ASSESSMENT OF RADIATION RISK TO PATIENT AND STAFF DURING HYSTEROSALPINGOGRAPHY (HSG) USING CONVENTIONAL X-RAY IN KATSINA STATE, NIGERIA

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MAY, 2017

DECLARATION PAGE

I declare that the work in this thesis entitled "**ASSESSMENT OF RADIATION RISK TO PATIENT AND STAFF DURING HYSTEROSALPINGOGRAPHY (HSG) USING CONVENTIONAL X-RAY IN KATSINA STATE, NIGERIA"** has been performed by me in the department of physics. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

Dimas Skam JOSEPH	_____	_____
(Name of Student)	(Signature)	(Date)

CERTIFICATION PAGE

This thesis entitled **"ASSESSMENT OF RADIATION RISK TO PATIENT AND STAFF DURING HYSTEROSALPINGOGRAPHY (HSG) USING CONVENTIONAL XRAY IN KATSINA STATE, NIGERIA"** by Dimas Skam JOSEPH meets the regulations governing the award of the degree of Masters of Science (Radiation Biophysics) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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To God be the glory for his goodness and blessings in my life. I wish to recognise the contributions of Prof (Mrs) I G E Ibeanu, Dr I Y Zakari, Prof. D. J. Adeyemo, Dr Elisha Joseph, Mallam Sani Ibrahim at CERT and Mustapha Ndawashi for their contributions to the success of this work.

DEDICATION

This work is dedicated to my mother, my wife and my daughter Sarah Silaini Dimas.

ABSTRACT

Scientific evidence has revealed radiation as one of the causes of cancer and the use of radiation in medicine is on a continuous increase; studies have revealed that the medical use of x-ray is the major contributor of man-made source of radiation to the world's population. The drive for this study was the increase in the number of patients available for hysterosalpingography, HSG investigation. The aim of the study was to determine the radiation risks to the patients and staff during HSG procedure. A cross sectional study was conducted on 38 female patients in two diagnostic facilities in Katsina state of Nigeria." It is important to know that the staff performing the procedure stays in the radiographic room together with the patient while the x-ray exposures take place, this should not be confused with the operator of the x-ray machine". Quality control tests were conducted on the x-ray machines involved in the study as preliminary tests to ascertain the credibility of the generated data. The entrance surface doses ESDs to the patients' pelvis and anterior neck surface of the staff were measured by placing TLDs on the patients' pelvic surface and the shirt collar of the staff respectively. The mean measured patient ESD and staff ESD were 10.88mGy and 0.12mGy. The patients' mean measured effective doses to the ovaries, uterus, bladder, rectum, pelvic bone surface and the pelvic skin surface were 0.87mSv, 1.31mSv, 0.44mSv, 1.31mSv, 0.11mSv and 0.11mSv. While, the staff mean measured effective doses to thyroid, eyes and facial skin were 4.8µSv, 14.4µSv and 1.2µSv. The total exposed films used were between 4 to 6 films, this implies that the patients' ESD per film is 1.8 to 2.8mGy which is below the IAEA diagnostic reference level of 10mGy for Antero-posterior (AP) projection pelvis. And the mean radiation dose received by the staff is below the recommended occupational dose of a radiation worker by international commission on radiological protection ICRP 103. Though the mean measured effective dose values obtained were low, it does not indicate zero health effect since in radiation protection there is no safe dose for now. It should be understood in principle that dose acquisition has cumulative effect. Therefore, there is need for further optimization of procedure by reducing the number of patient radiation exposures (x-ray films taken), proper choice of exposure factors, tighter x-ray beam collimation and regular QC checks.

Keywords: Entrance surface dose, effective dose, hysterosalpingography HSG.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background of the study

X-ray is a form of electromagnetic radiation which was discovered on November 8, 1895 by Wilhelm Conrad Roentgen. This ground breaking discovery gave birth to radiography on December 27, 1895; when Roentgen took the first x-ray image of his wife's hand (Explorable.com, 2010). This made scientists at that time use this amazing ray to create images of the inside of the human body. But it was not for long when people started complaining of skin burns and cancer. In the late 1896, Elihu Thomson, an American physicist, deliberately exposed the little finger of his left hand to an x-ray tube for several days, half an hour per day which resulted in pain, swelling, stiffness, erythema and blistering.

In 1942, the leaders of the Manhattan District of U.S. asked Ernest O. Wollan, a cosmic ray physicist at the University of Chicago, to form a group to study and control radiation hazards and this was when the word 'health physics' was born. However, because of the various complaints that arose as a result of the uses of x-rays, various bodies (both governmental and non-governmental) were created to provide solutions and recommendations on how to reduce the adverse effects of radiation (Kathren & Ziemer, 1980; Turner, 2007). .

1.2 Introduction

Radiation has several applications; it is used in the industry, agriculture, medicine and research. The medical use of radiation involves its use in conventional radiography, fluoroscopy, angiography, nuclear medicine (scintigraphy), computed tomography, mammography and radiotherapy.

The use of ionizing radiation in clinical practice is on the increase both locally (in Nigeria) and globally. Certain checks have to be periodically done in order to ensure the optimization and protection of patients from these dangerous rays; in addition to investigate compliance level. 'Survey data showed that physicians underestimate the magnitude of radiation doses and their associated detrimental effects and thus underestimating the level of risk to patients (Mercuri *et al*., 2011).

Measurements through quality control tests provide a means for setting and checking standards to ensure good practice as an aid to the optimization of patients' protection. Also estimates of the absorbed and effective doses to skin and tissues/organs in the patient are needed to determine the associated risks. Data generated provide for improvement in operations hence justifying techniques and procedures put in place in diagnostic investigations.

Currently, the two fundamental principles (justification of practice and the optimization of protection) have been placed under serious scrutiny in the achievement of ALARA in the diagnostic radiology. In the light of the aforementioned, medical exposures are receiving increasing attention with the realisation that clinical x-rays make the major contribution from manmade sources to the population collective dose; also, there is considerable potential for reducing doses without detriment to patient care (IRPA9, 1996).

Hysterosalpingography (HSG) is a special radiographic examination of the uterine cavity and the fallopian tubes using radio-opaque dye for the evaluation of infertility in women. 'It involves unavoidable irradiation to the ovaries of women in child bearing age; therefore, optimization is required in all involving procedures to ensure reduction in the probability of the associated risk' (Suleiman *et al*., 2008). With the growing concern about radiation doses received by patients and cancer incidence over the years,

there has been an emergent requirement for information on typical doses and the range of doses received during x-ray examinations (Gyekye *et al.,* 2012). This study therefore tend to provide such information, so that there is justification of such procedure and that the radiation doses to both the patient and staff is as low as reasonably practicable (ALARP) without affecting the image quality and patient care during the investigation.

To ensure that the radiation worker and members of the public remain healthy devoid of radiation effects involve continuous quality control checks of those factors in radiation facilities especially radio-diagnostic units that may change leading to an overall increase of radiation dose to the staff, the public and the environment. The building and design construction of x-ray rooms are of paramount importance in radiation protection, but continuous quality control checks of x-ray machine ensures that leakage radiation level is known, scattered radiations are reduced and that x-ray machines are operating within optimal limits. Other factors to be assessed in this study involve personnel monitoring and the availability of radiation protection devices such as lead aprons. Therefore, quality assurance will ensure optimal performance of x-ray machines, optimal image quality and optimization of procedures which will ensure reduced radiation dose to both patients and radiation workers.

1.3 Statement of the Problem

Scientific fact revealed that radiation is one of the causes of cancer; this was demonstrated after the discovery of x-ray when there were various complaints as a result of the uncontrolled use of radiation. Furthermore, the medical use of radiation is on a continuous increase both locally and globally. And the medical use of radiation has been reported to be the major contributor of radiation to man.

However, because of the deleterious effects of radiation; practice involving the use of radiation must be justified and optimized. Various individuals and groups have

attempted to study and provide recommendations on the safe use of radiation but this only reduce the adverse effects associated with radiation; furthermore, more studies are required.

It was observed that there was high increase in the number of patients in Katsina undergoing HSG examinations which called for investigation of potential risk. The acquired data will assist in justification and optimization of such procedures involved in the investigations. The unavailability of data bank on the radiation dose and associated risks to patients and staff during such investigations became an issue of great concern and needed immediate attention hence the drive in the current study.

1.4 Justification of Study

HSG is a diagnostic procedure that involves multiple radiation exposures to women of child bearing age, which may result in serious over exposure of the problem sites and surrounding cells. In addition, there is tendency of potential radiation exposure of the staff conducting the investigations. According to ICRP 2007 for such medical procedure to be undertaken, it has to be fully justified to ensure that the benefits to the patients outweigh the risks to the exposed patients. This then demands that generally, the practice must be justified and the dose to patient optimized. Hitherto, no such data were available in the country to the best of my knowledge.

1.5 Aim and Objectives

The aim of this study is to assess the radiation risk to the patients undergoing the procedure (HSG) and the staff performing the radiographic procedure using conventional x-ray in Katsina state, Nigeria.

The objectives include the following:

i. To sketch the building layout and design of the x-ray room.

ii. To conduct area monitoring of various strategic points from the x-ray source.

iii. To conduct the following quality control checks on the x-ray machines employed in the study.

- Kilovolt Peak (kV_p) Accuracy And Reproducibility
- Filtration Check
- Milli-ampere Second (mAs) And Timer Linearity And Reciprocity
- Radiation Output Reproducibility
- Light Beam Alignment (Light Field-Radiation Congruence)
- Accuracy of Source to Image Distance (SID/FFD) Scale
- Radiation Leakage
- Lead Apron Check

iv. To measure the entrance surface doses (ESD) to the patient's pelvis and to the anterior surface of the neck of the radiologic staff performing the procedure.

v. To determine the radiation risk to the patient's pelvic organs and to the thyroid, eyes and face of the radiologic staff.

1.6 Scope of the Study

The scope of this study involved sketching the x-ray room design with Microsoft publisher 2007. Quality control tests were also performed on the various x-ray machines used in this study. And ESD measurements performed on the patients and staff during the HSG procedure in the radio-diagnostic facilities in the study; in Federal medical centre (as facility 1) and Nadda diagnostic centre (as facility 2) in Katsina state of Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Radiation Effects

Radiation injuries can be classified into somatic and genetic effects.

2.1.1 Somatic effects

These are effects in which the radiation damage appear in the individuals exposed to such radiation. When ionising radiation come into contact with living beings, they could cause some deleterious effects which would be detrimental to such a creature. Somatic radiation can be further classified into acute deterministic (non stochastic) and stochastic effects. Acute deterministic (non-stochastic) effect is dependent on threshold and the severity of such an effect increases as the radiation dose increase example reddening of the skin, gastrointestinal disturbance and radiation induced cataract (Sanderud, n.d.).

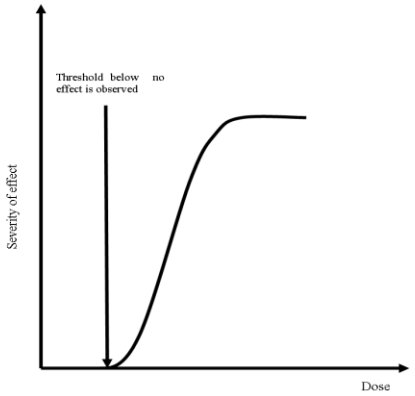


Figure 2.1 shows Acute deterministic effect graph, the various effects are nausea, erythema and cataract.

