00*	0.02	3.374
	DAP	16.26±0.00	7.90±1.00*	0.03	14.480
Barium swallow	KVp	65.67±10.00	80.00±3.50	0.25	2.343
	mAs	24.17±4.00	50.00±5.00*	0.04	6.987
	ESD	1.62±1.00	2.62±1.00	0.75	1.225
	DAP	7.62±1.00	6.24±1.00	0.25	2.390
Bariummeal	KVp	66.97±6.00	86.00±2.50*	0.03	5.071
	mAs	24.42±10.00	29.67±10.00	0.06	0.643
	ESD	0.34±0.20	0.55±0.20	0.08	1.286
	DAP	7.33±0.00	7.90±1.00	0.06	0.987

Key:**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Key-IVU- Intravenous urography, HSG- Hysterosalpingography, RUG- Retrograte urethrography, ESD- Entrance skin dose, DAP-Dose area product,

kVp- kilo volt peak, mAs- milli ampere seconds.

Table 4.5c shows the T-test comparison of radiation dose and some technical parameters for computed tomography examination between hospital A and B. Detail result from the table shows that when the mean doses (CTDIvol) and DLP of the hospitals were compared, there was statistical significant relationship ($p<0.05$) for DLP for CT head and CT abdomen while CTDIvol showed no statistical significant relationship ($p>0.05$) for CT head, chest and abdomen. DLP for chest CT showed no significant relationship ($p>0.05$).

Table 4.5c- Comparison of patient's radiation dose and technical parameters for computed tomography examination between Hospital A and Hospital B

Examination	Parameters	Mean±Std (Hospital A)	Mean±Std (Hospital B)	P-value	T-value
CT Head	CTDIvol	57.26±10.00	44.08±10.00	0.06	1.614
	DLP	892.48±10.00	958.52±10.00*	0.04	8.088
CT Chest	CTDIvol	17.06±5.00	16.22±2.00	0.15	1.614
	DLP	655.60±10.00	662.60±10.00	0.06	79.481
CT Abdomen	CTDIvol	17.90±5.00	17.52±10.00	0.07	0.871
	DLP	1033.20±10.00	1546.94±10.00*	0.02	62.920

*=Significant at P<0.05 when compared between Hospital A and Hospital B variables

CT- Computed tomography, CTDIvol – Computed tomography volumetric dose index, DLP- Dose length product

Table 4.5d shows the T-test comparison of radiation dose and some technical parameters for mammography examination between hospital A and B. Detail result from the table shows that when the mean doses for the hospitals were compared there was no statistical significant relationship ($p>0.05$) between mAs, kVp and mean glandular dose for the hospitals.

Table 4.5d- Comparison of patient's mean glandular dose and technical parameters for mammography examination between Hospital A and Hospital B

Examination	Parameters	Mean±Std (Hospital A)	Mean±Std (Hospital B)	P-value	T-value
Cranio Caudal View	mAs	80.17±10.00	80.53±5.00	0.07	0.056
	kVp	21.17±10.00	20.50±4.00	0.09	0.108
	MGD	0.31±0.20	0.50±0.10	0.06	1.472
Medio Lateral Oblique (MLO)	mAs	80.20±10.00	80.20±2.00	0.08	0.000
	kVp	21.03±10.00	20.23±5.00	0.07	0.124
	MGD	0.69±0.10	0.73±015	0.06	0.411

*=Significant at P<0.05 when compared between Hospital A and Hospital B variables

MGD- Mean glandular dose, kVp- kilo volt peak, mAs- milli ampere seconds

4.6 Comparison of established diagnostic reference levels for radiographic examination in this study with European commission, United Kingdom and Australia.

Table 4.6a shows comparison of established diagnostic reference levels for radiographic examination with European commission, United Kingdom and Australia. The DRL for PA chest x-ray and lateral in this work were 0.59mGy and 1.02mGy while that of ARPANSA, EC and UK are 0.15mGy and 0.5mGy, 0.3mGy and 0.4mGy, 0.2mGy and 0.5mGy respectively. PA skull x-ray and lateral skull x-ray shows 1.02mGy and 1.01mGy for this work while 1.85mGy and 1.5mGy, 0.7mGy and 1.0 mGy, 1.8mGy and 1.1mGy for ARPANSA, EC and UK respectively. The DRL for PA elbow and lateral elbow in this work were 0.57mGy and 1.77mGy while that of ARPANSA, EU and UK are 0.4mGy and 0.5mGy, 0.3mGy and 0.3mGy, 0.4mGy and 0.4mGy respectively. AP shoulder x-ray and lateral shows 0.71mGy and 0.83mGy for this work while 0.2mGy and 0.5mGy, 0.7mGy and 0.6 mGy, 0.5mGy and 0.5mGy for ARPANSA, EC AND UK respectively.

Table 4.6a- Comparison of DRLs for radiographic examination in this work with European Commission, United Kingdom and Australian radiation protection and nuclear safety agency DRLs

Examination	ARPANSA DRL(mGy)	EU DRL (mGy)	UK DRL (mGy)	DRL(mGy) This work
PA chest x-ray	0.15	0.3	0.2	0.59
Chest x-ray lateral	0.5	0.4	0.5	1.02
PA skull x-ray	1.8	0.7	1.8	1.02
Lateral skull	1.5	1.0	1.1	1.01
AP elbow	0.4	0.3	0.4	0.57
Lateral elbow	0.5	0.3	0.4	0.77
AP shoulder	0.2	0.7	0.5	0.71
Lateral shoulder	0.5	0.6	0.5	0.83
Dorsi plantar foot	0.3	0.5	0.5	0.58
Dorsi plantar oblique foot	0.3	0.4	0.4	0.61
AP dorsal spine	3.7	2.0	3.5	1.03
Lateral dorsal spine	5.0	3.0	4.0	1.09
AP cervical spine	5.0	4.0	3.0	0.62
Lateral cervical spine	6.0	7.0	5.0	0.79
AP lumbo- sacral spine	10	5.0	5.7	1.22
Lateral lumbo sacral -spine	14	8.0	10	1.59
AP wrist	0.4	0.4	0.3	0.52
Lateral wrist	0.5	0.4	0.6	0.87
AP Knee x-ray	0.4	0.4	0.3	0.50
Lateral knee x-ray	0.5	0.7	0.3	0.91
Abdominal x-ray	6.0	3.0	4.4	1.01
Pelvic x-ray AP	4.0	4.0	4.0	0.82
Hand dorsi palmar oblique	0.2	0.5	0.2	0.28
Hand dorsi palmar	0.4	0.3	0.5	0.83
Dental x-ray (periapical view)	0.4	0.2	0.6	0.46

Key -AP- anterior posterior, PA- Posterior anterior, EC- European commission, UK- United Kingdom, ARPANSA-Australian radiation protection and nuclear safety agency.

Table 4.6b shows comparison of established diagnostic reference levels for contrast radiographic examination with that of European commission, United Kingdom and Australia. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA) were 16mGy.cm^2, 4 mGy.cm^2, 13 mGy.cm^2,31 mGy.cm^2,11mGy.cm^2 and 13 mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG respectively. From the table, European commission (EC) DRL are 14 mGy.cm^2,2 mGy.cm^2,12 mGy.cm^2,23 mGy.cm^2,3.4 mGy.cm^2 and 7 mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG respectively. United kingdom DRL are presented as follows 10,2,5,15,4 and 15mGy and 14,4,12,21,7.5 and 7 in mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG . DRL for this study are 6.68 mGy ,10.66 mGy.cm^2 for IVU, 2.31mGy,3.6723 mGy.cm^2 for HSG, 2.66mGy,8.98 mGy.cm^2 for barium meal, 12.78mGy,20.64 mGy.cm^2 for barium enema,2.73 mGy and 6.56 mGy.cm^2 for barium swallow and 2.05mGy, 7.77 mGy.cm^2 for RUG.

Table 4.6b- Comparison of DRLs for contrast radiographic examination in this work with European Commission, United Kingdom and Australian radiation protection and nuclear safety agency DRLs.

Examination	ARPANSA DRL		EC, DRL		UK, DRL		DRL This work	
	mGy	DAP	mGy	DAP	mGy	DAP	mGy	DAP
IVU	----	16	---	14	10	14	6.68	10.66
HSG	----	4	---	2	24		2.31	3.67
Barium meal	----	13	---	12	5.0	12	2.66	8.98
Barium enema	----	31	---	23	15	21	12.78	20.64
Ba swallow	----	11	---	3.4	4	7.5	2.73	6.56
RUG	----	13	---	7	15	7	2.05	7.77

Fluoroscopy time is between 2 - 15 seconds with mean time of 8.12±1.03 minutes

Key- DAP - dose area product in mGy.cm2. EC- European commission, UK- United Kingdom, ARPANSA-Australian radiation protection and nuclear safety agency.

Table 4.6c shows comparison of established diagnostic reference levels for mammography examination with that of European commission, United Kingdom and Australia. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA), EC, UK and this work were 0.88mGy, 2.0mGy, 2.0mGy and 0.63mGy for cranio-caudal view. DRL for Medio-lateral oblique were 1.30mGy,2.0mGy, 2.1mGy and 1.04mGy for ARPANSA, EC, UK and present work respectively. The DRL values for mammography in this study are higher compared to that of ARPANSA, UK and European Commission respectively.

Table 4.6c Comparison of DRLs for mammography in this work with European Commission, United Kingdom and Australian radiation protection and nuclear safety agency DRLs

Examination	ARPANSA DRL(mGy)	EC DRL (mGy)	UK DRL (mGy)	DRL(mGy) This work
Cranio-caudal	0.88	2.0	2.0	0.63
Medio lateral oblique	1.30	2.0	2.1	1.04

Key-EC- European commission, UK- United Kingdom

ARPANSA-Australian radiation protection and nuclear safety agency

Table 4.6d shows comparison of established diagnostic reference levels for computed tomography examination with that of European commission, United Kingdom and Australia. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA) for CT were 47mGy, 9.5mGy and 10.9mGy for CT head, chest and abdomen respectively. That of European commission was 60mGy, 30mGy, and 35mGy for head CT, chest CT and CT abdomen respectively. Similarly, UK values were 66mGy, 17mGy and 19mGy for CT head, chest and abdomen respectively. The DRL values obtained in this work were 67.90mGy, 18.83mGy and 19.20mGy for head CT, Chest CT and CT abdomen respectively.

Table 4.6d- Comparison of DRLs for CT in this work with European Commission, United Kingdom and Australian radiation protection and nuclear safety agency DRLs

Examination	ARPANSA DRL(mGy)	EC DRL (mGy)	UK DRL (mGy)	DRL(mGy) This work
CT Head	47	60	66	67.90
CT Chest	9.5	30	17	18.38
CT Abdomen	10.9	35	19	19.20

Key-CT -computed tomography, EC- European commission, UK- United Kingdom ARPANSA-Australian radiation protection and nuclear safety agency

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

The study established diagnostic reference levels for radiological examinations in some selected university teaching hospitals in North eastern Nigeria. The hospitals studied were divided into two A and B respectively. There are three university teaching hospitals in North Eastern Nigeria as at the time of the study. However, teaching hospitals A and B were chosen because they met the inclusion criteria for the study having the necessary functional imaging facility suitable for the study. A total of one thousand and eighty (1080) patients were considered in this study, six hundred and forty eight (648) were males and four hundred and thirty two (432) were females. It is recommended that dosimetric measurements be made on statistically significant sample of patients (minimum 10) whose weights are near the standard adult patients of average weight 70±10kg as a major step to establish standardized patients for our population (European commission, 1996;Hart *et al.,* 2012; Saravanakumar, 2014). This study complied with the recommendations and therefore the estimate of ESDs for the various examinations could be considered sufficiently as a representative value for specific protocols and examination. This corroborates with other studies by ARPANSA, UK, CEC and IPEM, 2005 (Hart *et al.*, 2012)

. This study has provided some initial baseline data on the size of average adult patient in North Eastern Nigeria and the corresponding dose for radiological examination using different imaging modalities. The mean weight recorded in this study was 60.01±9.0kg while the mean patient age was 38.10±9.3 years. This corroborates with a study by International atomic energy agency (IAEA,1998). In the IAEA study in 2004, on patients undergoing radiographic examination in some European and Asian countries an average

weight of 70±10kg was considered appropriate for the European participating countries while 65±10kg was used for the Asian countries. The average age of the only African country that participated in the study, morocco was not stated but a compromise was made to enable a comparison of the measured dose to reference levels. The radiographic technical parameters recorded show that there are variations in technical factor when compared to the recommendations of European commission quality criteria (EC, 1996). Varying radiographic voltages and reduced FFD were noted in this study. All this factors have adverse influence on the outcome of the dose to patients. The above outcome is not isolated to this study, this corroborates with a study in Ghana (Eric,2013) but it is common in other developing countries (Johnson and Brenan,2000; Wall *et al.,* 2001; Kings and Pitcher, 2002).This problems could be attributed to inadequate training of imaging staff, variation in patients body built, different types of equipment and the variety of techniques used in different hospitals. Different methods of documenting data on radiation dose could lead to apparent dose variations (Kings and Picher; Minigh, 2005). This study reveals that there are some discrepancies in the use of focus to film distance as recommended by European quality criteria. The European quality criteria recommended an average focus to film distance of 115cm. However, the focus to film distance in our study is 88.34 and the range is 48.00±119. Most diagnostic centers use focus to film distance values below the average values 88.34±3.00 cm. Since the Entrance skin dose is inversely proportional to the of the focus film distance for the same kVp and mAs, the dose reaching the patient is expected to be high. Although the general trend across most centers is the use of lower focus to film distance and this in part might explain higher Entrance skin dose in most of the radiographic examinations. It can be seen that the result did not show this as a universal trend as doses vary with hospitals and technique. Findings from table 4.2a shows the mean and standard

deviation of entrance skin doses in mGy received by patients during radiographic examinations in both hospitals and the established diagnostic reference levels in mGy.