Stochastic effect; as the name implies, stochastic effects are those that occur in a statistical manner. Cancer is one example. If a large population is exposed to a significant amount of a carcinogen, such as radiation, then an elevated incidence of cancer can be expected. Although we might be able to predict the magnitude of the increased incidence, we cannot say which particular individuals in the population will contract the disease and which will not. Also, since there is a certain natural incidence of cancer without specific exposure to radiation, we will not be completely certain whether a given case was induced or would have occurred without the exposure this radiation effect is dependent on probability. The probability of occurrence is not dependent on threshold (Amin & Bradley, 2001; Turner, 2007).

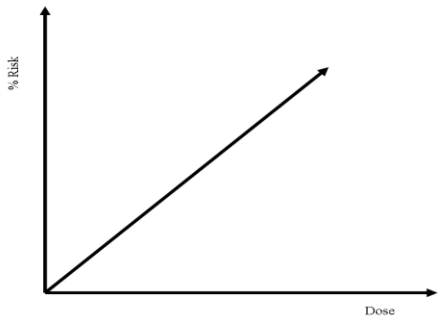


Figure 2.2 shows Stochastic effect graph, the effects are cancer and hereditary anoma-

2.1.2 Genetic effects:

This is effect observed by offspring of individuals exposed to such radiation. The genetic effect involves the mutation of very specific cells, namely the sperm or egg cells. Mutations of these reproductive cells are passed to the offspring of the individual exposed. Radiation is a physical teratogenic agent. There are many chemical agents (such as thalidomide) and many biological agents (such as the viruses which cause German measles) that can also produce malformations while the baby is still in the embryonic or foetal stage of development. One very important fact is that radiation will not produce new types of mutations but simply increase the incidence of existing ones. One possible reason why genetic effects from low dose exposures have not been observed in human studies is that mutations in the reproductive cells may produce such significant changes in the fertilized egg that the result is a nonviable organism which is spontaneously aborted during the earliest stages of fertilization. Therefore, not all

mutations would be lethal or even harmful; it is prudent to assume that all mutations are bad (Amin & Bradley, 2001; U.S.NRC, 2015).

2.2 Radiation Dosimetry

2.2.1 Radiation quantities and units

2.2.1.1 Absorbed dose

Absorbed dose (Radiation absorbed dose) is used to measure the amount of radiation absorbed by an object or person, which reflects the amount of energy that radiation sources deposit in materials through which they pass. The radiation-absorbed dose (rad) is the amount of energy (from any type of ionizing radiation) deposited in any medium (example water, tissue, air). An absorbed dose of 1 rad means that 1 gram of material absorbed 100 ergs of energy as a result of exposure to radiation. The international system unit is the gray (Gy), where 1 Gy is equivalent to 100 rad (U.S.NRC, 2016). Also, $1Gy = 1Jkg^{-1}$.

$$D = \frac{dE}{dm} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad (2.1)$$

Where; **D** is absorbed dose and **m** is the mass of material.

However, absorbed dose in tissue cannot be measured directly by any practical methods. Dose measuring devices, dosimeters, can be placed on the surface, but it is generally not reasonable to insert them into most internal tissues or organs. The absorbed dose in most body tissues is usually determined by indirect means. A common method is to first determine the entrance surface exposure, or air kerma, over

the tissue or organ of interest and then use published dose factors to calculate the dose in a specific tissue location (Sprawls, n.d.).

2.2.1.2 Air kerma

Air kerma in air is the sum of kinetic energy of all charged particles liberated per unit mass. Also, it is sometimes used to express the radiation concentration delivered to a point, such as the entrance surface of a patient's body A number of publications in the past have expressed measurements in terms of absorbed dose to air. Recent publications and an IAEA Code of Practice point out the experimental difficulty in determining the dose to air, especially in the vicinity of an interface, and that, in reality, what the dosimetry equipment registers is not the energy absorbed from the radiation by the air, but the energy transferred by the radiation to the charged particles resulting from the ionization. For these reasons the IAEA Code of Practice and ICRU Report 74 recommend the use of air kerma rather than absorbed dose to air. This correction applies to the quantities determined in air, such as entrance surface air kerma (rather than entrance surface air dose), computed tomography air kerma index (instead of computed tomography dose index), kerma area product (rather than dose area product) and air kerma area length (rather than dose length product). The above recommendation refers to air. When referring to tissues, it is also correct to estimate absorbed dose to the skin, by applying the necessary correction coefficient to obtain the absorbed dose to the tissue from the air kerma (IAEA RPOP, 2013).

The quantity, air kerma, has two things going for it;
(a) It is easy to measure with an ionization chamber. Since the ionization produced in air by radiation is proportional to the energy released in the air by the radiation, ionization chambers actually measure air kerma as well as exposure. An ionization

chamber can be calibrated to read air kerma, or a conversion factor can be used to convert between air kerma and exposure values. (b) It is expressed in a practical metric SI unit. Air Kerma (Kinetic energy released in a unit mass of air) is expressed in the units of joule per kilogram, J/kg. This is also the unit gray, Gy, used for absorbed dose. Therefore, if air kerma is measured (or calculated) at a point where soft tissue is located, the absorbed dose in the tissue will be just about equal to the air kerma (Sprawls, n.d.)

2.2.1.3 Dose equivalent (equivalent dose)

Dose Equivalent, in the unit, sievert (Sv), is a quantity that expresses the relative biological impact of the radiation by including a radiation weighting factor ($w_{\mathbf{R}}$).

$$\text{Dose Equivalent, } H_T = \Sigma\ w_{\mathbf{R}} \times D_{T,R} \quad (2.2)$$

The value of the radiation weighting factor ($w_{\mathbf{R}}$) is a characteristic of each specific type of radiation. All photons have a $w_{\mathbf{R}}$ value of 1. $\mathbf{D_{T,R}}$ is the mass-averaged absorbed dose in tissue T by radiation type R. Therefore,

$$\text{Dose Equivalent, } H_T \text{ (Sv)} = \text{Dose (Gy)} \quad (2.3)$$

Some other types of radiation, like the larger particles, might have higher values for $w_{\mathbf{R}}$. What this means is that these radiations will produce more biological effect per unit of absorbed dose. Where we will most often encounter dose equivalent is in expressing the radiation received by personnel working in radiation environments, etc. For example, the values measured with personnel monitoring devices (film badges, TLDs, etc) are

usually reported in sieverts (Sprawls, n.d.). Below is a table showing the radiation weighting factor for various types of radiation.

Table 2.1: Radiation Weighting Factor W_r In Accordance with Euratom Basic Standards 1996 **(**European nuclear society, n.d.)

Radiation type and energy	**Radiation weighting factor W_R**
Photons, all energies	1
Electrons, myons, all energies	1
Neutrons	
< 10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5
Protons > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

2.2.1.4 Effective dose

Effective dose is becoming a very useful radiation quantity for expressing relative risk to humans, both patients and other personnel. The "effective dose" is a biological dose commonly used in radioprotection, as it determines how dangerous an individual's exposure to radiations can be. It takes into consideration not only the nature of the incoming radiation but also the sensitivities of the body parts affected. It is actually a simple and very logical concept. It takes into account the specific organs and areas of the body that are exposed. The point is that all parts of the body and organs are not equally sensitive to the possible adverse effects of radiation, such as cancer induction and mutations. The unit of 'effective dose' is the sievert, the same unit as is used for the

equivalent dose absorbed locally by an organ, a gland or any other part of the body (Radioactivity.eu.com, n.d.).

$$\text{Effective dose, } E = \Sigma\ w_T \times H_T \quad - \quad - \quad - \quad - \quad - \quad (2.4)$$

$$E = \Sigma\ w_T \times \Sigma\ w_R.D_{R,T} \quad - \quad - \quad - \quad - \quad - \quad (2.5)$$

Table 2.2: Tissue Weighting Factors According To ICRP 103 (ICRP 2007)

Tissue	**Tissue weighting factor w_T**	**Σw_T**
(*) Remaining tissues: Adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine, spleen, thymus, uterus/cervix (♀).		
Bone-marrow (red), colon, lung, stomach, breast, remaining tissues(*)	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
	Total	1.00

Source: Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR (2012)

2.2.1.5 Entrance surface dose

An entrance surface dose of x-rays is the absorbed dose at the surface of the skin where the x-ray beam enters the body. An x-ray beam enters the body from the direction of the x-ray tube. A small share of the beam exits from the body on the opposite side which is called the exit dose, where it is detected by the image receptor (an x-ray film or

phosphor material). The share of the beam which never exit from the body is absorbed as extra energy by the body's internal organs and bones (Gofman & O'Connor, 2000).

$$ESD = ID \times BSF \quad - \quad - \quad - \quad - \quad - \quad (2.6)$$

Where ID: Incident absorbed dose and BSF: Backscatter factor

The contribution of the BSF is included; it depends on the x-ray beam spectrum, x-ray field size, thickness of the patient and the difference between the effective centre of the dosimeter and the surface. Below is a table of BSF; (Wall, 1996)

Table 2.3: Typical BSF values in diagnostic x-ray measured with TLD and water

HVL	**Field size**				
	10 × 10	15 × 15	20 × 20	25 × 25	30 × 30
2.0	1.26	1.28	1.29	1.30	1.30
2.5	1.28	1.31	1.32	1.33	1.34
3.0	1.30	1.33	1.35	1.36	1.37
4.0	1.32	1.37	1.39	1.40	1.41

Source: Wall (1996)

Another formula for determining the ESD is given below (Jarvinen ,2011).

$$\text{Also, ESD or ESAK} = {}_nK_a(U,F).\left(\frac{100\,cm}{FSD}\right)^2.PIt.BSF \quad - \quad - \quad - \quad -(2.7)$$

$$\text{Therefore, ESD} = \left(\frac{mGy}{mAs}\right) \times \left(\frac{100\,cm}{FSD}\right)^2 \times mAs \times BSF \quad - \quad - \quad - \quad -(2.8)$$

Where; $_nK_a(U,F)$: tube output (mGy/mAs) at a distance of 100cm from the focus, with high voltage of U and total filtration F

ESAK: entrance surface air kerma

FSD: focus-to-skin distance (cm)

PIt : tube current-time product used (mAs)

BSF: back scatter factor

2.2.1.6 Occupational dose

This refers to the radiation dose received by a radiation worker in the course of discharging his/her duties, which is; as a result of the occupation.

Table 2.4: Dose limits recommended by ICRP according to a certification program on radiation safety.

Application	**Dose limits**	
	Occupational	Public
Effective dose	20 mSv per year, averaged over defined period of 5 years. In a year, With no more than 50 mSv averaged in a single year	1 mSv over defined period of 5 years. In a year, over 5 years
Annual equivalent dose to Eyes	150mSv	15 mSv

Skin	500mSv	50mSv
Hands and feet	500mSv	---------
Equivalent dose to the abdomen of pregnant women	2mSv after being declared pregnant up to term	

2.3 Radiation Detection and Measurement

This involves the use of some instruments or devices that provide information about the dose rate and dose at the location where the instrument or device is placed. These instruments are calibrated to give measurements in units of sievert Sv or Gray Gy. The instruments are however grouped into; (a) Survey instrument and (b) Personnel monitoring instruments or dosimeters (Tsoulfanidis, 1995)

2.3.1 Survey instrument of the problem

Radiation survey instruments are area monitoring devices that both detect and measure the radiation level in an area. By detection, it simply means that it indicates the presence or absence of radiation (Sherer *et al.,* 2002).

The portable survey instruments are detectors, the most commonly used are GM counters and the so-called "cutie pie" meter. Many commercial GM counters offer a fixed thin window that will allow betas and photons to traverse it and be counted, and one or more movable windows that will stop the betas and allow only the gammas to enter the counter. The cutie pie is an ionization counter that can be used to detect X-rays, alphas, and some high-energy betas.

The non-portable instruments are set at fixed locations to detect the radiation field; they are usually equipped with an alarm that will provide an audio and/or visual signal when the field intensity exceeds a preset limit. Examples are continuous air monitors and personnel monitors (e.g., hand, foot, and whole body)'' (Tsoulfanidis, 1995).

2.3.2 Personnel monitoring instrument (dosimeters)

It is recommended that individuals who are occupationally exposed to radiation are monitored. This is mandatory when the radiation exposure is 10% or more of the annual occupational effective dose limit of 50 mSv (5 rem). Personnel monitoring device records only the exposure received over the area it is worn. It determines occupational exposure by detecting and measuring the quantity of the ionizing radiation to which the device or instrument has been exposed to over a specific period of time. It has to be noted that this instrument does not protect the wearer against radiation, rather gives a record of the radiation received (Sherer *et al.*, 2002).

Personnel radiation exposure must be monitored for both safety and regulatory purposes. This assessment may need to be made over a period of several minutes to several months. There are three main types of individual radiation recording devices called personnel dosimeters used in diagnostic radiology and nuclear medicine: (a) film badges, (b) dosimeters using storage phosphors (e.g., thermo-luminescent dosimeters, TLDs), and (c) pocket dosimeters, each with its own specific advantages and disadvantages. Ideally, one would like to have a single personnel dosimeter capable of meeting all of the dosimetry needs in medical imaging. The ideal dosimeter would instantaneously respond, distinguish between different types of radiation, and accurately measure the dose equivalent from all forms of ionizing radiation with energies from several keV to MeV; independent of the angle of incidence. In addition, the dosimeter would be small, lightweight, rugged, easy to use, inexpensive, and unaffected by

changes in environmental conditions (e.g., heat, humidity, pressure) and non-ionizing radiation sources. Unfortunately, no such dosimeter exists; however, the majority of these characteristics can be satisfied to some degree by selecting the dosimeter best suited for a particular application'' (Knoll, 2011).

Personnel dosimeters can be worn on front of the body at the collar level by attaching it to the clothing on the front of the body at the collar level. When placed at the collar level, it provides an approximation of the dose equivalent to the thyroid gland, the eye lenses, the head and the neck. Fluoroscopy and special radiographic procedures produce the highest occupational radiation exposure for medical diagnostic imaging professionals, when a protective lead apron is being used, the personnel dosimeter should be worn outside the lead apron at the collar level on the front of the body because the unprotected head and neck region received over 10 times more than the protected parts of the body. Also, during special radiographic procedures, a second dosimeter can be worn underneath the lead apron at the waist level. This is to monitor the dose equivalent to the lower trunk. This use of second dosimeter is also necessary for pregnant diagnostic imaging professionals (Sherer *et al.,* 2002).

2.3.2.1 Thermo-luminescent dosimeter TLD

Thermo-luminescent dosimeters (TLDs) are based on the property of thermo-luminescence. The process is one in which electrons are elevated from the valence to the conduction band by the incident radiation but are then captured at various trapping centers. When ionizing radiation bombards a crystal, The electron may acquire enough energy to move from the valence to the conduction band, in which case the event is called ionization or the electron acquires enough energy to move to an excited state (to the exciton band) and form an exciton. An exciton, consisting of an electron and hole bound electrostatically, can migrate through the crystal. If the distance of the trap

energy level below the conduction band is sufficiently large, there is only a small probability per unit time at ordinary room temperatures that the electron will escape the trap by being thermally excited back to the conduction band. Therefore, exposure of the material to a continuous source of radiation, although not resulting in a significant yield of prompt scintillation light, leads to the progressive build up of trapped electrons. Electrons, holes and excitons may be caught in many "traps" that exist in the solid. Traps are formed in a variety of ways. Foreign atoms (impurities), interstitial atoms, dislocations, vacancies and imperfections may act as traps. The trapped carriers remain in place for long periods of time if the temperature of the crystal stays constant or decreases. If the temperature is raised, however, the probability of escape increases. As electrons and holes are freed and return to the ground state, they emit light. The emission of this light is called thermo-luminescence and is the property upon which the operation of TLDs is based. A TLD is essentially a piece of a thermo-luminescent material, exposed to the radiation being measured. After irradiation stops, the TLD is heated under controlled conditions, and the light intensity is measured either as a function of the time during which the temperature is raised. The result of such a measurement is a graph called ***glow*** curve. Glow curves have more than one peak, corresponding to traps at various energy levels. The amplitudes of the peaks sare proportional to the number of carriers trapped in the corresponding energy traps. The TLD sample is placed in a stream of heated gas or on a heated support, and its temperature is progressively raised. At a temperature that is determined by the level of the trap, the trapped electrons can pick up enough thermal energy so that they are re-excited back to the conduction band. Assuming that this temperature is lower than that required to free the trapped holes, the liberated electrons then migrate to near a trapped hole, where they can recombine with the emission of the a photon. The absorbed dose

may be measured either from the total light emitted by the glow cure or from the height of one or more peaks of the glow curve. If the sample is raised to a relatively high temperature, all the traps are depleted and the exposure record of the sample is "erased or annealed." TLD materials therefore have the very practical advantage of recyclability, and a single sample may be reused many times. The TLD returns to its original condition and is ready to be used again after being heated long enough then it is left of cool down to room temperature. Measurement of the light from the glow curve, and subsequent annealing, are performed by instruments generally called readers. Materials commercially available that satisfy most of these requirements are CaSO: Mn, CaF, (natural), CaF,: Mn, Li2B407M: n, and LiF. CaSO, and CaF, are used for gammas only. Other materials that have been studied are CaSO,: **Dy**, BeO, and A120,. A commercial Dosimetry package, based on a combination of CaSO, and Li2B407, and known as Panasonic UD-802 or UD-854 is used in nuclear power plants. The most commonly used TLD material for personnel Dosimetry is lithium fluoride (LiF). LiF TLDs have a wide dose response range of 10 ~Sv to 103 Sv (l mrem to 105 rem)and are reusable. Another advantage of LiF TLDs is that the effective atomic number is close to that of tissue; therefore, the dose to the dosimeter is close to the tissue dose over a wide energy range. TLDs do not provide a permanent record, because heating the chip to read the exposure removes the deposited energy. TLDs are routinely used in nuclear medicine as extremity dosimeters; a finger ring containing a chip of LiF is worn on the hand expected to receive the highest exposure during radiopharmaceutical preparation and administration. TLDs are also the dosimeter of choice when longer dose assessment intervals (e.g., quarterly) are required. TLDs have found wide use for measurements in mixed neutron-gamma fields. The TLD-100 containing natural lithium (92.6 percent 7~i7, 4 percent 6~I responds to gamma and thermal neutrons. Thermal neutrons are

detected through the ***(n,*** a) reaction with 6~i which has a cross section equal to 950 b for thermal energies. If a TLD-100 is exposed to about 3 x 10^{11} neutrons/m^2 (thermal), its light output is equivalent to that from 1 R of gamma radiation. The TLD-600, containing lithium enriched to 95.62 percent in 6~iis, extremely sensitive to thermal neutrons and also to gammas. The TLD-700, containing 99.993 percent 7~iis, sensitive to gammas only, because the neutron cross section for 7~is ive ry small (about 0.033 b for thermal neutrons). In a mixed neutron-gamma field, one can achieve ***y-n*** discrimination by exposing to the radiation a TLD-100 plus a TLD-700, or aTLD-600 plus a TLD-700. The difference in response between the two dosimeters of either pair gives the dose due to the neutrons only. A very sensitive LiF TLD has been reported consisting of LiF with three dopants: Mg, Cu, and P. Its sensitivity is supposed to be 23 times that of TLD-600 (Tsoulfanidis, 1995; Bushberg, 2002; Sherer *et al*., 2002; Knoll, 2011).

2.4 Radiation Protection

Radiation protection principles are based on the following;

- Justification of practice
- Optimization of practice
- Dose limitation

To ensure that the radiation is kept at ALARA, the prime fundamentals considered are working distance, working time and shielding.

Working distance: maximizing the distance from the radiation source during radiographic procedure minimizes the radiation dose to the radiation worker. This obeys

the inverse square law. The law states that the radiation intensity is inversely proportional to the square of the distance from the radiation source.

$$\text{Intensity, } I = 1 / d^2 \quad - \quad - \quad - \quad - \quad - \quad (2.9)$$

Working time: minimizing the working time at the radiation source minimizes the radiation dose or exposure.

$$\text{Therefore, Exposure} = \text{Dose rate } (\mu Sv/h) \times \text{Time (h)} \quad - \quad - \quad - \quad - \quad - \quad (2.10)$$

Shielding: This is an effective way of minimizing the radiation dose to an individual. This is achieved by introducing a barrier between the radiation source and an individual. The effective of shielding from a radiation source is dependent on the material used and also on the thickness of the material. Examples are; lead, concrete, water etc. This is mathematically represented as;

$$I = I_0 e^{-\mu x} \quad - \quad - \quad - \quad - \quad - \quad - \quad (2.11)$$

Where; I = Radiation intensity after passing through the shielding material, I_0 = initial radiation intensity, x = thickness of material and μ = total linear attenuation coefficient (Amin & Bradley, 2001).

2.4.1 Building design and layout

The building design layout by Keane and Tikhonov (1975) and safety code 35**:** In constructing and planning a radiation facility, some features will serve as built-in

safeties against radiation. Considerations have to be made in siting of facility and radiation protection requirements.

a) Siting of an x-ray room: The siting of an X-ray room is influenced by the associated facilities required, such as offices, waiting room, level approach, lifts, transport for outpatients, and access for staff. The x-ray room is preferable to be on the ground floor.

   Doors should be so constructed that it is possible for patients' beds to be wheeled into the X-ray room; double doors are particularly convenient for this purpose, one of them being sufficient for normal traffic and both are opened to admit stretchers or beds. The corridors leading to the X-ray room also need to be fairly wide and there should be enough space outside the X-ray room for stretchers or beds to be manoeuvred into the room. Attention to such matters can often avoid the need for a mobile X-ray unit.

   Darkrooms should be at least 6 m^2 in area, but a somewhat larger room may be necessary under particularly difficult conditions of temperature and humidity. The darkroom should be placed centrally within the X-ray department, preferably with direct connection through hatches to all X-ray rooms and with easy access to the main X-ray room.

   At least two changing cubicles of 1.5 m^2 minimum size should be available outside an X-ray room so that only one patient need be in the room during the time that the equipment is switched on.

The X-ray room should be built strongly enough to carry the equipment it will contain and be so constructed as to provide adequate radiation protection for people outside the room.

b). Standard and Efficient room layout: In the X-ray room, the layout of equipment should be designed to avoid unnecessary movement around obstacles "*en **route**"* to the darkroom, to the patient, and to the protected control panel.

Radiology rooms with static x-ray units, which can be accessed from public areas should be equipped with a self-closing door, and must be identified with warning signs incorporating the X-ray warning symbol and the words "Unauthorized Entry Prohibited". The uninterrupted X-ray beam should not be able to fall on the darkroom wall and should not routinely point towards doors or windows.