ESD values for the same type of examination in the hospitals vary possibly due to the differences in patient size and in the radiographic technique used by different radiographers. Variation in ESD values between different x-ray rooms will additionally be due to differences in radiographic equipment, film type, processing and processing conditions. The mean ESD values for the individual examinations varied considerably across all hospitals (Ofori *et al.,* 2013). The variation in dose among the study centers is in agreement with the findings of Shrimpton *et al.,* 1991 and Olerud, 1991. Who found variations in the centers to be up to 10 to 40 in UK and 8 to 20 in Norway. A common position among the hospitals in Nigeria is lack of regular patient dose monitoring and quality control in diagnostic radiology. A major reason for this is the cost of running a standard radiation protection and quality assurance facility. This is in consonance with a study by Egbe *et al.,* (2008) in three Nigerian hospitals in South South Nigeria .

Findings from table 4.2b shows the mean and standard deviation of doses received and the diagnostic reference levels in the hospitals for contrast radiographic examination in mGy and $mG.cm^2$

The mean and standard deviation of entrance skin dose in hospital A for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 2.17±1.94mGy, 1.41±0.66mGy, 1.66±0.44mGy ,10.63±1.05 mGy,1.62±0.35mGy and 1.18±0.65mGy respectively. The mean and standard deviation of entrance skin dose in hospital B for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 4.61±4.58 mGy, 2.30±1.45mGy, 2.61±1.31mGy,2.62±1.31,2.62±1.45 and 1.82±1.19 mGy respectively. The

total mean and standard deviation of entrance skin dose for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 4.89±3.26mGy, 1.44±0.55mGy, 2.14±0.88mGy, 11.95±1.90mGy, 2.12±0.90mGy and 1.50±0.92mGy respectively. The mean and standard deviation for dose area product in mGy.cm^2 for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 9.25±1.31, 2.97±0.55, 7.33±1.85, 16.2±3.23, 7.62±2.01 and 5.91±1.24 mGy respectively. The main factors affecting patient's dose in contrast radiographic examination are exposure factors, filtration, and source to skin distance, collimation pathology and patient size. Minor variations were observed among patient's populations in terms of age weight height, BMI and Thickness.

The established diagnostic reference levels for intravenous urography, hysterosalpingography, barium meal, barium enema, barium swallow and retrograde urethrography are 6.68mGy and 10.66mGy.cm^2, 2.31mGy and 3.67 Gy.cm^{2,} 2.66mGy and 8.98 Gy.cm^2, 12.78mGy and20.64 Gy.cm^2, 2.73mGy and 6.56 Gy.cm^2, 2.05mGy and 7.55 Gy.cm^2 respectively. There were variations in the mean doses as noted in Table 4.2b the variations in the data recorded demonstrate the importance of creating awareness by the radiographic staff on quality assurance and standardization of protocols to ensure satisfactory y standards and optimized radiation dose to patients and staff, this concurs with another study(Eric *et al.,* 2013). The variations encountered might have arisen from the differences in sample sizes as well as the inherent variations in patient radiation dose values for different types of examination. The variations in patient dose are relevant in the process of dose optimization (Charnock *et al.,* 2013). The inherent variations in doses among the investigated population are expected to be taken into consideration while setting up the tolerance and limiting values to act as trigger levels. According to the guidance mechanism for establishing DRL published by Institute of Physics and Engineering in Medicine (IPEM,

2004). The mean entrance skin dose for cranio-caudal and medio lateral oblique are 0.50±9.48mGy and 0.70 ±0.74mGy for Hospital A, 0.31±0.05mGy and 0.69±0.11mGy for hospital B. The total mean and standard deviation for both hospitals were 0.48±0.69mGy and 0.68±0.40mGy for cranio-caudal and Medio lateral oblique respectively. The mean glandular dose for cranio-caudal and Medio lateral oblique are 0.31±0.05 and 0.69±0.11 mGy. The diagnostic reference level for cranio-caudal and Medio lateral oblique are 0.63mGy and 1.04mGy. The use of fluoroscopy in patient's dose management is increasing due to technology advancement, availability of radiological equipment and health care cost cutting measures. The mean dose in general fluoroscopy examination was found to be larger than the values reported in the studies done in India and Sudan. In the study, the mean number of runs and images per examination category were comparable (Suleiman et al., 2011 and Livingstone, 2009). The uniformity trend in radiographic imaging technique for most examination in this study is also supportive for the potential for standardization of anatomical related imaging techniques and protocols.

The results of the MGD from this study shows that doses from mammography is lower compared to the result got an from a work done by Ogundare *et al.*, (2009) on mean glandular doses for woman undergoing mammography breast screening in Oyo State, Nigeria. The values gotten from his work were 0.26-2.26 mGy for the MLO views and 0.08 to 5.30 mGy for CC views. The difference can be due to difference in tube output and the use of film screen combination of which some Centre were using digital mammography. However this study agrees with another study which discovered that over 90 of patients had MGD values less than 2.5 mGy which is below the guidance level of 3 mGy. The value of MGD gotten from the work is also significantly lower than the one gotten from a study that calculates the MGD assessment for phantoms' and patients in which the phantom gave the MGD of 1.9 mGy. When MGD is supplemented by a patient dose survey, the average MGD

per image was 2.8 mGy for CC and 4.3 mGy for the MLO (Olivera *et al.*, 2010). The differences may be due to differences in tube output and breast granularity

Table 4.2d shows mean and standard deviation of computed tomography dose index (CTDI) and diagnostic reference level for computed tomography for head, chest and abdomen.

The mean CTDI for head CT, chest CT and CT Abdomen in hospital A are 57.26±12.50mGy, 13.94±4.48mGy and 13.92±5.57mGy. Those of hospital B includes 44.08±9.95 mGy, 10.64±4.78mGy and 10.92±5.57mGy for head CT, chest CT and CT Abdomen respectively. The total mean CTDI for the hospitals are 57.25±2.50 mGy, 12.58±4.20mGy and 12.24±4.28mGy for head, chest and Abdomen. The mean and standard deviation of dose length product are 958.52±6.3, 659.10±1.30 and 1290.07±1.71 for CT head, CT chest and CT abdomen respectively. This investigation revealed an observable change in CT practices, with a much wider range of studies being performed regularly. This reflects the improved capacity of CT scanners to scan longer distances and at finer resolutions as permitted by helical and multislice technology (Saravanakumar *et al.,* 2016). The mean computed tomography dose index for head in this study is higher (38.08 mGy) than the study done in Abuja North Central Nigeria by Abdullahi *et al.*,(2015) , Muhammad *et al.,* 2016 with findings of 52.2mGy CTDI for head in North cental Nigeria. Another study by Saravanakumar *et al.,* 2014 reported head CTDI of the 32mGy respectively. However, the values were lesser than the study by Santos *et al*., 2013 in Portugal which presented a value of 75mGy for head CT and a value of 65mGy for a study done by Treier *et al*.,2010.

Table 4.3a, showed the relationship between doses received by patients during radiographic examination and their anthropometric variables. Detail result from the table shows that, during chest PA x-ray radiological examination, the result indicated that there was a positive no significant relationship ($p>0.05$) between the height and weight of the patients with

Entrance skin dose (ESD) received, however, AP thickness showed a negative no significant relationship ($p>0.05$) with Entrance skin dose (ESD) received, while BMI showed a negative significant relationship ($p<0.05$) of the doses received by the patients during radiological examination. The entrance skin dose for lateral chest x-ray showed a positive no significant correlation between AP Thickness, height and BMI and showed a negative no significant correlation.

Similarly, the result showed that there was no significant relationship ($p>0.05$) between the height, weight and focus skin distances (FSD) of the patients, with entrance skin dose (ESD) received, while AP thickness and BMI showed a negative no significant relationship ($p>0.05$). Also, the table result shows that, during Lateral Skull radiological examination, the result indicated that there was a negative no significant relationship ($p>0.05$) between the weight and BMI of the patients with entrance skin dose (ESD) received by the patients, nevertheless, AP thickness and height of the patients showed a positive no significant relationship ($p>0.05$) with the entrance skin dose (ESD) dose received by the patients during radiological examination. There was no significant relationship ($p>0.05$) between ESD and AP thickness, weight, height and BMI for hand dosi-palmar, dosi-palmar oblique, abdominal x-ray, skull x-ray PA, skull lateral, knee AP, AP elbow, shoulder AP, shoulder lateral, AP dorsal spine, lateral dorsal spine, AP cervical spine, lateral cervical spine, AP lumbosacral, lateral lumbosacral, AP wrist lateral wrist and dental x-rays. However, significant relationship exists between ESD and AP thickness for lateral knee x-ray. There was significant relationship($p<0.05$) between ESD with height and BMI for lateral elbow and dorsi- plantar oblique foot while ESD showed positive significant relationship for AP pelvic x-ray and dorsi-plantar foot.

Table 4.3b shows the relationship between doses received by patients and anthropometric parameters for mammography examination. There was no statistical significant relationship ($p>0.05$) between the dose and compressed breast thickness, weight, height and BMI.

Table 4.3c shows the relationship between doses received by patients and anthropometric parameters for computed tomography examination. There was no statistical significant ($p>0.05$) relationship between computed tomography dose index with thickness, weight, and height BMI head CT and abdominal CT. However, Chest CT show statistical significant relationship ($p<0.05$) with weight and height.

Table 4.3d shows the relationship between doses received by patients and anthropometric parameters for contrast radiographic examination. There was statistical significant relationship between dose area product (DAP) and weight in intravenous urography (IVU). During hysterosalpingography procedure there was statistical significant relationship ($p<0.05$) between weight, height and DAP. There was no statistical significant relationship ($p>0.05$) between entrance skin dose and AP thickness, weight, height and BMI in intravenous urography, hysterosalpingography, retrograde urethrography, Barium meal, barium enema and barium swallow respectively. This agrees with the study reported by Caroline *et al.,* (2012), which showed no statistical significant relationship between weight and dose during barium studies in Western cape, South Africa. The absence of direct correlation in this study between the dose and weight of the patients is probably associated with complexdiagnosis of most patients who were emaciated with provisional diagnosis of upper gastrointestinal cancers associated with severe weight loss (Ayantunde *et al.,* 2007).

Table 4.4a, shows the relationship between doses received by patients during radiological examination and technical parameters. The result showed that when the mean dose of entrance skin dose (ESD) and technical variables (FSD, KVp and mAs) of various radiological examinations for chest x-ray PA/AP, chest x-ray lateral, hand dorsi palmar,

abdominal x-ray, pelvic x-ray, hand PA, hand dorsi palmar oblique, cranio caudal view, medio lateral oblique (MLO), dental x-ray, when correlated they all showed no statistical significant differences (P>0.05), but in PA chest x-ray there was a positive significant correlation (P<0.05) between focus to skin distance (FSD) and entrance skin dose (ESD), while kVp relationship with Entrance skin dose (ESD), showed a negative significant correlation (P<0.05). Although, breast thickness is not the only factor to have an effect on mean glandular dose, it is the most consistently reported. Other factors that affect MGD are not consistently reported (Suleiman *et al.,* 2014). However, other factors reported include kVp, target filter combination, HVL and mAs (Suleiman *et al.,* 2014). The lack of documented protocol and etiquette in establishing DRLs in Nigeria and other countries makes it difficult to come up with a guideline and recommendations on DRL for mammography (Dance , 1990).

Table 4.4b shows the relationship between doses received by patients during radiographic examination and technical parameters. Result showed statistical significant relationship (p<0.05) between ESD and tube current (mAs) for AP knee with ESD and tube potential (kVp) for AP shoulder. There was no statistical significant relationship (p>0.05) between technical parameters and ESD for PA skull x-ray and lateral, knee AP and lateral, elbow AP and lateral, Shoulder AP and lateral and dorsi- plantar foot.

Table 4.4c shows the relationship between doses received by patients during radiographic examination and technical parameters. Result showed no statistical significant relationship (p>0.05) between ESD and technical parameters (FSD, kVp and mAs) for AP dorsal spine, lateral dorsal spine, AP cervical spine, lateral cervical spine dorsi-plantar oblique foot AP wrist and lateral wrist respectively.

From table 4.4d, the relationship between doses received by patients during contrast radiographic examination and technical parameters. Result from IVU examination show that

there was statistical significant relationship ($p<0.05$) between FSD and ESD, mAs and DAP while kVp and mAs show no statistical significant relationship ($p>0.05$) with ESD. During HSG examination there was statistical significant relationship ($p<0.05$) between tube current (mAs) and DAP. For RUG examination, ESD and technical parameters (kVp, mAs and FSD) show no statistical significant relationship ($p>0.05$). There was statistical significant relationship ($p<0.05$) between FSD, tube potential (kVp) and DAP. kVp, mAs and FSD while DAP showed that there is no significant relationship ($p>0.05$). Similarly, for barium swallow and enema examination, kVp and mAs show statistical significant relationship ($P<0.05$) with ESD while DAP show no statistical significance ($p>0.05$) with kVp, mAs and FSD.

Table 4.5a, shows the T-test comparison of radiation dose and some technical parameters of patients received in the hospitals studied during radiological examination. Detail result from the table shows that when the mean doses (entrance skin dose) and technical variables (kVp and mAs) of AP elbow, lateral shoulder, dorsi plantar foot, AP dorsal spine,lateral dorsal Spine, AP cervical spine, lateral cervical spine, and lateral elbow of patients at hospitals were compared, they show no statistical significant differences ($P>0.05$) in the radiological dose and technical variables patients received in the both hospitals.

Table 4.5b shows the T-test comparison of radiation dose and some technical parameters of patients received in the hospitals studied during contrast radiographic examination. Detail result from the table shows that when the mean doses (Entrance skin dose) and technical variables (KVp and mAs) of IVU, HSG, RUG, barium enema, barium swallow and barium meal were compared, they show no statistical significant relationship ($p>0.05$). However, ESD and DAP show statistical significant relationship for barium enema while mAs and kVp showed statistical significant relationship for barium swallow and barium meal respectively.