When funds and facilities are severely limited, several pieces of equipment should not be installed in one room as this involves particular hazards; for example, staff setting up a patient on one side of the room may be irradiated by exposures taking place on the other side.

Adequate protective screens should be provided between each X-ray tube area. For each special technique such as tomography, angiography, or plain chest fluorography, a separate room should be provided.

Any X-ray room should be of adequate size (not less than 6 m X 4 m) for simple radiography). The rooms should be designed to provide adequate working space to the equipment operator and to allow for ease of patient movement

Archives, offices and waiting rooms should be provided. Reporting on films must not be in the room in which radiography is being carried out; separate viewing rooms that can be darkened should be provided. Also, it is desirable to have at least one patient preparation and recovery room for special procedures.

c). Basic protection requirements

The radiation protection of a general purpose X-ray room about 6 X 4 X 3 metres in size requires a wall thickness in all directions equivalent to 2 mm of lead. It is important that the doors, the darkroom hatch, and the covers for services and other intrusions through the wall should be protected by the same thickness of lead. All cracks and flanges around the door should be protected by additional strips of lead. windows, if essential, should be at least 2 m from the ground outside the X-ray room and at least 1.6 m from the floor level inside the room; they should be sited so that scattered radiation does not pass straight through them into other windows nearby.

A control booth must be provided for the protection of the operator, if applicable, for the type of equipment. The control booth, and the viewing window, must have shielding properties such that no operator is occupationally exposed to more than 0.4mSv / week.

d). Choice of protective materials

While lead is always accepted as the standard material for radiation protection, in the range 70-125 kV, 15 cm of concrete or 25 cm of brick with plaster are approximately equivalent to 2 mm of lead.

e). Conversion from existing structures

When X-ray room is being converted from an existing structure some compromise may be possible. For example, if the existing walls are of brick and plaster 13 cm thick, another 1 mm of lead supported by plywood would probably suffice to make up the 2 mm total lead equivalent. A particular problem with old buildings arises where doorways have been blocked up with material of inferior radiation-absorbing qualities (such as coke breeze or a wooden panel) that has been covered with a thin layer of plaster so that it resembles the existing wall surface. Cavities of this nature must be sought out and tested. In case of doubt, they should be covered by additional lead ply or barium plaster. At the junction between materials of different lead equivalents, the overlaps should be at least equal to the maximum thickness of material of either type used.

f). Provision for later expansion

The possibility of subsequently adding another X-ray room and other facilities should be borne in mind during the original planning. Wherever possible, the location of doors and facilities should be such as not to preclude the later addition of a second or third X-ray room in reasonable proximity to the darkroom.

g). Design requirements for operators booth (CMR 220)

- Space Requirements:

1. The booth should be not less than 7.5 square feet ($0.697m^2$) of unobstructed floor.

2. The booth shall be located or constructed such that unattenuated direct scatter radiation originating during examination does not reach the operator's station in the booth.

- Structural Requirements:

1. The booth walls shall be permanently fixed barriers at least 7 feet (2.13m) high.

2. When a door of the booth should have an interlock which will prevent an exposure when the door or panel is not closed.

-X-Ray Control Console Placement:

1. The x-ray control for the system shall be fixed within the booth and Shall be at least 40 inches (1.02m) from any open edge of the booth wall which is nearest to the examining table.

- Viewing System Requirements:

1. Each booth shall have at least one viewing device which will be so placed that the operator can view the patient during any exposure, and

2. The device shall be so placed that the operator can have full view of any occupant of the room and should be so placed that the operator can view any entry into the room. If any door which allows access to the room cannot be seen from the booth, then that door must have an interlock controlling the exposure which will prevent the exposure if the door is not closed.

3. The viewing window shall be at least 1 square foot (0.0929 m^2).

4. The design of the booth shall be such that the operator's expected position when viewing the patient and operating the x-ray system is at least 18 inches (0.457 m) from the edge of the booth.

5. The material constituting the window shall have the same lead equivalence as that required in the booth's wall in which it is mounted.

2.4.2 Quality assurance and control

The Quality Assurance (QA) Program is a program designed to ensure the quality of a product or service. For the completeness of such a program, it must constitute of a wide-ranging aspects; including customer feedback, employee empowerment, and quality control. Therefore, Quality control (QC) involves specific actions designed to keep measurable aspects of the process involved in manufacturing a product or providing a service within specified limits. Examples of QCs are; measurement of a process variable, checking the measured value against a limit, and performing corrective action if the limit is exceeded (Winston, 2001).

In the radiography, quality control play a fundamental role in ensuring that optimal diagnostic images are produced thereby reducing the radiation dose to the staff, patient and members of the public. QC tests are performed periodically depending on the test in question. For the purpose of this study, below is a list of some QC tests in conventional radiography (Winston, 2001; Papp, 2006).

1. Kilovolt peak (KV_p) Accuracy and reproducibility
2. Filtration Check
3. Milli-ampere Second (mAs) and timer linearity and reciprocity
4. Radiation Output Reproducibility

5. Beam alignment test (Light Field-Radiation Congruence)
6. Radiation Leakage
7. Lead Apron Check

2.5 Anatomy and Physiology of the Pelvis

The human pelvis comprises of the skin and the overlying soft tissue, the bony pelvis and the pelvic organs (which are the urinary bladder, reproductive organs and the rectum).

2.5.1 The bony pelvis (pelvic girdle)

The bony pelvis is made up of the innominate bones, the sacrum and the coccyx, bound to each other by dense ligaments. The innominate bones articulate with each other anteriorly at the pubis symphysis and with the sacrum posteriorly. Each innominate bone is composed of the ilium, the ischium and the pubis which fuse at the acetabulum.

The ilium is a flat curved bone and bears the iliac crest superiorly. The anterior and posterior superior iliac spines are on either end of the iliac crest, with the anterior and posterior inferior iliac spines below them. The inner surface of the bone is smooth and has the iliopectineal line running from front to back, demarcating the true from the false pelvis.

The pubic bone consists of a body, and inferior and superior rami. The body of the pubic bone articulates with its fellow at the symphysis pubis. It bears a tubercle on its supero-medial aspect. The articular surfaces of the symphysis pubis are covered in hyaline cartilage with a fibro-cartilaginous disc between them. The pubic bone is strengthened on all sides by dense ligaments.

The ischium is composed of a body and an inferior ramus, which joins the inferior pubic ramus. The body bears a tuberosity inferiorly and a spine posteriorly. The ischial spine defines the greater and lesser sciatic notches above and below. The obturator foramen is bounded by the body and rami of the pubic bone and the body and ramus of the ischial bone.

The sacrum five fused vertebrae comprise this triangular bone, which is curved posteriorly. The anterior part of its upper end is termed the sacral promontory. It articulates with the lumbar spine superiorly and with the coccyx inferiorly. Anteriorly the sacrum has four pairs of sacral foramina, which transmit nerves from the sacral canal. Lateral to these are the lateral masses or alae of the sacrum. (Ryan *et al*., 2004).

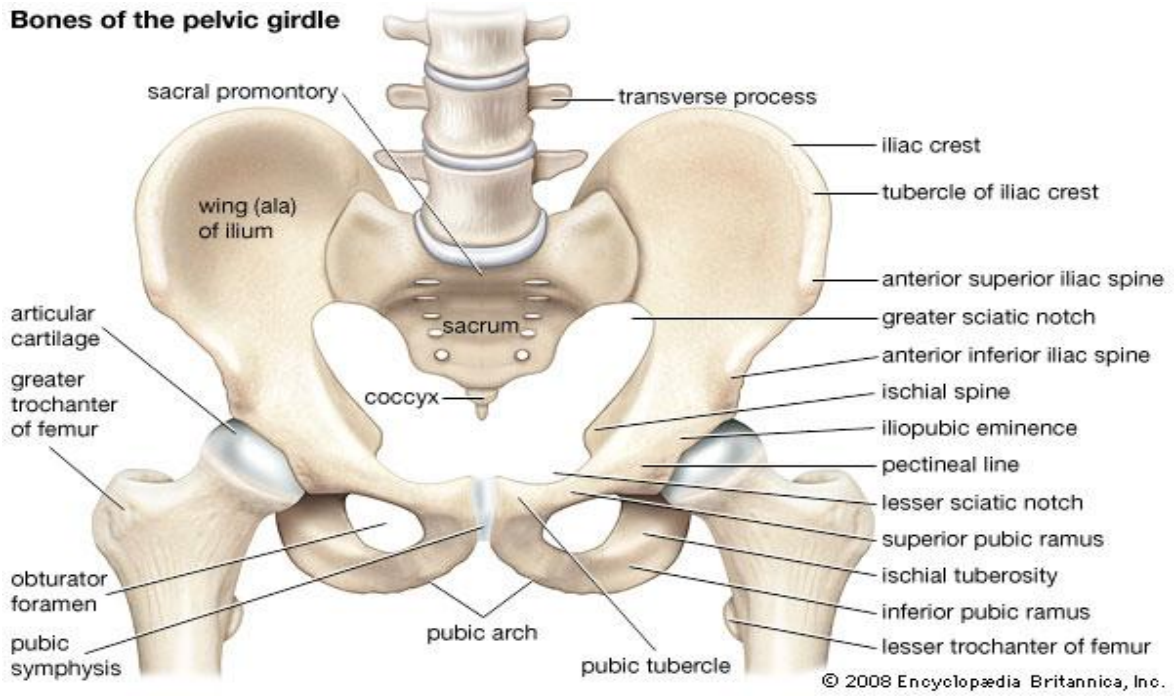


Figure 2.3 shows the Pelvic Girdle (Encyclopædia Britannica Online, 2015)

2.5.2 The female reproductive system

The female reproductive system consists of the female internal and external genitalia and the mammary glands. The internal genitalia consist of the ovaries, the uterus, the uterine tubes and the vagina (Singh, 2009). The female external genitalia include the; the mons, labia majora et minora pudenda, the clitoris, vestibule, vestibular bulb and the greater vestibular glands (Bannister *et al*., 1999). The mons pubis is a fatty hair covered elevation over the symphysis pubis; and two pairs of skin fold, the labia majora and inner labia minora which surround a median cleft, the vestibule, into which the urethra enters and the vaginal orifice posteriorly. Anterior to the urethra is the clitoris, a small sensitive mass of erectile tissue, homologous with the penis attached to the ischiopubic rami. It posseses two small corpora cavernosae and a diminutive glans. In the superficial pouch, alongside the vagina are the bilateral vestibular bulbs lying on the membrane covered by the bulbospongiosus muscles into which drain the greater vestibular glands or bartholins (Abrahams *et al.*, 2005).

The function of the female reproductive system is the production of sex hormones and ova or egg cells which if fertilized are supported and protected until birth (McGuinness, 2002). During all the reproductive years (13 to 46 years) of a female, about 400 to 500 0f the primordial follicles develop enough to monthly expel their ova (Guyton & Hall, 2006).

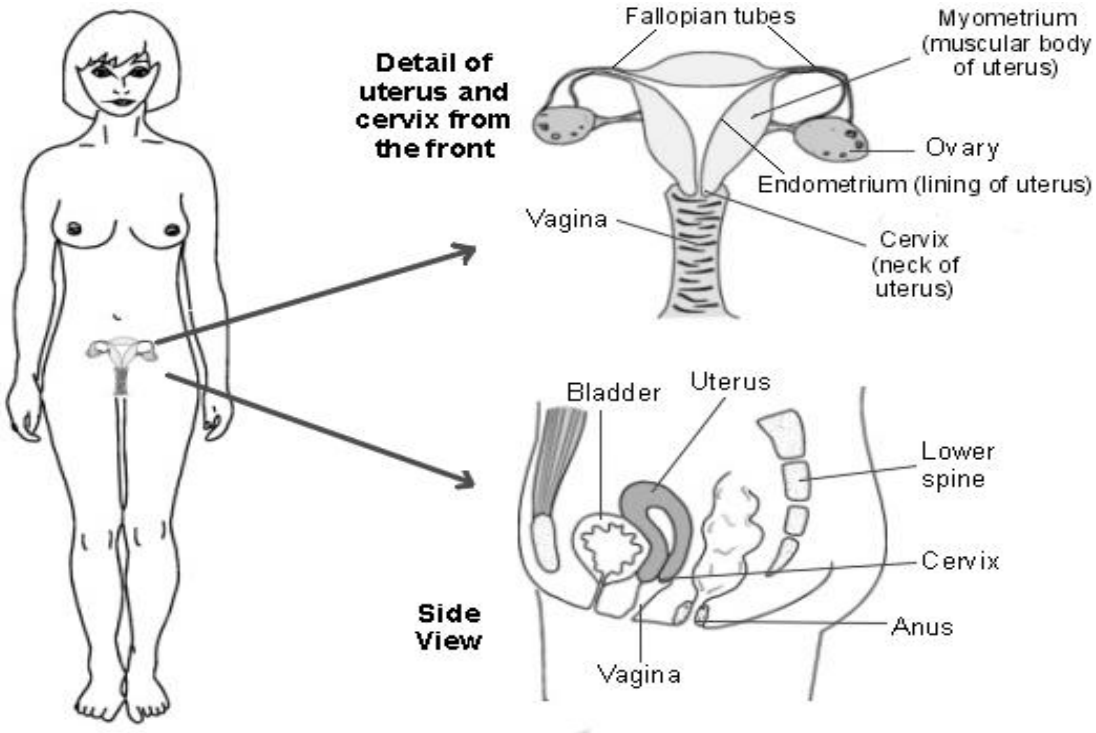


Figure 2.4: Female pelvic organs showing relation to each other (Newson, 2015)

2.5.2.1 The uterus

The uterus is a thick walled, pear shaped hollow muscular organ which is normally situated in the lesser pelvis between the bladder and the rectum. It has a length of 7.5cm, 5cm in its maximum width and about 2.5cm in thickness (antero-posterior). It is about 90 grams in weight. It consists of the fundus, the body and the cervix. The fallopian tubes enter into each supero-lateral angel (the cornu) above which lies the fundus (Abrahams *et al*., 2005; Singh, 2009; Ellis & Mahadeva, 2010).

The body of the uterus narrows to a waist termed the isthmus, continuing into the cervix which is embraced about its middle by the vagina. The pear shaped uterine body gradually narrows from the fundus down to the internal os. It is related anteriorly to the urinary bladder, between the urinary bladder and the uterus is a peritoneal reflection called the uterovesical pouch. The posterior or the intestinal surface of the uterus is

convex transversely. It is related to a peritoneal reflection; the recto-uterine pouch (of Douglas). The cervix of the uterus approximately 2.5cm long in an adult non pregnant woman is divided into supravaginal and vaginal parts (Romanes, 1996; Bannister *et al.*, 1999; Abraham *et al.*, 2005).

The wall of the body of the uterus is made up of three layers; **the perimetrium** – the outer serous layer, **the myometrium** – the middle muscular layer and **the endometrium** – the inner mucous coat. The amount of muscular tissue in the cervix is far greater than that in the body of the uterus which makes it mostly fibrous (Bannister *et al.*, 1999; Moore & Dalley, 1999; Ellis & Mahadeva, 2010). The uterus overlies the posterior part of the superior surface and the upper part of the base of the bladder. Thus, when the bladder is empty, the uterus is tilted forwards (anteversion of the uterus) at right angle to the vagina and to the plane of the superior aperture of the lesser pelvis. Also, the body is slightly bent downwards (anteflexion of the uterus) at the isthmus on the firmer, more fibrous cervix. The body is enclosed between the layers of the broad ligament is freely mobile. Thus as the bladder fills, the uterus is raised and may be forced back till it lies in line with the vagina when the bladder is fully distended; it is then said to be retroverted, and even bent backwards on itself at the isthmus, a condition known as retroflexion (Romanes, 1996).

The uterus is supplied by blood from the uterine and the ovarian arteries; its lymphatic drainage is by the uterine plexus and innervated by the uterovaginal plexus (Moore & Dalley, 1999).

2.5.2.2 The uterine (Fallopian) tubes

The uterine tubes (fallopian tubes) approximately 10cm long extends laterally from the uterine horns and open into the peritoneal cavity near the ovaries. The uterine tubes are

divided into the following arts; the uterine (intramural) part, the isthmus, the ampulla and the infundibulum (fimbriated part)

- The **uterine** (intramural) part; is a short intramural segment that passes through the wall of the uterus. It is about 1cm long
- The **isthmus** (2 – 3 cm) is the thick walled part that enters the uterine horn. It has a lumen that is about 0.1 – 0.5 mm in diameter.
- The **ampulla** is the expanded region of the tube consisting of more than lateral half of its length. It is thin walled with a tortuously folded luminal surface marked by 4 – 5 longitudinal ridges which locate a large number of secondary plicae. The widest luminal diameter is about 1cm.
- The **infundibulum (the fimbriated end)** forms the funnel shaped expansion of the tube. It opens into the peritoneal cavity through the abdominal ostium (the fimbrae), some of which, the ovarian fimbriae are attached to the ovary. Near the time for ovulation, the infundibulum expands medially over the ovary making it possible for the discharged ovum to be easily carried into the tube by the action of the ciliated columnar epithelium covering fimbriae and lining the mucous membrane of the tube (Romanes, 1996; Bannister *et al.,* 1999; Moore & Dalley, 1999).

The uterus is specialised to perform the function of receiving an ovum (or ova) and serves as an area where the foetus grows and develops. After puberty, the uterus undergoes a regular cycle of changes which prepares it to receive, nourish and protect a fertilized ovum. During pregnancy, the walls of the uterus relax to accommodate the growing foetus which if the ovum is not fertilized results in a short period of bleeding at the end of the cycle (McGuinness, 2002). The uterine tube gets its blood supply from branches of the uterine and ovarian vessels (Romanes; 1996).

2.6 Hysterosalpingography, HSG

The technique of HSG by Whitley *et al.* (1999) is described below;

This is an investigation performed to assess the patency of the fallopian or uterine tubes and demonstrate any cause of obstruction and abnormality of the uterine cavity. It therefore involves injecting a contrast agent (radiopaque dye) into the uterine cavity via the cervix with radiographs taken either using a fluoroscopy or conventional xray machine.

Indications: Primary and secondary infertility, recurrent abortions, the assessment of tubal surgery and prior to artificial insemination.

Contraindications: Pregnancy, purulent discharge, recent abortion, dilatation and cauterisation, and unprotected intercourse.

Patient preparation: The investigation is performed during the 10^{th} – 14^{th} day of the menstrual cycle, during which time the uterine mucosa is restored and the cavity is free of cloth and debris. The patient's bladder must be evacuated and care must be taken to reassure nervous patients. Patient privacy and dignity must be ensured at all times.

Imaging procedure: the patient is placed in lithotomy position. Using aseptic procedure a speculum is introduced to dilate the vagina and a cervix adaptor attached. Suction is now applied to seal the uterine cavity. Contrast agent (10 – 20ml) is then administered under fluoroscopic control and radiographs taken. It is important that peritoneal spillage is demonstrated during the examination.



Figure 2.5: Hysterosalpingogram (moondragon.org, n.d.)

2.7 Related Studies

Yousef *et al.* (2014) conducted a study titled; Radiation dose measurements during hysterosalpingography. The objective of the study was to determine and evaluate the radiation dose for females undergoing HSG during the reproductive period. A total of 50 patients was studied from three hospitals, patient dose measurements were performed using unfors dosimeter. Organ dose and effective doses were estimated using National Radiological Protection Board software. The mean patient dose was 20.1 and 28.9 and 13.6 for the three health facilities. The ovaries and uterus have the highest dose compared to other organs.

Khoury *et al.* (2001) conducted a study titled; Patient Dosimetry in Hysterosalpingography. The entrance doses were measured using four thermo-

luminescent dosimeters per patient, attached to anatomical landmarks on the patient's skin. The study was carried out on 25 patients between 21 and 45 years of age who underwent the HSG examinations. The number of exposures performed ranged from 4 to 15 radiographs per patient measured. ESD varied between 4.99 and 36.6mGy, with an average of 12.6mGy. The doses to the ovaries and uterus ranged from 0.80 mGy to 5.8 mGy and 1.10mGy to 8.05 mGy, respectively.

Canevaro *et al.* (2008) conducted a study titled; Radiation Exposure of Patients and Workers during Hysterosalpingography. This work presents dosimetric results from 86 HSG procedures. Patient exposures were measured in terms of kerma-area product (P_{KA}). By using ionization chamber of great area. The obtained P_{KA} values was (706 ± 388) $cGy.cm^2$ (mean).. To evaluate the doses received by the radiologist, thermo-luminescent dosimeters (TLD) calibrated in personal dose equivalent, $H_P(d)$, were employed. TLDs were attached to the forehead, both right and left hands. For hands, $H_P(d)$ values higher than 340µSv were obtained, and for head, higher than 342µSv.

A study by Sulieman *et al.* (2008) titled; Radiation dose optimization and risk estimation to patient and staff during hysterosalpingography. Thirty-seven patients with infertility were examined using two digital X-ray machines. Thermo-luminescent dosimeters (TLD) were used to measure entrance surface dose (ESD) for patients and staff during the procedure. The mean ESD and thyroid surface dose of the patient were 3.60 and 0.17mGy, respectively, while the mean ESD for the staff was 0.18 mGy per procedure. The patient overall risk for cancer and hereditary effects is 24 x 10(-6), while the risk for the staff is negligible. HSG with fluoroscopic technique reduces the surface dose by a factor of 3, without compromising the diagnostic findings''.

Gyekye *et al.* (2012) conducted a study on cancer incidence risks to patients due to hysterosalpingography (HSG) on 120 patients. Air KERMA were measured for patient Dosimetry. PCXMC version 15 was used to estimate the organ and effective doses of the ovary, colon, bladder and uterus. The effective dose to patients was estimated to be 0.20 ± 0.03mSv and 0.06 ± 0.01 mSv for procedures with and without screening respectively.

Perisinakis *et al*. (2003) conducted titled; Radiogenic risk from Hysterosalpingography. The fluoroscopy time, number of radiographs taken and entrance surface dose (ESD) were measured in 78 patients undergoing HSG. Organ dose values per radiograph per minute of fluoroscopy were separately determined using an anthropomorphic phantom and thermo-luminescent dosimeter. The average dose to the female pelvis during the HSG procedure was 2.7 mGy and the effective dose was 1.2 mSv.

Fernandez *et al.* (1996) conducted a study titled; Patient dose in Hysterosalpingography, which measured the imparted dose on 41 patients undergoing HSG. The dosimetric evaluations were carried out by measuring both the dose area product using a transmission ionization chamber and the ESD using TLD. Ovarian dose were calculated and a median value of 4.6 mGy for the whole examination. The median effective dose value was 3.1 mSv with a range of 1.0 – 1.8 mSv.