Table 4.5c shows the T-test comparism of radiation dose and some technical parameters for computed tomography examination between hospital A and B. Detail result from the table shows that when the mean doses (CTDIvol) and DLP of the hospitals were compared there is statistical significant relationship ($p<0.05$) for DLP for CT head and CT abdomen while CTDIvol showed no statistical significant relationship ($p>0.05$) for CT head, chest and abdomen. DLP for chest CT showed no significant relationship ($p>0.05$).

Table 4.5d shows the T-test comparison of radiation dose and some technical parameters for mammography examination between hospital A and B. Detail result from the table shows that when the mean doses for the hospitals were compared there was no statistical significant relationship ($p>0.05$) between mAs, kVp and mean glandular dose for the hospitals. This corroborates with another study done by Lourenco et al., 2013, sponsored by European society of Radiologist which indicated that there is no statistical significant relationship between two hospitals ($p=0.090$).

Table 4.6a shows comparison of established diagnostic reference levels for radiographic examination with European commission, United Kingdom and Australia. The DRL for PA chest x-ray and lateral in this work were 0.59mGy and 1.02mGy while that of ARPANSA, EC and UK are 0.15mGy and 0.5mGy, 0.3mGy and 0.4mGy, 0.2mGy and 0.5mGy. PA skull x-ray and lateral skull x-ray shows 1.02mGy and 1.01mGy for this work while 1.85mGy and 1.5mGy, 0.7mGy and 1.0 mGy, 1.8mGy and 1.1mGy for ARPANSA, EC and UK respectively. The DRL for PA elbow and lateral elbow in this work were 0.57mGy and 1.77mGy while that of ARPANSA, EU and UK are 0.4mGy and 0.5mGy, 0.3mGy and 0.3mGy,0.4mGy and 0.4mGy respectively. AP shoulder x-ray and lateral shows 0.71mGy and 0.83mGy for this work while 0.2mGy and 0.5mGy, 0.7mGy and 0.6 mGy, 0.5mGy and 0.5mGy for ARPANSA, EC AND UK respectively. The DRL for dorsi-plantar foot and dorsi-plantar oblique foot in this work were 0.58mGy and 0.61mGy while that of

ARPANSA, EC and UK are 0.3mGy and 0.3mGy, 0.5mGy and 0.4mGy, 0.5mGy and 0.4mGy respectively. AP dorsal spine x-ray and lateral dorsal spine shows 1.03mGy and 1.09mGy for this work while 3.7mGy and 5.0mGy, 2.0mGy and 3.0 mGy, 3.5mGy and 4.0mGy were for ARPANSA, EC AND UK respectively. The DRLs values for PA chest, lateral chest, AP elbow, lateral elbow, AP shoulder, lateral shoulder, dorsi-plantar foot, dorsi-plantar oblique foot, AP wrist, lateral wrist, AP knee, lateral knee and hand dorsi-palmar were higher when compared with that of ARPANSA, UK and European commission DRL while that of AP dorsal spine, AP cervical spine, lateral cervical, AP lumbosacral spine and abdominal and pelvic x-ray were below the DRLs of ARPANSA , UK and European commission. The higher DRL in our study may be attributed to the variation in technical parameters, clinical complexity of patients and untimely quality control program in most of the hospitals. This concurs with another study in North central Nigeria by Abdullahi *et al*., (2015). The established DRL for PA skull x-ray (1.02mGy) is higher than that of European commission (0.7mGy) and lower than that of ARPANSA (1.8mGy), and United Kingdom (1.8mGy). Similarly, the DRL for hand dorsi-palmar oblique in this work (0.28mGy) is higher than that of ARPANSA and UK with DRL values of 0.2mGy each but lower than that of European commission with DRL of 0.5mGy. The DRL for dental (peri-apical) x-ray is in this study is 0.46 mGy, this value is higher when compared with the values of ARPANSA (0.4mGy) and EC (0.2mGy) but lower than that of UK (0.6mGy).

Table 4.6b shows comparison of established diagnostic reference levels for contrast radiographic examination with that of European commission, United Kingdom and Australia. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA) were 16mGy.cm^2, 4 mGy.cm^2, 13 mGy.cm^2,31 mGy.cm^2,11mGy.cm^2 and 13 mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG respectively. From the table, European commission (EC) DRL are 14 mGy.cm^2,2

mGy.cm^2,12 mGy.cm^2,23 mGy.cm^2,3.4 mGy.cm^2 and 7 mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG respectively. United kingdom DRL are presented as follows 10,2,5,15,4 and 15mGy and 14,4,12,21,7.5 and 7 in mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG . DRL for this study are 6.68 mGy ,10.66 mGy.cm^2 for IVU, 2.31mGy,3.6723 mGy.cm^2 for HSG, 2.66mGy,8.98 mGy.cm^2 for barium meal, 12.78mGy,20.64 mGy.cm^2 for barium enema,2.73 mGy and 6.56 mGy.cm^2 for barium swallow and 2.05mGy, 7.77 mGy.cm^2 for RUG respectively. DRLs for IVU , HSG Barium meal and Barium enema in this work recorded lower values when compared with that of European ,UK and ARPANSA respectively a possible explanation for that may be due to the fact that the patient exposure parameters and techniques used in our study differs this agrees with a study by Mohammed and Abdelhalim, 2010. Implementation of DRLs could achieve an ESD reduction between 30% and 60% below the CEC recommendation (NG *et al.,* 2008; Vano *et al.,*2002). Several studies show it is possible to achieve a dose reduction of 50% without losing image quality when CEC guidelines are well established (Saure *et al.,* 1995).

Table 4.6c shows comparison of established diagnostic reference levels for mammography examination with that of European commission, United Kingdom and Australia. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA), EC, UK and this work were 0.88mGy, 2.0mGy, 2.0mGy and 0.63mGy for cranio-caudal view. DRL for Medio-lateral oblique were 1.30mGy,2.0mGy, 2.1mGy and 1.04mGy for ARPANSA, EC, UK and present work respectively. The DRL values for mammography in this study are higher compared to that of ARPANSA, UK and European Commission respectively. The higher DRL encountered might have arisen from differences in sample sizes as well as the inherent variations in patient radiation dose values for different types of examination. The

higher dose values suggest the need for patient dose optimization this agrees with the study conducted by Charnock *et al.*,(2013).

Table 4.6d shows comparison of established diagnostic reference levels for computed tomography examination with that of European commission, United Kingdom and Australia. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA) for CT were 47mGy, 9.5mGy and 10.9mGy for CT head, chest and abdomen respectively. That of European commission was 60mGy, 30mGy, and 35mGy for head CT, chest CT and CT abdomen respectively. Similarly, UK values were 66mGy, 17mGy and 19mGy for CT head, chest and abdomen respectively. The DRL values obtained in this work were 67.90mGy, 18.83mGy and 19.20mGy for head CT, Chest CT and CT abdomen respectively. The DRL obtained in this study is higher when compared with the reported values for ARPANSA, European commission and United Kingdom (Joseph and Nzotta, 2016) and disagrees with the study of Abdullahi *et al.*, 2016 in North central Nigeria with a value of 38.0mGy lower than European commission. The DRL for head CT obtained in this work is lower than the value obtained in another study in Nigeria by Garba *et al.*, 2014 and Ogbole and Obed, 2014 with DRL values of 79mGy and 73.5 mGy respectively. Although this study may not be a representation of what happens in every hospital but it is an indication that a considerable optimization potential of CT practice through standardization of medical imaging protocols and etiquette. The higher dose received in this study is attributed to variation in technical parameters, clinical procedures, radiographic technique, untimely quality control program and perhaps the condition of the CT machine. The UK study, ARPANSA study and EC study are better means of comparing with this study because their values were obtained from a survey of multi- slice CT scanners. However, result of comparison suggests the need for optimization of doses for more hospitals in Nigeria. The resultant DRL value is based on exposure parameters were found to be lower than the ARPANSA and UK but lesser when

compared with EU values for CT chest and Abdomen respectively. Lower DRLs could be due to the fact that hospital and technique vary in their operation and specifications. In some cases authors setting up DRLs do not report on the patient dose influencing factors like added filtration, screen film speed, generator type, use of automatic exposure controls manual method and image receptor technology. Diagnostic Reference Levels is a measure of patient dose and serves as a quantitative guide to optimization of radiological protection. The Ionizing Radiation Medical Exposure Regulations IR(ME)R states that if the DRL for an examination is exceeded by a particular piece of equipment or operator, legislation requires that reasons be investigated and remedial action be taken. It is hoped the study will contribute to the establishment of a national DRL for Radiologic procedure in Nigeria (Pillai and Jain 2014).

5.2 Summary of findings

1. The DRL for PA chest x-ray and lateral in this work were 0.59mGy and 1.02 mGy, PA skull x-ray and lateral skull x-ray were 1.02mGy and 1.01mGy. The DRL for PA elbow and lateral elbow in are 0.57mGy and 1.77mGy. AP shoulder x-ray and lateral were 0.71mGy and 0.83mGy The DRL for dorsi-plantar foot and dorsi-plantar oblique foot in this work were 0.58mGy and 0.61mGy .AP dorsal spine x-ray and lateral dorsal spine are 1.03mGy and 1.09mGy. AP cervical spine and lateral shows 0.62mGy and0.79 mGy. DRL contrast radiographic examination for this study are 6.68 mGy ,10.66 $mGy.cm^2$ for IVU, 2.31mGy,3.6723 $mGy.cm^2$ for HSG, 2.66mGy,8.98 $mGy.cm^2$ for barium meal, 12.78mGy,20.64 $mGy.cm^2$ for barium enema,2.73 mGy and 6.56 $mGy.cm^2$ for barium swallow and 2.05mGy, 7.77 $mGy.cm^2$ for RUG respectively.

2. The DRLs for mammography examination in this study are 0.63 mGy and 1.04 mGy for cranio-caudal and medio-lateral view respectively.
3. The DRLs for computed tomography examination are 67.90 mGy, 18.38mGy and 19.20 mGy for CT head, CT chest and CT abdomen respectively.
4. There is statistical significant relationship ($p<0.05$) between ESD and tube current (mAs) for AP knee with ESD and tube potential (kVp) for AP shoulder. The is no statistical significant relationship ($p>0.05$) between technical parameters and ESD for skull x-ray AP and lateral, knee AP and lateral, elbow AP and lateral, Shoulder AP and lateral and dorsi- plantar foot. There was no statistical significant relationship ($p>0.05$) between ESD and technical parameters (FSD, kVp and mAs) for AP dorsal spine, lateral dorsal spine, AP cervical spine, lateral cervical spine dorsi-plantar oblique foot AP wrist and lateral wrist respectively. Table 4.14 shows the relationship between doses received by patients during contrast radiographic examination and technical parameters. Result from IVU examination show that there was statistical significant relationship ($p<0.05$) between FSD and ESD, mAs and DAP while kVp and mAs show no statistical significant relationship ($p>0.05$) with ESD. During HSG examination there was statistical significant relationship ($p<0.05$) between tube current (mAs) and DAP. For RUG examination, ESD and technical parameters (kVp, mAs and FSD) show no statistical significant relationship ($p>0.05$). There was statistical significant relationship ($p<0.05$) between FSD, tube potential (kVp) and DAP. Barium enema show statistical significant relationship ($p<0.05$). Between DAP, ESD and FSD while kVp and mAs show no significant relationship with ESD and DAP. There is statistical significant relationship ($p<0.05$) between kVp, mAs

and FSD while DAP showed that there is no significant relationship ($p>0.05$). Similarly, for barium swallow and enema examination, kVp and mAs show statistical significant relationship ($P<0.05$) with ESD while DAP show no statistical significance ($p>0.05$) with kVp, mAs and FSD.

5. T-test comparison of radiation dose and some technical parameters of patients received in the hospitals studied during radiological examination. Detail result from the table shows that when the mean doses (Entrance skin dose) and technical variables (KVp and mAs) of AP elbow, Lateral Shoulder, Dorsi Plantar Foot, AP Dorsal Spine,Lateral Dorsal Spine, AP Cervical Spine, Lateral Cervical Spine, and Lateral Elbow of patients at Hospitals were compared, the show no statistical significant differences ($P>0.05$) in the radiological dose and technical variables patients received in the both hospitals. The T-test comparison of radiation dose and some technical parameters of patients received in the hospitals studied during contrast radiographic examination. Detail result from the table shows that when the mean doses (Entrance skin dose) and technical variables (KVp and mAs) of IVU, HSG, RUG, barium enema, barium swallow and barium meal were compared, they show no statistical significant relationship ($p>0.05$). However, ESD and DAP show statistical significant relationship for barium enema while mAs and kVp showed statistical significant relationship for barium swallow and barium meal respectively. T-test comparison of radiation dose and some technical parameters for computed tomography examination between hospital A and B. Detail result from the table shows that when the mean doses (CTDIvol) and DLP of the hospitals were compared there is statistical significant relationship ($p<0.05$) for DLP for CT head and CT abdomen while

CTDIvol showed no statistical significant relationship ($p>0.05$) for CT head, chest and abdomen. DLP for chest CT showed no significant relationship ($p>0.05$). T-test comparison of radiation dose and some technical parameters for mammography examination between hospital A and B. Detail result from the table shows that when the mean doses for the hospitals were compared there was no statistical significant relationship ($p>0.05$) between mAs, kVp and mean glandular dose for the hospitals