Buls and Osteaux (2001) conducted a study on patient and staff dose during HSG. The Dose-area product measurements in a group of 34 patients allowed an estimation of the median effective dose (0.83 mSv) and the median dose to the ovaries (1.63 mGy) of the patient per procedure. The dose to the staff was estimated using TLD. The following median entrance surface doses were estimated per procedure: 0.22 mGy to the lens of the eye, 0.15 mGy to the neck at thyroid level and 0.9 mGy to the back of the hand.

Sulieman *et al.* (2011) carried a study titled; Reduction of Radiation Doses to Patients and Staff during Endoscopic Retrograde Cholangiopancreatography (ERCP). The ESD, organ and effective doses were estimated for patients and staff. Fifty-seven patients were studied using thermo-luminescent dosimeters (TLD) to measure ESD at different body sites. Organ and surface dose to specific radiosensitive organs was carried out. The mean ESD, exit and thyroid surface dose were estimated to be 75.6 mGy, 3.22 mGy and 0.80 mGy, respectively. The mean effective dose for both gastroenterologist and assistant is 0.01 mSv. The mean patient effective dose was 4.16 mSv, and the cancer risk per procedure was estimated to be 2×10^{-5}. ERCP with fluoroscopic technique demonstrate improved dose reduction, compared to the conventional radiographic based technique, reducing the surface dose by a factor of 2, without compromising the diagnostic findings. The radiation absorbed doses to the different organs and effective doses are relatively low.

Tamboul *et al*. (2014) carried out a study on the assessment of patient's entrance surface dose (ESD) and the health risk from conventional radiography in daily clinical practice. A total of 191 patients were included in this study. The results showed that mean values for chest, abdomen and limps were 0.31 mGy, 0.05 mGy respectively. And the results obtained in this work, range from (10.3) for lumbo-sacral lat to (0.004) for elbow.

More so, the study of roentgen exposure in diagnostics is a constant obligation everywhere because (a) the higher number of people undergoing roentgen examination and (b) relative high exposure doses during examinations. The use of ionizing radiation in Albania is as follows: about 70% belong to the medical application and 30% to the others, research, agriculture and industrial applications. From the medicine uses 80% belong to the X-ray and 20% radioactive sources. The use of X-ray procedure in

medicine is 85% in diagnostic and 15% in radiotherapy. The amount of exposure dose as well as the collective dose coming up from X-ray in diagnostic is about 75% of total value for above mentioned parameter (Qafmolla & Shehi, 2001).

Calicchia *et al.* (1998) carried out an analysis in Hysterosalpingography. The dosimetric survey was carried out on 35 patients, 22 to 40 years old. The doses were measured with LiF TLD, while an ionization chamber enabled us to the calculate dose area product. Ovaries and uterus doses were calculated with a Monte Carlo program using skin entrance exposure data and some technical parameters of the examination.. The mean dose was 4.5 mGy for the ovaries and 6.2 mGy for the uterus. Following the recommendations of the International Commission on Radiological Protection ICRP, both effective dose equivalent, with a mean value of 2.0 mSv, and effective dose, with a mean value of 1.95 mSv, were estimated.

A study by Weiden and Zijl (1989) compared the radiation dose from conventional HSG and radionuclide HSG. The ovarian radiation dosage during HSG varied from 0.33 using fluoroscopy to 3.74 mGy during radionuclide HSG and increased with both the number of spot films taken and the duration of fluoroscopic exposure. Furthermore, radionuclide HSG delivers an approximately 25 times higher dose of ionizing radiation to the ovaries when compared with conventional HSG.

Nwokorie *et al.* (2011) conducted a study to determine the entrance surface Dose (ESD) among patients who presented for routine radiological examinations using thermo-luminescent dosimeter (TLD) chips placed on averagely built adult [(30 cm) chest width, The ESD measurements are as follows 8.03 mGy for Abdomen, 0.13 mGy for chest AP, 0.69 mGy for chest lateral, 0.5 mGy for cervical spine; AP: 0.38 mGy for cervical spine lateral; 4.75 mGy for hip AP: 12.83 mGy for hip lateral: 5.74mGy for

lumbar spine, AP lumbar spine lateral is 15.15 mGy. 1.38m Gy is for pelvis AP. 2.93mGy for skull AP/PA 1.2mGy for skull lateral, 5.46mGy for thorax AP, while the lateral is 14.90m Gy. The average dose value is 9.28mGy Range 0.13-14.90mGy (Percentage standard error; +/- 1.45). From this studies Radiation doses delivered for routine investigations are generally lower than IAEA reference doses but it does not rule out possibility for stochastic effects.

Al-Kinani and Mohsen (2013) carried out a study on QA tests to measure different parameter such as patient entrance surface dose air kerma ESD, reproducibility of peak tube voltage, linearity of tube current, linearity of exposurevtime, the filtration. The mean (ESD) were measured for different organ using (Dosimax), (Unfors) ionization chamber and dosimeter (TLD). (TLD) reading was higher than average value of ionization chamber because the scattering of radiation in patient body, the scattering coefficient were range between (1.1- 1.05) voltage stability for the machine were tested for three (A, B and C) and found the percentages of voltage ripple to B and C are (3.79) and (4.856) respectively and for machines A was 11.4. The Linearity of current and exposure time exposure were assessed, and found that this relationship is linear machines B and C but not for the machine A.

Shahbazi-Gahrouei (2006) carried a study to measure ESD in Chaharmahal and Bakhtiari hospitals, Iran. Geiger-Muller counter and TLD were used to measure the ESD for four common radiographic views in six hospitals (seven x-ray machines). The ESD was measured on 20 randomly selected patients (male and female) for each X-ray examination. The ESD for the PA and lateral chest X-ray examinations were found to be in the range of 0.22-1.45 and 0.34- 4.90 mGy, respectively. The ESD values for the AP or PA skull and LAT skull were in the range of 2.55-8.45 and 2.85-9.12 mGy, respectively.

Taha *et al.* (2014) assessed the ESD of 500 patients undergoing diagnostic x-ray examinations. The ESD was determined indirectly via measurements and from X-ray output factors. The measurements parameters such as X-ray dose output, back scatter factor, and focus to skin distance and questionnaire physical parameters such as mAs and kV in mathematical model. The mean and standard deviation for entrance skin doses for chest PA, skull AP, abdomen, Cspine, pelvic AP, hand and foot were 0.138 ± 0.04, 2.07 ± 0.12, 2.5 ± 0.140, 0.18 ± 0.11, 5.41 ± 0.33, and 0.102 ± 0.01 mGy, respectively.

Ibrahim *et al.* (2014) carried a study to establish the ESD received by patient during x-ray examination in Federal Medical Centre, Keffi in Nasarawa state, Nigeria. The ESDs for chest radiography, AP/PA (anterior/posterior) were measured. A total of 200 patients presented with age ranging from 15 to 68 years old while the weight and height of these patients ranged from 37.5kg to 98.5kg and 130.0cm to 175cm, respectively. The patent's skin dose were determined using Edmond's formula, which is based on the X-ray tube and the radiographic exposure parameters of kVp, mAS, SSD and the total filtration of the beams. The calculated mean skin dose ranges from 0.013± 0.01mGy to 0.851±0.023mGy. The ESDs measured were found to be lower than the reference level set by the Nigerian Basic Ionizing Radiation Regulation (NBIRR, 2003) standard and other international bodies and does not pose any significant health risk to the patience or the workers.

Osman *et al.* (2010) carried out a study on Radiation Dose Measurements in Routine X ray Examinations. Extensive quality control tests were conducted on the x-ray machines used. ESDs were calculated from patient exposure parameters using DosCal software and the X- ray tube out-put were measured in (mGy/mAs) using Unfors Xi Dosimeter. ESD was calculated according to the following formula;

$$ESD = OP \times \left(\frac{kV}{80}\right)^2 \times mAs \times \left(\frac{100}{FSD}\right)^2 \times BSF. \quad - \quad - \quad - \quad - \quad (2.12)$$

Where (OP) is the output in mGy/ (mAs) of the X-ray tube at 80 kV at a focus distance of 1 m normalized to 10 mA s, (kV) the tube potential,(mA s) the product of the tube current (in mA) and the exposure time(in s), (FSD) the focus-to-skin distance (in cm) and (BSF) the backscatter factor. The mean ESD for the chest, AP abdomen, AP pelvis, thoracic spine AP, lateral lumber spine , anteroposterior lumber spine, lower limb and for the upper limb were; 231±44μGy, 453±29μGy, 567±22μGy, 311±33μGy, 716±39μGy, 611±55μGy, 311±23μGy and 158±57μGy respectively. Data shows asymmetry in distribution. The results of were comparable with previous study in Sudan.

Furthermore, protecting the gonads of children and adults is of particular importance during diagnostic imaging of the pelvis since evidence suggests that -rays could cause direct damage to the gonad which could result in mutation. Dose measurements were calculated on 323 patients (137 (42%) male, 186 (58%) female, ages, 38.56 yr ± 9.0; range 20–68). The Entrance Surface Dose (ESD) was determined by an indirect method, using the patient's anatomical data and exposure parameters utilized for the specific examination. Eighty percent of the hospitals recorded lower ESD values below IAEA recommended diagnostic reference levels (10 mGy) and 40% of the hospitals exceeded the UK national reference value (4 mGy) (Ofori *et al.*, 2012; 2013).

The method adopted in this study involved sketching the x-ray room layout, conducting QC tests and measuring the ESDs of the patient undergoing the HSG and the staff performing such investigation by using TLDs. The advantage of using the TLD is that it

gives a record of all the cumulative exposures of a patient and that of the staff during the examination.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

1. Conventional x-ray machines
    a) Shimadzu Static X-ray Machine: Model 1/2P13DK, manufactured 2008, three phase 12 pulse multi-purpose x-ray machine, Maximum kV_p = 150, Maximum mAs = 500, 1.5mm Al at 70 kV_p.
    b) Siemens Static X-ray machine with Wolverson tube, three phase 12 pulse multi-purpose x-ray machine, Maximum kV_p = 150, Maximum mAs = 500.
    c) Mobile X-ray Machine, Model DM-105N by DONG-A X-ray Co Ltd, Maximum kV_p = 100, Maximum mAs = 100
2. Measuring tape
3. Digital kV_p meter
4. Digital dosimeter
5. Lead apron
6. Pieces of different thickness of Aluminium (1mm each).
7. Adhesive tape
8. Loaded x-ray cassettes
9. Nine metallic coins
10. Thermo-luminescent dosimeters (TLDs)

3.2 Methods

3.2.1 X-Ray room design and layout

The building layout of the radiographic room was sketched using Microsoft publisher 2007 to show the dimension and adjoining structures (such as offices, reception area, x-ray archive etc). The chest stand, x-ray machine and the control console were also shown in the sketch and the distances between them were also measured. The sketch showed the absence of windows, lead wall thickness and also the lead lining on the doors.

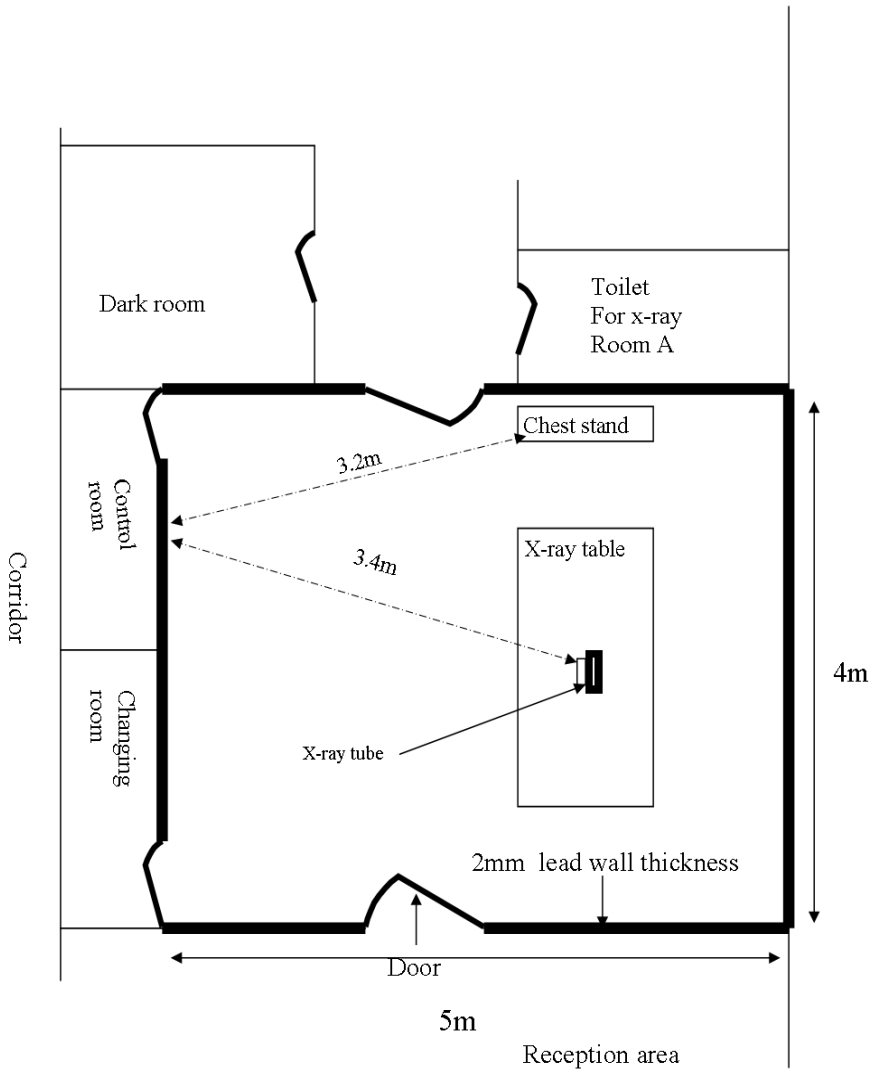


Figure 3.1 : Layout of X-ray room A

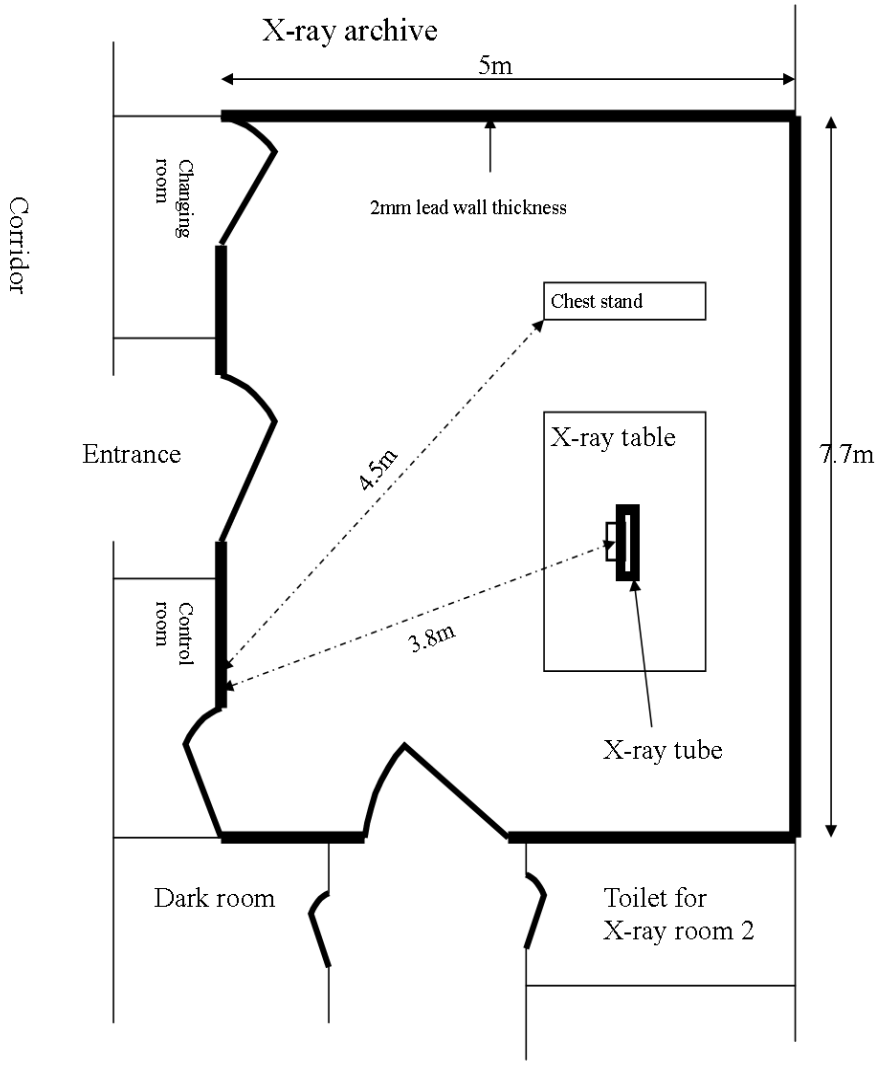


Figure 3.2: Layout of X-ray room B

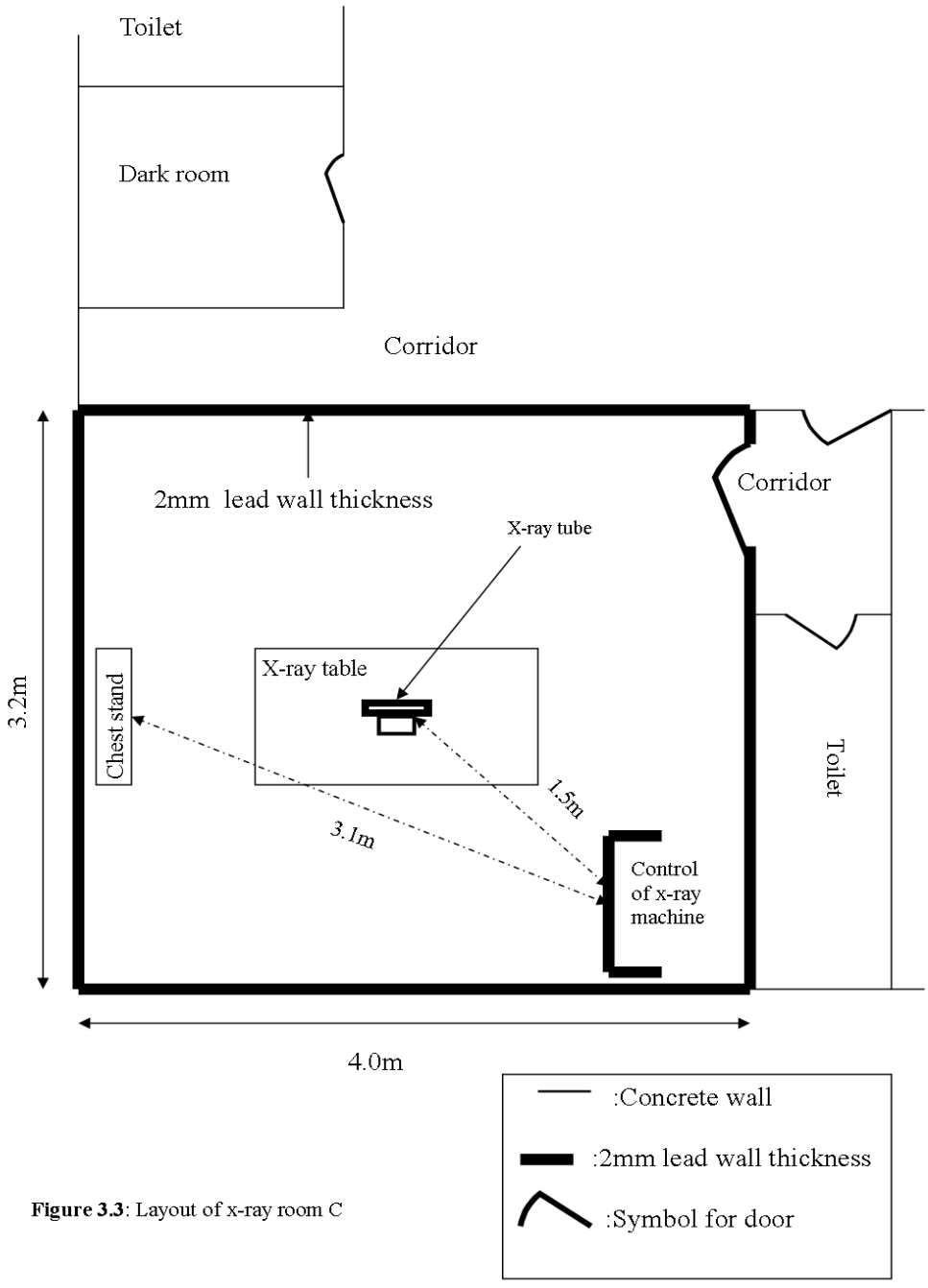


Figure 3.3: Layout of x-ray room C

3.2.2 Quality control tests

The working condition of the x-ray machines were evaluated through quality control tests with quality control kit obtained from Centre for Energy Research and Training (CERT), ABU Zaria. Below is a list of the quality control tests performed.

1. Kilovolt peak (kV_p) accuracy and reproducibility
2. Filtration check (half value layer, HVL)
3. Milli-ampere second (mAs) and exposure timer linearity and reciprocity
4. Radiation output reproducibility
5. Light beam alignment test (light field-radiation congruence)
6. Radiation leakage
7. Lead apron check

3.2.2.1 Kilovolt peak (kV_p) accuracy and reproducibility

3.2.2.1.1 kV_p accuracy

To investigate the variation between the peak voltage (kV_p) set on the control panel with that recorded by the kV_p meter, that is the measured kV_p**;**

1. The digital kV_p meter was placed on the x-ray table
2. Exposures were made on the kV_p meter starting from 50 kV_p with increments of 10 kV_p.
3. The readings displayed on the light emitting diode (LED) of the kV_p meter were recorded.
4. Three different exposures for each kV_p set were made and average taken.
5. The SID/ FFD was maintained at 100cm.