6. The DRL for PA chest x-ray and lateral in this work were 0.59mGy and 1.02mGy while that of ARPANSA, EC and UK are 0.15mGy and 0.5mGy, 0.3mGy and 0.4mGy, 0.2mGy and 0.5mGy respectively. PA skull x-ray and lateral skull x-ray shows 1.02mGy and 1.01mGy for this work while 1.85mGy and 1.5mGy, 0.7mGy and 1.0 mGy, 1.8mGy and 1.1mGy for ARPANSA, EC and UK respectively. The DRL for PA elbow and lateral elbow in this work were 0.57mGy and 1.77mGy while that of ARPANSA, EU and UK are 0.4mGy and 0.5mGy, 0.3mGy and 0.3mGy,0.4mGy and 0.4mGy respectively. AP shoulder x-ray and lateral shows 0.71mGy and 0.83mGy for this work while 0.2mGy and 0.5mGy, 0.7mGy and 0.6 mGy, 0.5mGy and 0.5mGy for ARPANSA, EC AND UK respectively. The DRL for dorsi-plantar foot and dorsi-plantar oblique foot in this work were 0.58mGy and 0.61mGy while that of ARPANSA, EC and UK are 0.3mGy and 0.3mGy, 0.5mGy and 0.4mGy, 0.5mGy and 0.4mGy respectively. AP dorsal spine x-ray and lateral dorsal spine shows 1.03mGy and 1.09mGy for this work while 3.7mGy and 5.0mGy, 2.0mGy and 3.0 mGy, 3.5mGy and 4.0mGy were for ARPANSA, EC AND UK respectively. The DRLs values for PA chest, lateral chest, AP elbow, lateral elbow, AP shoulder, lateral shoulder, dorsi-plantar foot, dorsi-plantar

oblique foot, AP wrist, lateral wrist, AP knee, lateral knee and hand dorsi-palmar were higher when compared with that of ARPANSA, UK and European commission DRL while that of AP dorsal spine, AP cervical spine, lateral cervical, AP lumbosacral spine and abdominal and pelvic x-ray were below the DRLs of ARPANSA , UK and European commission

7. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA) were 16mGy.cm^2, 4 mGy.cm^2, 13 mGy.cm^2, 31 mGy.cm^2,11mGy.cm^2 and 13 mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG respectively. From the table, European commission (EC) DRL are 14 mGy.cm^2,2 mGy.cm^2,12 mGy.cm^2,23 mGy.cm^2,3.4 mGy.cm^2 and 7 mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG respectively. United kingdom DRL are presented as follows 10,2,5,15,4 and 15mGy and 14,4,12,21,7.5 and 7 in mGy.cm^2 for IVU, HSG, barium meal, barium enema and barium swallow and RUG . DRL for this study are 6.68 mGy ,10.66 mGy.cm^2 for IVU, 2.31mGy,3.6723 mGy.cm^2 for HSG, 2.66mGy,8.98 mGy.cm^2 for barium meal, 12.78mGy,20.64 mGy.cm^2 for barium enema,2.73 mGy and 6.56 mGy.cm^2 for barium swallow and 2.05mGy, 7.77 mGy.cm^2 for RUG respectively. DRLs for IVU , HSG Barium meal and Barium enema in this work recorded lower values when compared with that of European ,UK and ARPANSA respectively.

8. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA), EC, UK and this work were 0.88mGy, 2.0mGy, 2.0mGy and 0.63mGy for cranio-caudal view. DRL for Medio-lateral oblique were 1.30mGy, 2.0mGy, 2.1mGy and 1.04mGy for ARPANSA, EC, UK and

present work respectively. The DRL values for mammography in this study are higher compared to that of ARPANSA, UK and European Commission respectively.

9. The DRL for Australian radiation protection and nuclear safety agency (ARPANSA) for CT were 47mGy, 9.5mGy and 10.9mGy for CT head, chest and abdomen respectively. That of European commission was 60mGy, 30mGy, and 35mGy for head CT, chest CT and CT abdomen respectively. Similarly, UK values were 66mGy, 17mGy and 19mGy for CT head, chest and abdomen respectively. The DRL values obtained in this work were 67.90mGy, 18.83mGy and 19.20mGy for head CT, Chest CT and CT abdomen respectively. The DRL obtained in this study is higher when compared with the reported values for ARPANSA, European commission and United Kingdom.

5.3 Conclusion

This study established DRLs for radiological procedures in two university teaching hospitals in North Eastern Nigeria. The DRLs values were high when compared with that of ARPANSA, UK and European commission DRL while that of AP dorsal spine, AP cervical spine, lateral cervical, AP lumbosacral spine and abdominal and pelvic x-ray were below the DRLs of ARPANSA, UK and European commission. DRLs for IVU , HSG Barium meal and Barium enema in this work recorded lower values when compared with that of European ,UK and ARPANSA respectively. The DRL values for mammography in this study are higher compared to that of ARPANSA, UK and European Commission and that of computed tomography is higher when compared with the reported values for ARPANSA, European commission and United Kingdom. The present work has demonstrated that an efficient and fully integrated radiological dose information system can play an important

role, providing data to support radiologist, radiographers, medical physicist, academicians, professional bodies and regulatory bodies in adopting the best strategy in ensuring that radiation doses to patients are adequately optimized. This study has an educational and regulatory function to the radiology community and furthermore provides a benchmark to assist any statutory organization to establish DRLs for diagnostic radiology practices in Nigeria, Africa and the world entirely.

5.4 Contribution to knowledge

This study have successfully established the first DRLs for radiographic examination, contrast radiographic examination, dental examination, mammography examination and computed tomography examination for adult patients in North eastern Nigeria. The result in this study would be submitted to Nigerian Nuclear Regulatory Authority, the department of radiology in the respective hospitals studied so that they would have reference guidance for their examination in the clinical setting. This will help to suppress unwarranted dose, and compare with studies that will be carried out in different regions of the country. It has also bridge the gap between theory and practice in the hospitals studied.

This study has successfully compared the radiation doses in different teaching hospitals and with internationally established dose values. This is imperative because it gives us an idea of good practice in our low resource setting.

This study has successfully provided empirical evidence of the comprehensive dose received by patients and has established DRLs which will be useful to concerned bodies and associations like Nigerian nuclear regulatory Authority, Radiographers registration board of Nigeria, Association of radiographers of Nigeria, Nigerian society of Radiation protection and Nigerian association of medical physicist for consideration and implementation as a

reference document for monitoring on a large scale the dose received by patients in various hospitals.

This study has come up with comprehensive framework and protocols for setting DRLs in our setting in Nigeria.

5.5 Recommendations

1. The research work shows that there is need to optimize operations in hospitals in North eastern Nigeria and probably in most hospitals in Nigeria. The optimization step may start with the regulatory body mandating radiographers to take part in various refreshers and update course for them to be aware of the current trends and recent developments on how to properly and effectively dispense radiation in diagnosis.
2. The hospital should implement a functional and standing radiation safety committee appoint a radiation safety adviser and radiation safety officer that will be trained by the regulatory body on radiation safety. The essence of enacting this committee is to saddle them with the responsibility of monitoring the staff, developing a facility patient dose database that will be used to evaluate radiation dose whenever the need arises and ensuring radiation safety culture in radiation practices.
3. This kind of study should be conducted in all the regions of Nigeria so that Nigeria can successfully have a National DRLs for radiological examination. It is therefore suggested that the Nigerian Nuclear Regulatory Authority should collaborate with academicians and clinical researchers to come up with regional and national DRLs and should also come up with a policy for periodic review after every five years as a DRLs guidelines and publish it as a regulatory guideline in ionizing radiation regulations.

4. A culture of regular dose measurement, quarterly quality control, film reject analysis, image quality assessment should be inculcated in each facility as recommended by IAEA as a main part of diagnostic radiology procedures and installations.
5. Nigerian Nuclear regulatory Authority should come up with DRLs document and guidelines for Nigeria by having a sample from representative Geo-political zones in Nigeria. This study suggests that a committee should be constituted and mandated to Set DRLs for Nigeria and it should be revisited after every five years. This committee should comprise of academic researchers, clinical researchers, radiographers, radiologist, medical physicist and engineers.

5.6 Limitations of the study

1. This study did not consider different patient's body built according to BMI classification to determine DRLs according to the classification.
2. The study did not cover all the teaching hospitals in the North Eastern part of Nigeria as such it limited our study to only two teaching hospitals.
3. Frequent equipment breakdown and repair in some centers occurred during the study period and these might have affected the machine output and /or dose though it was not possible to investigate such.
4. So many of the patients rotated their body and moved from one position to the other resulting to poor quality which leads to cancellation of procedure and/or repetition which affects the dose.
5. The researcher was unable to evaluate individual radiographers and/or imaging scientist at the various study centers to ascertain the effects of

technique on radiation dose so as to account for the observed variation of the radiation dose to patients at the study centers.

6. Some patients in the study centers did not agree to participate therefore most of the images and examination set up were not available.
7. We were not able to cover one of the teaching hospital in North eastern Nigeria due to equipment breakdown
8. There were financial challenges because the TLD annealing process was expensive and there was no funding for the research work

5.7 Areas of further study

1. The study can be extended to other regions in Nigeria as a major step to establish national DRLs.
2. Regional DRLs for pediatric radiography is imperative as a major step to establishing national DRLs.
3. Radiation dose and image quality assessment for radiological examination for different body built is necessary as a major optimization step in establishing DRLs
4. DRLs for Nuclear medicine procedures and interventional radiology procedure should be considered.

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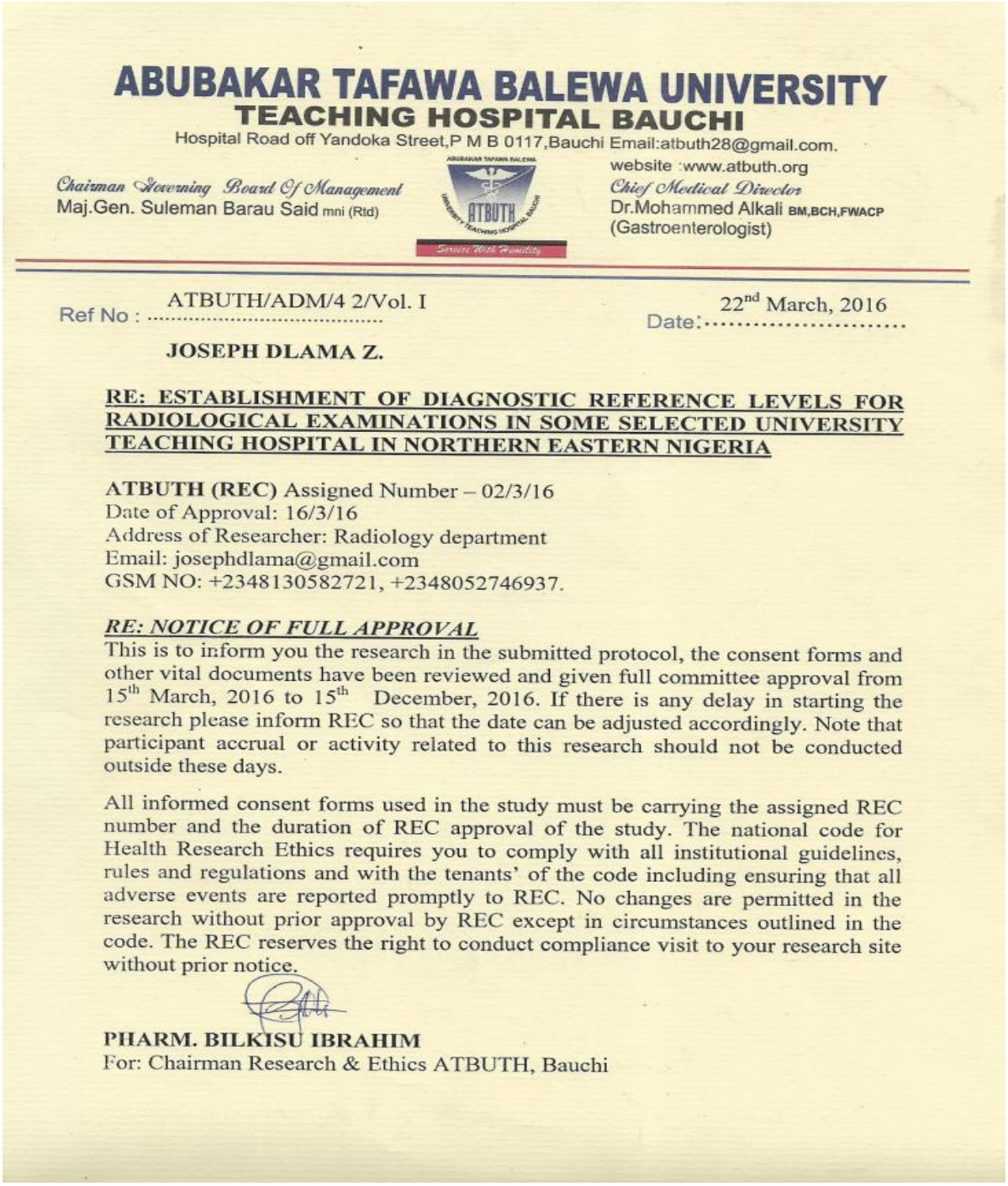
LIST OF APPENDICES

Appendix A: Ethical Clearance from Hospital A



ABUBAKAR TAFAWA BALEWA UNIVERSITY
TEACHING HOSPITAL BAUCHI
Hospital Road off Yandoka Street,P M B 0117,Bauchi Email:atbuth28@gmail.com.
website :www.atbuth.org

Chairman Governing Board Of Management
Maj.Gen. Suleman Barau Said mni (Rtd)

Chief Medical Director
Dr.Mohammed Alkali BM,BCH,FWACP
(Gastroenterologist)

Ref No : ATBUTH/ADM/4 2/Vol. I

Date: 22nd March, 2016

JOSEPH DLAMA Z.

RE: ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS FOR RADIOLOGICAL EXAMINATIONS IN SOME SELECTED UNIVERSITY TEACHING HOSPITAL IN NORTHERN EASTERN NIGERIA

ATBUTH (REC) Assigned Number – 02/3/16
Date of Approval: 16/3/16
Address of Researcher: Radiology department
Email: josephdlama@gmail.com
GSM NO: +2348130582721, +2348052746937.

RE: NOTICE OF FULL APPROVAL

This is to inform you the research in the submitted protocol, the consent forms and other vital documents have been reviewed and given full committee approval from 15th March, 2016 to 15th December, 2016. If there is any delay in starting the research please inform REC so that the date can be adjusted accordingly. Note that participant accrual or activity related to this research should not be conducted outside these days.

All informed consent forms used in the study must be carrying the assigned REC number and the duration of REC approval of the study. The national code for Health Research Ethics requires you to comply with all institutional guidelines, rules and regulations and with the tenants' of the code including ensuring that all adverse events are reported promptly to REC. No changes are permitted in the research without prior approval by REC except in circumstances outlined in the code. The REC reserves the right to conduct compliance visit to your research site without prior notice.

PHARM. BILKISU IBRAHIM
For: Chairman Research & Ethics ATBUTH, Bauchi

Appendix B: Ethical Clearance from Hospital B

FEDERAL TEACHING HOSPITAL, GOMBE

Ashaka Road, Gombe
P.M.B. 0037

Tel: 072-223410,
223064
Fax:072-223909

Our Ref: NHREC/25/10/2013

Date: 15 February, 2016

Dlama Zira Joseph
Department of Radiology
University Teaching Hospital,
Bauchi, Bauchi state.

Sir,

Ethical Clearance

I am directed to inform you that your application and proposal Titled: **'ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS FOR RADIOLOGICAL EXAMINATIONS IN SOME SELECTED UNIVERSITY TEACHING HOSPITALS IN NORTHERN NIGERIA'.** Submitted to the Hospital Research and Ethics Committee, have been duely reviewed and approved. On behalf of the committee, I wish you a successful execution.

Thank you,

B.A. Sambo Mrs. (Jp, CLN, ADL)
Secretary R&EC.

Chief Medical Director: Dr. Abubakar Sa'idu MBBS, FMCP

Appendix C: Ethical Clearance from Bauchi state ministry of Health

SECRET

GOVERNMENT OF BAUCHI STATE

MINISTRY OF HEALTH

Tel: 077-542895

Ref. No. _____
P.M.B. 065
Bauchi.

MOH/GEN/S/1409/I

31st March 2017

PROTOCOL REG. N0: BSMOH/NREC/35/2016
PROTOCOL APPROVAL N0: NREC/12/05/2013/2017/35

Joseph Dlama Zira,
Dept of Radiology,
ATBUTH
Bauchi.

ETHICAL CLEARANCE FOR SUBMITTED PROTOCOL:
"Establishment of Diagnostics Reference Level for Radiology Examination in Specialist Hospital Bauchi- Bauchi State'.

The Bauchi State Health Research Ethics Committee (HREC) under the State Ministry of Health has received the above named protocol for ethical clearance and approval in line with the guidelines set by the Committee. The protocol was reviewed and the committee noted that that the research falls under the low risk Category which does not entails clinical trials or any invasive procedures.

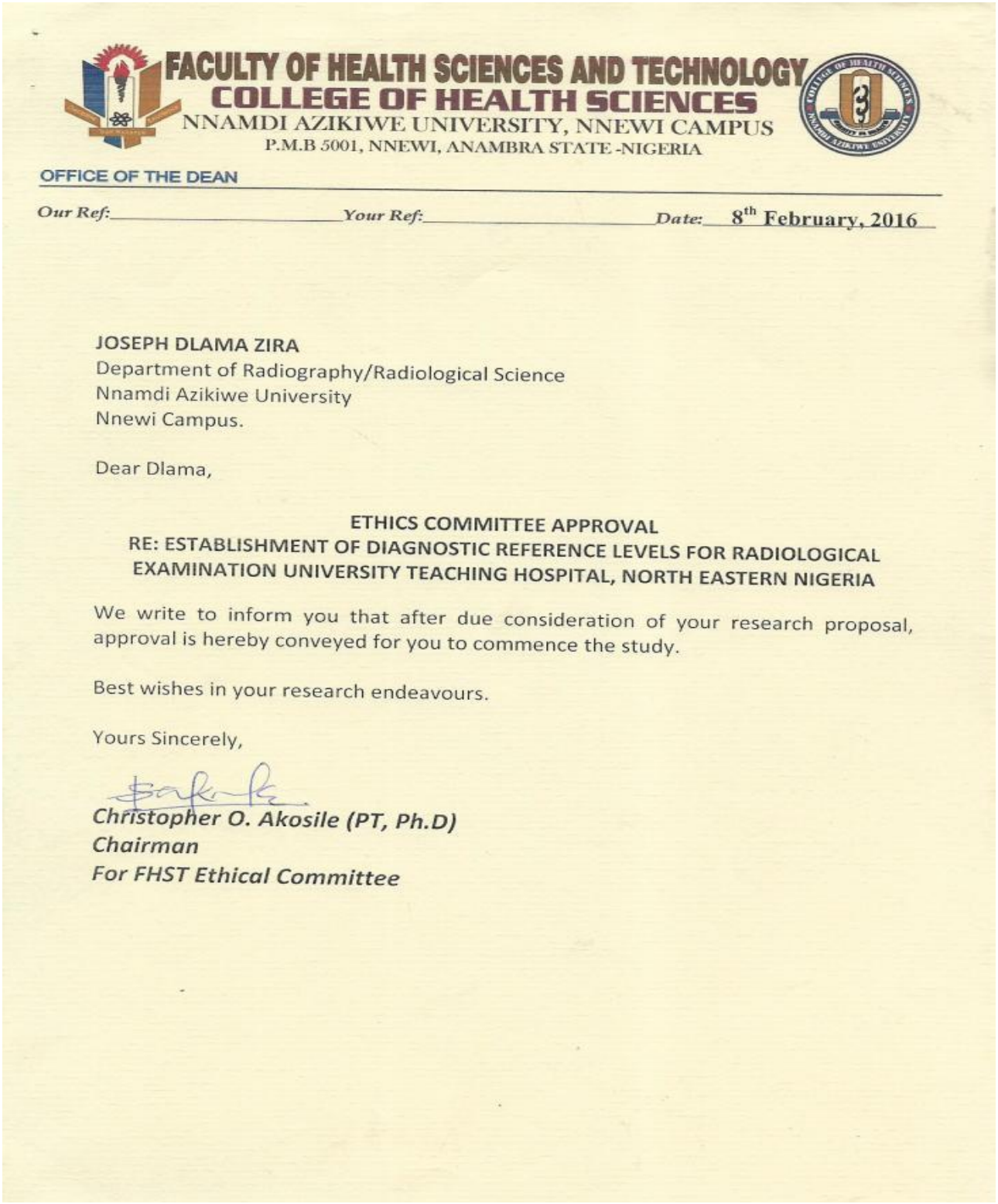
2. Consequently, the Committee hereby granted approval for the research to be conducted. However, you should share with us your workplan clearly indicating the start date, where and when to visit the research site(s) and also **the final results of your findings.**

3. The Committee requires you to comply with all Institutional Guidelines, Rules and Regulations and with the tenets of the National Health Research Ethics Committee Code including that all adverse events are reported promptly to the Committee. **No changes are permitted in the research without prior approval by the Committee** except in circumstances outlined in the Code. The Committee reserves the right to conduct compliance visit to your research site without prior notice.

4. Thank you.

(Usman U. Muhammad)
For: Hon. Commissioner.

Appendix D: Ethical Clearance from Faculty of Health Science and Technology Nnamdi Azikiwe University.



FACULTY OF HEALTH SCIENCES AND TECHNOLOGY
COLLEGE OF HEALTH SCIENCES
NNAMDI AZIKIWE UNIVERSITY, NNEWI CAMPUS
P.M.B 5001, NNEWI, ANAMBRA STATE -NIGERIA

OFFICE OF THE DEAN

*Our Ref:*_____ *Your Ref:*_____ *Date:* 8th February, 2016

JOSEPH DLAMA ZIRA
Department of Radiography/Radiological Science
Nnamdi Azikiwe University
Nnewi Campus.

Dear Dlama,

ETHICS COMMITTEE APPROVAL
RE: ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS FOR RADIOLOGICAL EXAMINATION UNIVERSITY TEACHING HOSPITAL, NORTH EASTERN NIGERIA

We write to inform you that after due consideration of your research proposal, approval is hereby conveyed for you to commence the study.

Best wishes in your research endeavours.

Yours Sincerely,

Christopher O. Akosile (PT, Ph.D)
Chairman
For FHST Ethical Committee

Appendix E: Introduction letter from the faculty sub-dean

FACULTY OF HEALTH SCIENCES AND TECHNOLOGY
COLLEGE OF HEALTH SCIENCES
NNAMDI AZIKIWE UNIVERSITY, NNEWI CAMPUS
P.M.B 5001, NNEWI, ANAMBRA STATE -NIGERIA

OFFICE OF THE DEAN

Our Ref: _____ *Your Ref:* _____ *Date:* _____

4th July, 2016

The Director Radiological Safety,

Nigeria Nuclear Regulatory Authority,

Sir,

INTRODUCTION LETTER

The Bearer of this letter Mr. Joseph Dlama Zira is a PhD student in the Department of Radiography and Radiological Sciences in the above named University.

He is currently working on his Dissertation titled: ***Establishment of diagnostic references levels for radiological examination in North eastern Nigeria***. He will need to make use of dose area product (DAP) meter to enable him collect data for his research work.

You may please wish to give him any assistance needed.

Thank you.

Yours faithfully,

Dr. Christian C. Nzotta

Faculty Sub-Dean (P-G)

Appendix F: Letter of introduction and recommendation to hospitals by Head of Department

DEPARTMENT OF RADIOGRAPHY/RADIOLOGICAL SCIENCES
FACULTY OF HEALTH SCIENCES AND TECHNOLOGY
COLLEGE OF HEALTH SCIENCES
NNAMDI AZIKIWE UNIVERSITY, NNEWI CAMPUS
P.M.B. 5001 NNEWI, ANAMBRA STATE- NIGERIA
E-mails:tonybulling@yahoo.ca, ac.ugwu@unizik.edu.ng
Tel: 08076241297

DR. ANTHONY C. UGWU.Ph.D, KSM, FMISON.

19th November, 2015.

To Whom It May Concern

Sir,

LETTER OF RECOMMENDATION
RE: JOSEPH DLAMA ZIRA REG NO.: PG/2014647004F

The above referred is a Ph.D student in this department. His specialty is radiation and environmental protection. He is interested in carrying out a research entitled: "Establishment of Diagnostic Reference Levels for Radiological Examinations in some selected University Teaching Hospitals in Northern Nigeria".

Please kindly assist him.

Thank you.

Faithfully yours,

Dr. Anthony C. Ugwu
Head of Department (Ag)

Appendix G: Filled consent form used during the data collection

CONSENT FORM

My name is Joseph Dlama Zira a PhD student of Radiography in Nnamdi Azikiwe University Awka, Anambra State. I want to carry out a study on the topic **ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS FOR RADIOLOGICAL EXAMINATIONS IN SOME SELECTED UNIVERSITY TEACHING HOSPITALS IN NORTHERN NIGERIA".**

Diagnostic reference level is defined as an investigation level used to identify unusually high radiation doses for Radiological examinations. They are dose levels in medical radiodiagnostic practices for typical examinations for group of standard sized patients or phantoms for broadly defined types of equipments. This study will find out the doses you receive during radiological procedure and to determine where it is high or within the recommended levels.

This study will involve placing Dosimeters such as Thermoluminiscent Dosimeters (TLD) or Dose Area Product (DAP) Meter on the area or region of the body to be examined to measure dose received including organ doses. The exposure to x-rays will not take more that 15-20mins.Participation is voluntarily and you can decide not to participate at any point.

You will not be denied examination if you refuse to participate. All information from this work will be kept strictly confidential and your identity will not be disclosed. However data obtained from this study that does not identify you individually may be presented or published in conferences or journal articles.

If you accept to participate in the study, Kindly sign the space below.

I (Initials) SALIHU AHMED ..... have asked questions regarding this research and have been satisfactorily answered. I therefore wish to participate in this research. sign.....

Thank you

Signature of Parent/ Guardian..... Date. 15/9/2016

Signature of Witness ..... Date 15/9/2016

Signature of Investigator..... Date 15/09/2016.

Appendix H: Data capture sheet for radiographic, dental and mammography examination

RADIOLOGY DEPARTMENT

ABUBAKAR TAFAWA BALEWA UNIVERSITY TEACHING

HOSPITAL BAUCHI

DATA CAPTURE SHEET

S/N	FSD(CM)	AGE (YRS)	SEX	AP THICKNESS(CM)	WEIGHT (Kg)	HEIGHT (M)	BMI (KG/M^2)	kVp (Tube Potential)	mAs (Tube Current)	ESD (mGy)
22										
23										
24										
25										
26										
27										
28										
29										
30										

Appendix I: Data capture sheet for computed tomography examination

PATIENTS DATA CAPTURE SHEET FOR COMPUTED TOMOGRAPHY EXAMINATION

1. Center code……..
2. Please complete the form for each patient participating in this study.

DEMOGRAPHIC INFORMATIONOF PATIENT:

3. Date:……./……/……Age……..Gender…….CT exam no.....Scanned Area……Weight.....

SCANNING PARAMETERS:

4. KV…… mAs …….Table distance……No. of Slice……Multislice……Slice thickness……..Pitch…….. Scan length ….....Field of view……..
   DOSE PARAMETER:
5. CTDIvol ……..DLP…….
6. CT Radiographer: ……..
7. All forms will be collected by: **JOSEPH DLAMA ZIRA contact no: +2348130582721**

   (Adopted from IAEA Technical report series number 457)

Appendix J : Shows machine specification

Machine Specification	Hospital A	Hospital B
Conventional x-ray		
Model	XR6000	UT84104-4298
Manufacturer	China x	Variant Medical System USA
Year of manufacture/ installation	October 2009/August 2010	November 2009/November 2014
Serial Number	SOSO 1984	H218871
Filters	1.5 mmAl at 100kVp	0.8 mmAl
kVp/mAs range	40-150/0.5-630	40-200/0.5-400
Mammography		
Manufacturer	Planmed OY, Helsinki Finland	Halogic Inc USA
Year of manufacture/ installation	April 2008/2010	July 2012/ July 2014
Serial number	TCHD31260	18008127023
kVp/mAs range	20-35/10-500	20-40/10-400
Filters	30µM Molybdenum, 0.5mmAl, 25 µM Rhodium	30µM Molybdenum, 0.5mmAl, 25 µM Rhodium
Fluoroscopy	Over couch	
Model	98900086111	-
Manufacturer	Philips	-
Year of manufacture/ installation	February 2010, March 2011	-
Serial Number	27657A228154	-
Filters	2.5mmAl	-
kVp/mAs range	40-150/0.5-850	-
Dental		
Model	PC-2500 A	PC-1000
Manufacturer	Philips	Fort Iwayne USA
Year of manufacture/ installation	2000/2002	2002/2004
Serial Number	SA21355	12406
kVp/mAs range	50-90/0-7	70-90/6mAs
Computed Tomography		
Model	453567078851	454110131601
Manufacturer	Philips	Neurosoft Med system Philips
Year of manufacture/ installation	April 2010/ 2011	December 25th 2013/ December 2016
Serial Number	6171	N16E130043
kVp/mAs range	30-120/30-500	40-140
Number of slices	16 Slices	16 slices

Appendix K: Shows a sample result of exposed thermo luminescent dosimeters.

CENTRE FOR ENERGY RESEARCH AND TRAINING

Ahmadu Bello University, Zaria

RADIATION PROTECTION SERVICES RECORDS

Joseph Dlama Zira Date: 12th January 2016

Dept. of Radiography and Radiological Sciences,

Nnamdi Azikiwe University

S/No	Chip ID	Dose (mSv)
1.	2-3 mGy 85Kv 56 mAs	**3.21**
2.		**3.07**
3.		**2.97**
4.		**3.95**
5.		**15.45**
6.		**13.00**
7.		**9.82**
8.		**17.29**
9.		**15.86**
10.		**8.49**
11.		**14.44**
12.		**13.85**
13.		**16.39**
14.		**15.63**
15.		**18.26**
16.		**11.47**
17.		**16.62**
18.		**1.47**
19.	1-2 ESD 10 88Kv 52 mAs	**2.59**
20.		**1.49**
21.		**3.45**
22.		**1.32**
23.		**1.50**
24.		**2.24**
25.		**2.19**
26.		**0.80**
27.		**6.28**
28.		**2.15**
29.		**11.97**
30.		**11.62**
31.		**10.72**
32.		**14.68**

33.		**14.17**
34.		**12.61**
35.		**13.78**
36.		**13.97**
37.	HSG 23 1-3 MGy 83Kv 40 mAs ESD	**11.34**
38.		**12.42**
39.		**11.78**
40.		**13.65**
41.		**13.77**
42.		**14.28**
43.		**11.87**
44.		**10.07**
45.		**15.42**
46.		**12.68**
47.		**14.80**
48.		**6.12**
49.		**12.96**
50.		**14.66**
51.		**12.07**
52.		**11.26**
53.		**12.30**
54.		**14.27**
55.		**22.33**
56.		**19.76**
57.		**18.46**
58.		**17.53**
59.		**20.10**
60.		**21.69**
61.		**15.39**
62.	2-3 MGy MCKG 10 ESD	**18.48**
63.		**17.37**
64.		**16.89**
65.		**20.65**
66.		**18.34**
67.		**19.29**
68.		**19.71**
69.		**19.92**
70.		**0.72**
71.		**3.55**
72.		**6.23**
73.		**2.17**
74.		**0.70**
75.		**3.65**
76.		**1.80**
77.		**2.78**
78.	Ba Swallow 10 ESD	**1.21**
79.		**1.46**

80.		**3.68**
81.		**4.51**
82.		**5.16**
83.		**2.59**
84.		**3.47**
85.		**2.64**
86.		**8.17**
87.	Ba Enema 10 ESD 3-4 MGy ESD10	**2.83**
88.		**2.09**
89.		**3.66**
90.		**2.95**
91.		**3.79**
92.		**1.58**
93.		**1.60**
94.		**1.76**
95.		**3.74**
96.	Ba Meal10 2-3 MGy 64KV 24mAs	**2.00**
97.		**4.64**
98.		**1.63**
99.		**3.59**
100.		**5.54**
101.		**3.61**
102.		**1.72**
103.		**3.28**
104.		**6.48**
105.		**1.98**

Compiled by: S. Abdullahi

Appendix L: Shows result of exposed thermo luminescent dosimeters.

CENTRE FOR ENERGY RESEARCH AND TRAINING

Ahmadu Bello University, Zaria

RADIATION PROTECTION SERVICES RECORDS

Joseph Dlama Zira Date: 27th April 2016

Dept. of Radiography and Radiological Sciences,

Nnamdi Azikiwe University

S/No	Chip ID	Dose (mSv)
1.	CHEST X-RAY	0.82
2.		0.60
3.		0.14
4.		0.31
5.		0.26
6.		0.46
7.		0.18
8.		0.58
9.		0.23
10.		0.61
11.		0.22
12.		1.35
13.		1.62
14.		0.39
15.		1.98
16.		0.20
17.		0.44
18.		0.61
19.		0.41
20.		0.38
21.		0.29
22.		0.41
23.		0.98
24.		0.57
25.		0.34
26.		0.38
27.		0.82
28.		0.60
29.		0.14
30.		0.31

1.	ABDOMINAL BACK 80kV 50m	0.53
2.		0.63
3.		0.51
4.		0.77
1.	ABDOMEN X-RAY	1.00
2.		1.17
3.		0.78
4.		0.67
5.		0.72
6.		0.65
7.		1.07
8.		0.95
9.		0.59
AB23		1.06
AB22		0.51
AB14		0.83
1.	AB 79kV 32ms	0.52
2.		0.61
3.		0.54
AB15		0.76
AB24		1.08
AB3		0.85
AB15		1.90
AB6		1.52
AB5		0.99
AB4		0.76
AB2		0.73
AB1		0.77
19		0.60
20		1.03
AB7		0.73
	FRONT T118	0.43
	PELVIS 79kV 40mAs	
1.		0.69
2.		0.58
3.		0.58
4.		0.74
	PELVIS 80kV 40mAs	0.42
1.		0.98
2.		0.38
3.		0.62
4.		0.42
	PELVIS 90kV 63mAs	
1.		0.82
2.		1.02
3.		0.97
4.		1.06

	MEDIOLATERAL OBLIQUE BREAST	1.89	
	TL2	0.34	
	TL1	1.85	
	MLO FRONT	0.28	
1.		0.42	
2.		0.42	
3.		0.31	
3.		0.89	
4.		1.89	
	MLO BACK	0.34	
	CRANIO CAUDAL BREAST	0.33	
	FRONT	1.28	
	TL1	3.47	
	TL3	1.12	
	BACK	0.85	
	TL2	0.57	
	CASE 1		
1.		0.57	
2.		0.45	
3.		0.48	
4.		0.43	
	CASE 2		
1.		0.33	
2.		0.86	
3.		0.81	
4.		1.06	
	CHEST X-RAY CODE 4925	1st	2nd
	4925	0.82	0.60
	4925	0.14	0.31
	4925	0.26	0.46
	4925	0.18	0.58
	4925	0.23	0.61
	4925	0.22	1.35
	4925	1.62	0.39
	4925	1.98	0.20
	4925	0.44	0.61
	4925	0.41	0.38
	4925	0.29	0.41
	4925	0.98	0.57
	4925	0.74	0.56
	4925	0.83	0.85
	4925	0.34	

Compiled by: S. Abdullahi

Appendix M: Shows a sample result of exposed thermo luminescent dosimeters

CENTRE FOR ENERGY RESEARCH AND TRAINING

Ahmadu Bello University, Zaria

RADIATION PROTECTION SERVICES RECORDS

Joseph Dlama Zira Date: 16th August 2016

Dept. of Radiography and Radiological Sciences,

Nnamdi Azikiwe University.

S/No	Chip ID	Dose (mSv)
1.	Dental Peri-Apical	**0.41**
2.	7	**0.28**
3.	4	**0.52**
4.	17	**0.23**
5.	10	**1.16**
6.	12	**0.61**
7.	9	**0.37**
8.	-	**0.09**
9.	11	**0.43**
10.	32	**0.17**
11.	13	**0.35**
12.	16	**0.33**
13.	20	**0.24**
14.	26	**0.37**
15.	-	**0.21**
16.	-	**0.43**
17.	Hand Dorsi Palmar kV483.8 mAs 2	**0.12**
18.	2	**0.61**
19.	7	**0.11**
20.	-	**0.30**
21.	5	**0.23**
22.	-	**0.69**
23.		**0.28**
24.		**0.71**
25.		**0.20**
26.		**0.37**
27.		**0.15**
28.		**0.16**
29.	Knee AP 50kV 4 mAs 6	**0.16**
30.	5	**0.52**
31.	25	**0.68**

32.	29	**0.49**
33.	3	**0.15**
34.	14	**0.82**
35.		**0.15**
36.		**0.39**
37.	28	**0.32**
38.	8	**0.28**
39.	15	**0.24**
40.	18	**1.25**
41.	Thoracic spine LAT 90kv 50mAs	**1.53**
42.		**2.28**
43.		**1.39**
44.		**0.99**
45.		**1.27**
46.		**0.89**
47.		**1.25**
48.		**1.21**
49.		**1.11**
50.		**1.02**
51.		**0.29**
52.		**1.53**
53.	Knee LAT 50kv 4 mAs	**0.92**
54.		**0.56**
55.		**0.53**
56.		**0.45**
57.		**0.22**
58.		**0.72**
59.		**0.24**
60.		**0.49**
61.		**0.25**
62.		**0.35**
63.		**0.26**
64.		**0.54**
65.		**0.10**
66.		**0.22**
67.	Wrist AP kV50 mAs 3.8	**0.21**
68.		**0.35**
69.		**0.66**
70.		**1.09**
71.		**0.15**
72.		**0.45**
73.		**0.18**
74.		**0.53**
75.		**0.10**
76.		**0.59**
77.	Thoracic spine AP 85kV 40mAs	**1.04**
78.		**1.30**

79.		**1.09**
80.		**0.74**
81.		**1.07**
82.		**0.69**
83.		**1.30**
84.		**0.96**
85.		**0.19**
86.	Elbow AP/LAT 50kV 3.8 mAs	**0.21**
87.		**0.73**
88.		**0.15**
89.		**0.34**
90.		**0.19**
91.		**0.34**
92.		**0.12**
93.		**0.60**
94.		**0.24**
95.		**0.45**
96.		**0.27**
97.		**0.43**
98.		**0.11**
99.		**0.27**
100.	Shoulder AP 56kv 7 mAs	**0.64**
101.		**0.49**
102.		**0.27**
103.		**0.71**
104.		**0.21**
105.		**0.48**
106.		**0.19**
107.		**0.51**
108.		**0.24**
109.		**0.55**
110.		**0.17**
111.		**0.46**

Compiled by: S. Abdullahi

Appendix N: Shows a sample result of exposed thermo luminescent dosimeters.

CENTRE FOR ENERGY RESEARCH AND TRAINING

Ahmadu Bello University, Zaria

RADIATION PROTECTION SERVICES RECORDS

Joseph Dlama Zira Date: 7th September 2016

Dept. of Radiography and Radiological Sciences,

Nnamdi Azikiwe University, Awka.

S/No	Chip ID	Dose (mSv)
1.	PLAIN ABDOMEN	**0.46**
2.		**0.76**
3.		**0.39**
4.		**0.76**
5.		**0.40**
6.		**0.77**
7.		**0.46**
8.		**1.07**
9.		**0.38**
10.		**0.73**
11.		**0.61**
12.		**0.86**
13.	KNEE LATERAL	**0.15**
14.		**0.67**
15.		**0.14**
16.		**0.43**
17.		**0.08**
18.		**0.50**
19.		**0.20**
20.		**0.53**
21.		**0.20**
22.		**0.42**
23.		**0.12**
24.		**0.90**
25.		**0.20**
26.		**0.49**
27.		**0.17**
28.		**0.51**
29.		**0.13**
30.		**0.42**
31.		**0.18**

32.		**0.48**
33.		**0.31**
34.		**0.49**
35.		**0.10**
36.		**0.49**
37.		**0.10**
38.		**0.46**
39.		**0.18**
40.		**0.30**
41.	LATERAL SKULL	**0.19**
42.		**0.64**
43.		**0.38**
44.		**0.50**
45.		**0.22**
46.		**0.61**
47.		**0.25**
48.		**0.54**
49.		**0.36**
50.		**0.51**
51.		**0.24**
52.		**0.68**
53.		**0.28**
54.		**0.26**
55.	PA/AP SKULL	**0.49**
56.		**0.92**
57.		**0.67**
58		**0.60**
59.		**0.46**
60.		**1.06**
61.		**0.32**
62.		**0.44**
63.		**0.52**
64.		**0.61**
65.		**1.19**
66.		**0.75**
67.	PELVIS	**0.42**
68.		**0.56**
69.		**0.54**
70		**1.06**
71.		**0.33**
72.		**0.67**
73.		**0.31**
74.		**0.71**
75.		**0.42**
76.		**0.62**
77.		**0.40**
78.		**0.28**

79.	KNEE AP	**0.16**
80.		**0.64**
81.		**0.13**
82.		**0.42**
83.		**0.15**
84.		**0.49**
85.		**0.11**
86.		**2.04**
87.		**0.23**
88.		**0.58**
89.	BREAST MEDIO LATERAL OBLIQUE	**0.40**
90.		**0.48**
91.		**0.46**
92.		**0.65**
93.		**0.57**
94.		**0.53**
95.		**0.41**
96.		**0.51**
97.		**0.44**
98.		**0.39**
99.		**0.45**
100.		**0.11**
101.	BREAST CRANIO CAUDAL	**0.20**
102.		**0.29**
103.		**0.23**
104.		**0.39**
105.		**0.19**
106.		**0.36**
107.		**0.30**
108.		**0.31**
109.		**0.26**
110		**0.44**
111.		**0.23**
112.		**0.70**

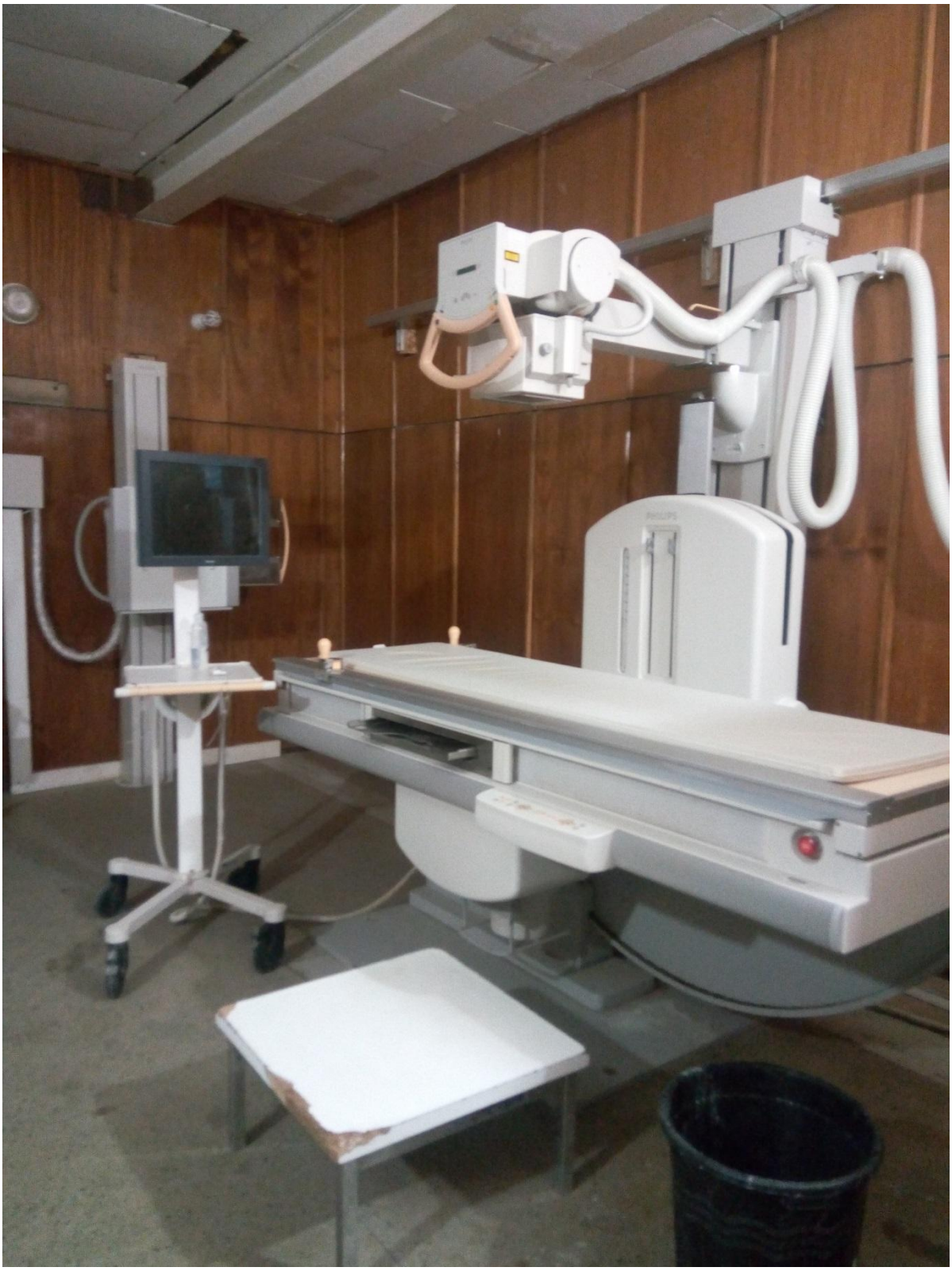
Compiled by: S. Abdullahi

Appendix O: The researcher giving instruction to one of the research participant

Appendix P: The researcher taking weight and height before examination in center B

Appendix Q: Some of the Thermoluminiscent dosimeter(TLD) Chips used in this study

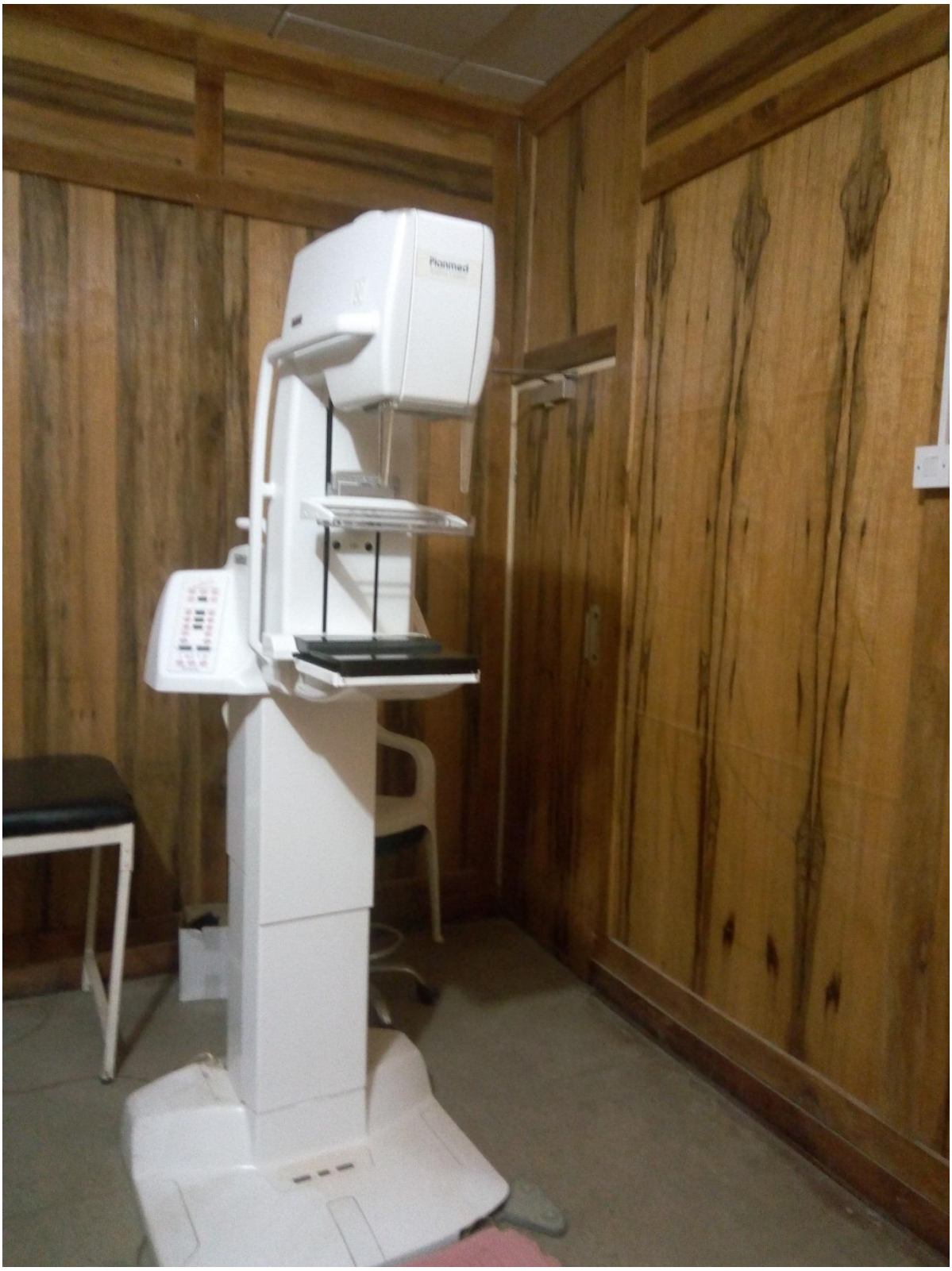
Appendix R: Fluoroscopy machine in Center A



Appendix S: X-ray machine in Center A

Appendix T: Computed tomography machine in Center A

Appendix U: Mammography machine in center A



Appendix V: Thermoluminiscent dosimeter profile and DAP meter.

$$D = \frac{Q \times ECC}{RCF}$$

- D - Reported Exposure Integral
- Q - Measured Charge
- ECC - Element Correction Coefficient
- RCF - Reader Calibration Factor

1. Annealing of TLD

· Anneal all TLD

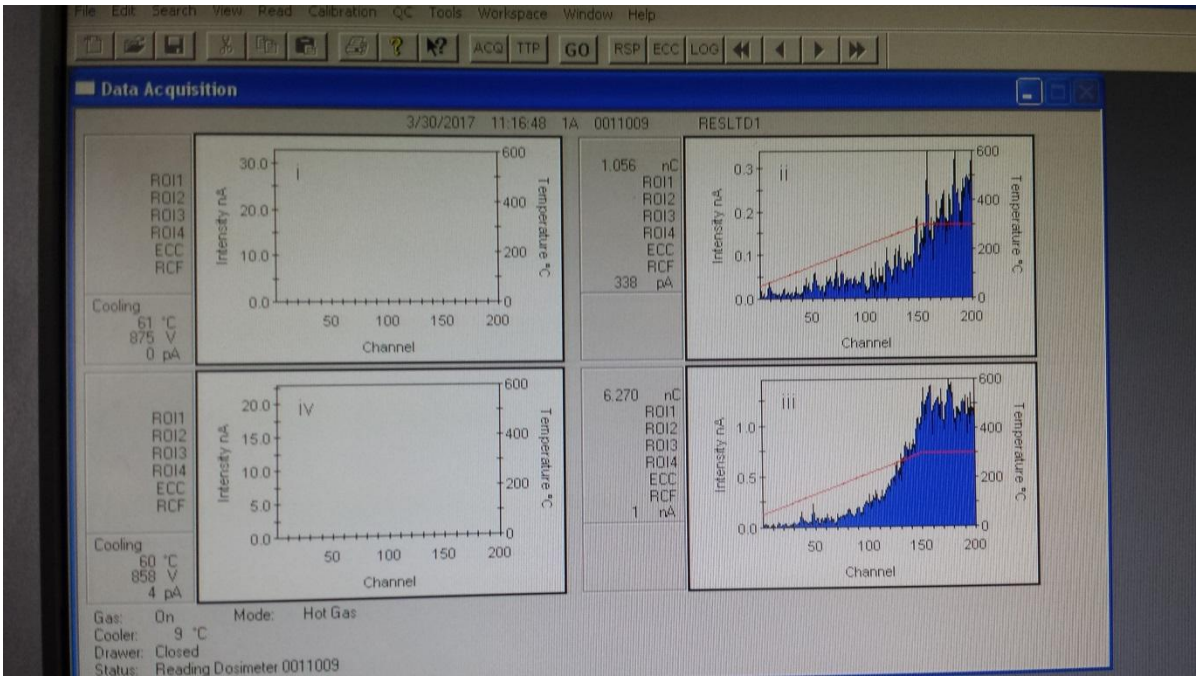
·Begin the reading process by selecting Read- start or Go from the menu bar. This bring up the Read Dosimeters Dialog box into view

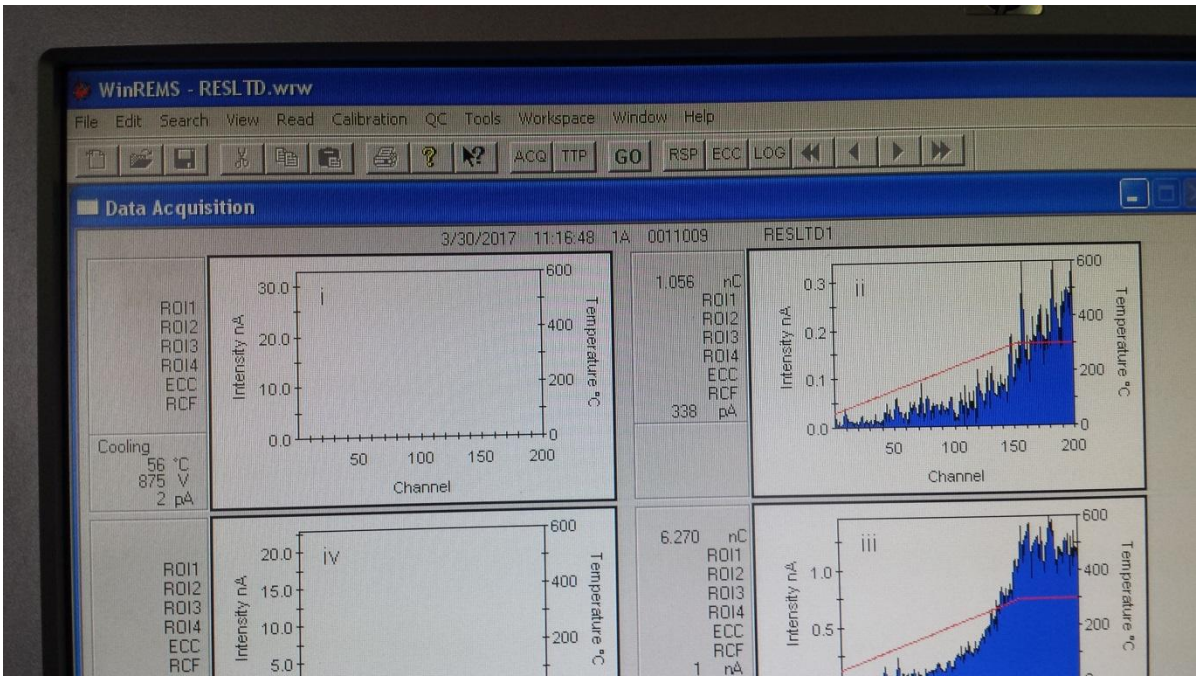
· Enter a unique Group – ID (name) e.g. HOST test.

· In the acquisition setup field select Anneal and earlier generated TTP i.e. 2 element TTP

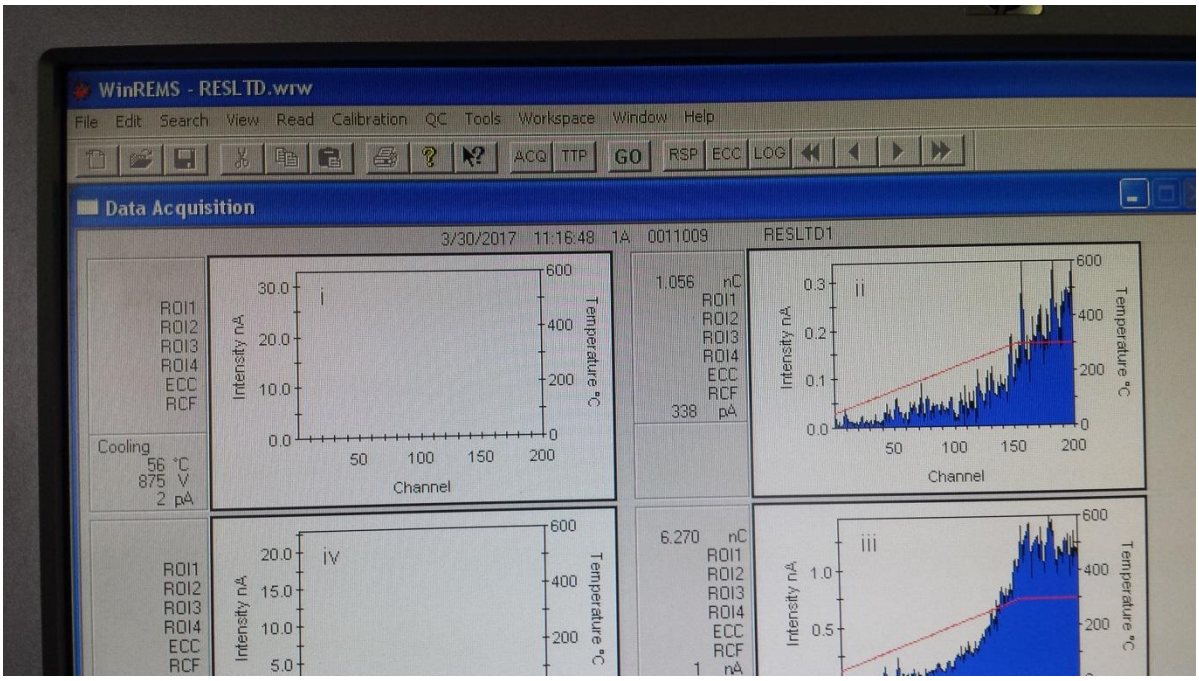
·Click on start (yes) now and when the green light on the reader is on, press the start button on the reader.
· Enter the card – ID (at the button of the screen) manually or by the use of Bar code – scanner.
·Open the reader drawer and insert the card, close and whenever the green light flashes on the reader, press start button.
·After read out of the cards open the drawer remove the card and start over again for the next card.
·When the read out is finish click on the done button on the PC.

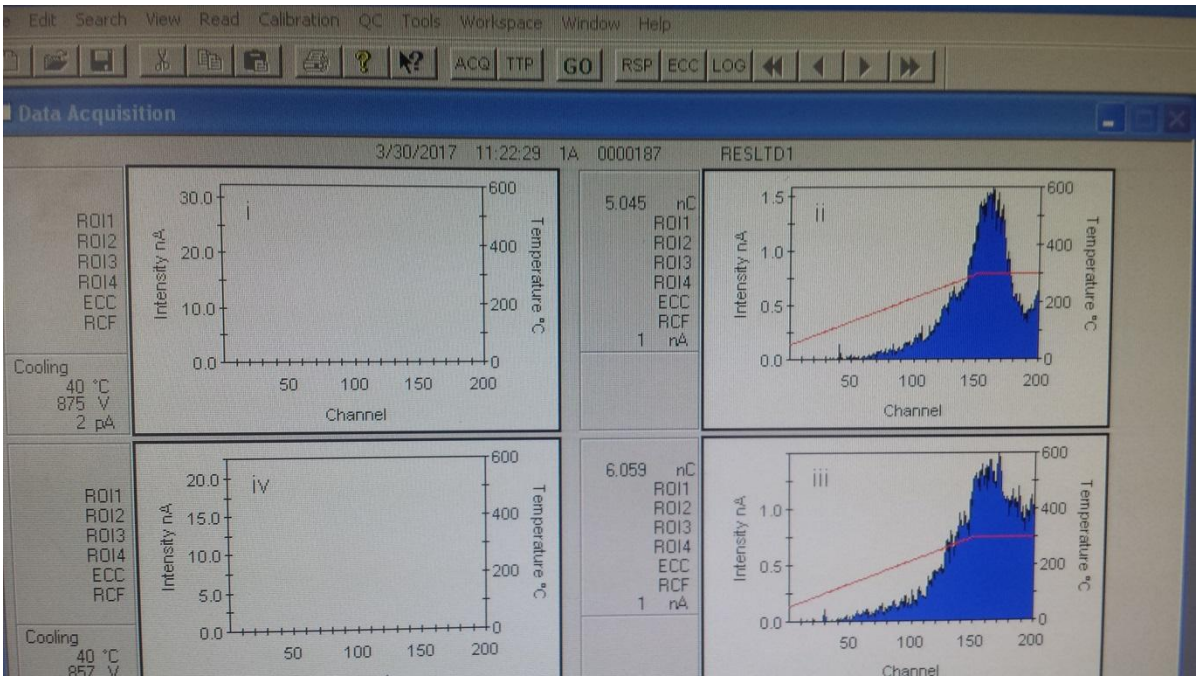
Appendix V: Thermoluminiscent dosimeter glow curve profile



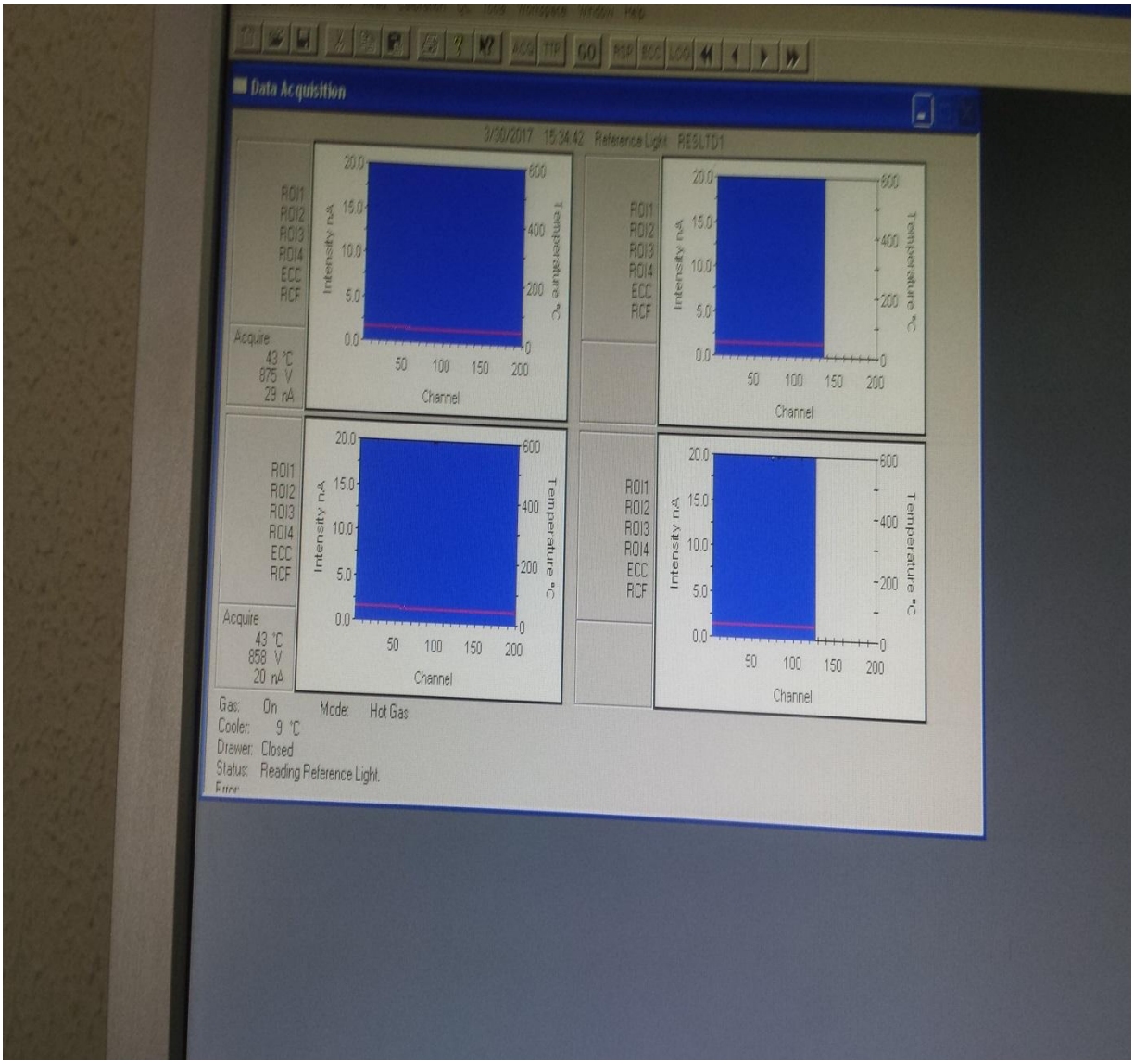


Appendix W: Thermoluminiscent dosimeter profile





Appendix X: Thermoluminiscent dosimeter profile



Appexdix X: Web based research training certificate on human research subject.

Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Dlama Joseph** successfully completed the NIH Web-based training course "Protecting Human Research Participants".

Date of completion: 12/08/2016.

Certification Number: 2250963.

Appendix Y: Consent form interpreted in Hausa

TAKARDAR YARDA DA SAKAMAKON NA BINCIKE

Sunnana **Joseph Dlama Zira** Dalibi a fannin daukar hoton majinyata, a jami'ar Nnamdi Azikiwe dake jahar Anambra. Inayin bincike akan ilimi sanin kaddamar da Asalin matsayin alamomin cuta da gwajegwajen a hanyar daukan hoto mara lafiya a asibitin koyarwa da ke yankin Arewancin Nigeria. Asalin matsayin alamomin cuta shine yin amfani da bincike ta hanyar daukan hoto maralafiya a gano yada kwayar magani yake gudanarwa. Matsayin wanan kwayar magani a harkan gudanarwa ta kiwon lafiyan sanin matsayin ciwor ta hanyar daukan hoto domin gwada taron marasa lafiya wanda suke daidai da wanan. Wannan bincike ilimin zai bankado ko bayyana yanda ake amfani da kwayar magani a lokacin da ake kokarin gudanar da daukan hoton marasa lafiya kuma a lura idan yana matsayin mafi dai –dai matsayin da ake so. Binciken nan a kan Establishment of Diagnostic Reference level for Radiological examination in selected university teaching hospitals in North eastern Nigeria.

Wannan bincike- ilimi zai amfani da nakurorin da ake amfani da su wagen gano gudanar kwayar magani kamar su nakural Thermoluminiscent Dosimeter da Dose Area Product a wurin sashin jikin da zaa gudanar da bincike gwajin yanda ake amfani da kwayar magani wanda ya hada har da sashin jikin wada yake sarrafa kwayoyi. Kokarin wajan gudanar da daukanr hoton mara lafiya baya daukar fiye da dakika Goma sha biyar zuwa ashirin. Shiga cikin gudanarwar ganin damarkane kuma zaka iya yanke shawarar kin shiga gudanar wa. Amma za ka iya kin yin kwajinba idan ka gugewa shiga cikin gudanarwar. Duk wasu labarum dake cikin wanan aikin za'a ajiyeshine a matsayin sirrin kuma matsayinka za'a bayyanashiba. Kuma labarum da aka bayannar a cikin wannan ilimi bazai bayannar da matsayin kaba kai kadaiba sai dai za'a iya gabatar dashi ko bugawa a cikin litattafin gudanar da ilimi ko taron karawa juna ilimi.

Idan ka yarda ko ka karbi cewa zaka shiga cikin gudanar da ilimin to ka sanya hannu a kasa.

Ni Nazim Ibrahim an tambayeni a game da wannan bincike kuma amsoshin da na bayar cikakune ko sun gamsar. Dan haka na yarda in shiga cikin wannan bincike.

Sa' hannu..... Na gode

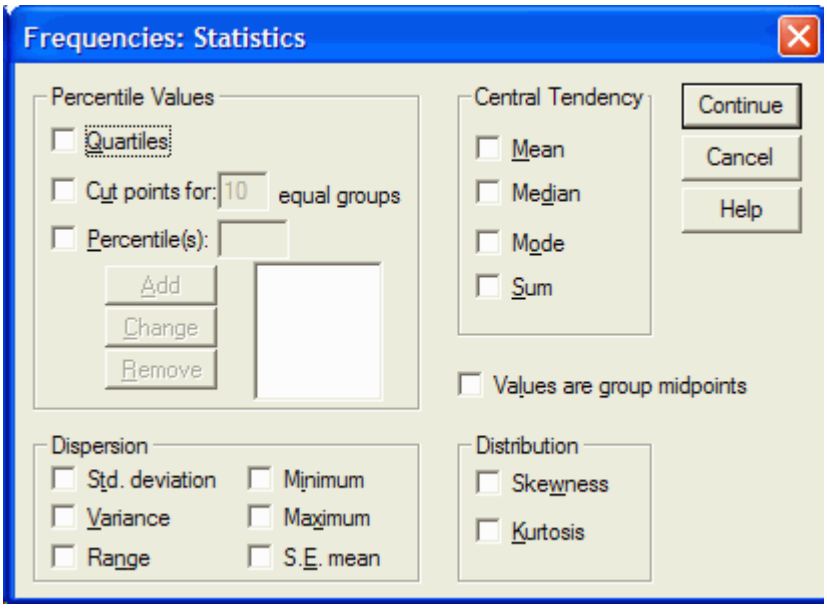
Sa hannun iyaye ko mai kula da kai ..... Kwanan wata 15-10-16

Sa hannun Sheda ..... Kwanan wata 15-10-16

Sa hannun mai bincike ..... Kwanan wata 15/10/16.

Na gode Allah ya sa albarka

Appendix Z: Calculating 75th percentile (3rd quartile) using SPSS Software



Appendix Z: Data collection from monitor of CT machine after CT examination