The variations between the kV_p set and the beam quality displayed on the kV_p meter was determined using the equation 3.1;

$$\% \text{ error} = \frac{\text{measured value} - \text{set value}}{\text{set value}} \times 100\% \quad - \quad - \quad - \quad -$$

(3.1)

3.2.2.1.2 kV_p reproducibility

To measure the consistency in the measured kV_p with the set kV_p;

1 The digital kV_p meter was placed on the x-ray table

2 Exposures were made on the digital kV_p meter with the kV_p set at 70kV_p and 20 mAs

3 The readings displayed on the LED of the kV_p meter were recorded.

4 Five different exposures for the set kV_p and mAs were made.

5 The SID/ FFD was maintained at 100cm.

The variation between the measured kV_p was determined using the equation 3.2;

$$kV_p \text{ Reproducibility variance} = \frac{(kVpmax - kVpmin)}{(kVpmax + kVpmin)} \quad - \quad - \quad - \quad -$$

(3.2)

3.2.2.2 Filtration check (HVL investigation)

To determine the half value layer (HVL). This is to ensure that low photon energies which contribute to excess dose are removed. This will ensure that the patient's skin dose is reduced.

1. A dosimeter was placed on the x-ray table on top of a lead apron (to prevent backscatter).

2. The dosimeter-to-tube distance was adjusted between 60 and 80cm, because values from 30 – 100cm show a variation of less than 4.1% (Marco *et al.*, 2007).

3. The dosimeter was placed within the adjusted field size of collimator.

4. Exposures were made with different aluminium thickness (starting from 1mm) at $80kV_p$ and 50mAs and the digital dosimeter readings were recorded per exposure.

5. The different aluminium plates were placed between the collimator and the dosimeter.

6. The procedure was repeated while adding aluminium plates in an increment of 1mm.

7. A graph of x-ray intensity (dosimeter reading) versus absorber mass thickness was plotted.

8. The HVL was determined from the graph by tracing half of the maximum dosimeter reading a line from this point on the Y axis to the curve and then another line from this point on the curve down to the X axis. The value on the X axis represented the HVL.

3.2.2.3 Milliampere second (mAs) and exposure timer linearity and reciprocity

3.2.2.3.1 mAs/ exposure timer linearity

mAs Linearity refers that sequential increase in mAs should produce sequential increase in radiation exposure produced. But since q = it (mAs), therefore it is also a test for the exposure timer. Where **i** and **t** are current and exposure time, respectively.

1. A dosimeter was placed on the lead apron which was on the x-ray table.

2. Three exposures for each mAs selected were made at 100cm FFD with the exposure factors set at $70kV_p$ and mAs of 5, 10. 20 and 40.

3. The dosimeter reading from each exposure was recorded and then divided the set mAs to yield mR per mAs.

4. The minimum, maximum and average readings of the four exposures were determined..

The linearity variance was calculated using the equation 3.3. Linearity is adequate when the value is less than 10% (0.1).

$$\text{Linearity variance} = \frac{\left(\frac{mR}{mAs}\right)max - \left(\frac{mR}{mAs}\right)min}{\left(\frac{mR}{mAs}\right)average} \div 2 \quad - \quad - \quad - \quad - \quad -$$

(3.3)

3.2.2.3.2 mAs and exposure timer reciprocity

Reciprocity refers to the same mAs being selected but with different selections of mA and exposure time (Papp, 2006).

1. A lead apron was placed on the x-ray table.
2. A dosimeter was placed on the lead apron.
3. Three exposures for each mAs selected were made at 80kV$_p$ and 20mAs, the set kV$_p$ remained constant while three different combinations of mA and exposure time were set to yield 20mAs.
4. The dosimeter readings were recorded and the dosimeter was reset after each exposure.
5. The FFD was maintained at 100cm.
6. The dosimeter readings displayed from each exposure were then divided the set mAs to yield mR per mAs.
7. The minimum, maximum and average readings of the five exposures were determined.

The reciprocity variance was calculated using the equation 3.4. The reciprocity variance

should be less than 0.1 (10%).

$$\text{Reciprocity variance} = \frac{(\frac{mR}{mAs})max - (\frac{mR}{mAs})min}{(\frac{mR}{mAs})average} \div 2 \quad - \quad - \quad - \quad - \quad (3.4)$$

3.2.2.4 Radiation output reproducibility

To investigate the x-ray machine out-put production consistency;

1. A lead apron was placed on top of an x-ray table.
2. A dosimeter was placed on the lead apron.
3. The central ray of the x-ray beam was centred to the dosimeter at an FFD of 100cm.
4. A series of five exposures to the digital dosimeter were done using the same machine parameters of 80 kV_p, 100mA and 100ms set at same dimensions.
5. After each exposure before another one was made, the dosimeter of the previous reading was recorded and then the digital dosimeter reset for a fresh exposure.

The equation 3.5 was used to obtain the reproducibility variance. The reproducibility variance should be less than 0.05 (or 5%).

$$\text{Reproducibility variance} = \frac{(mRmax - mRmin)}{(mRmax + mRmin)} \quad - \quad - \quad - \quad - \quad (3.5)$$

3.2.2.5 Beam alignment test (Nine penny test)

To assure that the light field accurately defines the x- ray field;

1. A loaded cassette was placed on the x-ray table at SID/FFD of 100cm.

2. The light field size was adjusted to be smaller than the film (18 x 24cm or 24 x 30cm).

3. Four coins were placed on the inside edge of the light field at the centre of each dimension, and the other four on the outside edge in contact with the inner coins.

4. A ninth coin was placed in the light field towards the cathode end of the x-ray tube to demonstrate on the image the direction of the misalignment.

5. X-ray exposure was made using low exposures (example 65 kV_p, 4 mAs) and x-ray film was developed.

6. The distances between the light (where the coins touch) and x-ray fields for all coin locations were measured.

The light and x-ray field misalignment does not exceed 2% of 100cm in either the length or the width of the film.

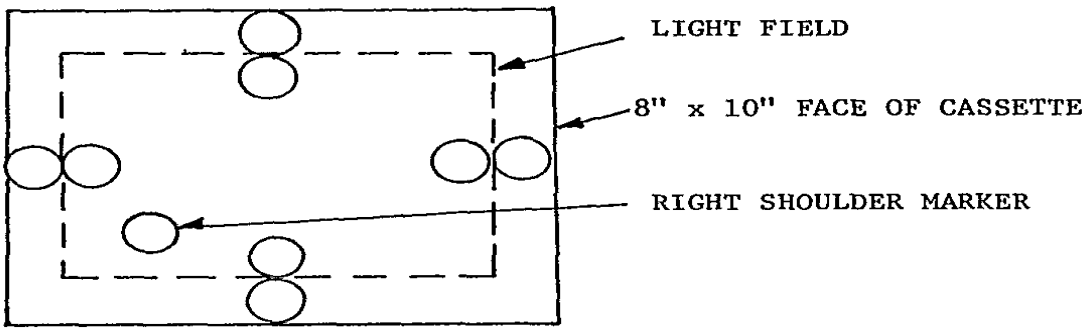


Figure 3.4: Nine penny test (Siedband 1977)

3.2.2 6: Accuracy of source to image distance (SID/FFD) Scale

To assure that the source-to-image distance (SID/FFD) is indicated accurately;

1. Note the indicated SID from the distance indicator.

2. The distance from the focal spot to the cassette was measured.

3. This distance should be within 2% of the indicated SID.

The actual SID should be within 2% of 100cm (2 cm)

Note: If the x-ray machine is not equipped with variable SID, this test need not be completed.

3.2.2.7 Radiation leakage

To determine the level of radiation leakage from the x-ray tube as this leakage radiation will increase the patient and staff doses, respectively.

1. The collimator shutter of the x-ray tube was completely closed and the x-ray tube turned vertically downward position.
2. A dosimeter was placed at 100cm from the x-ray tube and at 4 different sides of the tube to measure leakage radiation.
3. Five exposures were made using 125kV_p and 250mAs.
4. The dosimeter readings for each of the different positions of the dosimeter were recorded.
5. The average of the five readings was determined.

The leakage radiation at 100cm should be 0.1 Rh^{-1} when tube is operated at maximum tube current and potential.

3.2.2.8 Lead apron check

To assess the lead aprons for kinks and cracks to assure that the lead aprons provide optimal shielding required in compliance with radiation protection principles.

1. The lead aprons were closely inspected for kinks and irregularities.
2. Two radiograph of suspected areas were taken.
3. The x-ray film was processed and breaks in the lead lining were checked.

3.2.3 HSG procedure

The data collected during the HSG followed the procedure below;

1. The conventional X-ray machines were set at a focus to film distance FFD of 100cm while the HSG examination was performed.

2. Demographic data (e.g. age) and thickness of the patients for HSG examination were collected.

3. TLDs were used to measure the entrance surface doses, ESD while the patient was lying in supine position. A TLD was placed in the radiation field on the skin surface of a patient within the pelvic region such that the TLD placed did not affect the diagnostic value of the image. The TLD remained in position to capture the entire entrance dose received by the patient during the procedure.

4. The radiologic staff wore a lead apron which protected the trunk but the face and the neck region remained exposed to the radiation.

5. The radiation doses received by the Staff performing the investigation (HSG) was measured using a TLD attached to the shirt collar on the anterior aspect of the neck to capture the entrance surface dose (ESD) to the neck region. Each patient was allocated one TLD for the radiologic staff.

6. Meanwhile, the TLDs used for the HSG examination were calibrated, read and annealed in the Centre for Energy Research and Training CERT Zaria, Nigeria.

Below were the criteria for eligibility of patients for the study

Table 3.1: Selection criteria for the patients that participated in this study

Inclusion criteria	**Exclusion Criteria**
✓ Women of reproductive age, ages	✓ The study excluded all women not

between 15 to 44 years (World Health Organisation, 2013)

- ✓ The study involved only women who were presented for HSG examination.
- ✓ It excluded women who were within the reproductive age.
- ✓ It excluded women who were presented for other examinations.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 X-Ray Machine Specifications

Table 4.1 shows the x-ray machine specifications of the three machines employed in this study. The x-ray machines situated in rooms A and B are static multipurpose units while x-ray machine C is a mobile unit which will produce a lower out with respect to the static multi-purpose units (machines A and B).

Parameter	X-ray units		
	X-ray room A	X-ray room B	X-ray room C
Machine type	Static	Static	Mobile
Manufacturer	Shimadzu	Siemens	DONG-A Xray Co Ltd
Year of manufacture	2008	Unknown	Unknown
Country of manufacture	Japan	Unknown	South korea
TUBE RATING			
Inherent filter	1.5mm Al at 70 kV_p	-	-
Maximum kV_p	150	150	100
Maximum mAs	500	500	100
Common kV_p	65 - 100	70 -95	70 - 90
Common mAs	8 - 32	12 – 30	10 - 20

4.2 Quality Control Test Report

Below are the results of quality control tests conducted on the x-ray machines involved in this study.

Table 4.2 shows area monitoring of the various strategic areas from the x-ray tube when it is operational. Therefore, this refers to the x-rays reaching those places considered. The maximum dose rate was recorded at the control stand in x-ray room C. Areas registered as "no access" were inaccessible for measurements while in areas registered as "not sighted", no reading was registered by the digital dosimeter. However, most of the area monitoring readings are very close to the background radiation which is an indication that there is adequate radiation protection installed. That is, the various areas considered are relatively safe when x-ray machines are operated.

Area	Dose rate (μSv/h)		
	X-ray room A	X-ray room B	X-ray room C
Background	0.12 ± 00	0.12 ± 00	0.13 ± 00
Control stand	0.14 ± 01	0.12 ± 04	2.20 ± 00
X-ray room door	0.11 ± 00	0.13 ± 01	1.30 ± 06
Darkroom	0.10 ± 00	0.10 ± 00	0.10 ± 00
Reception	0.10 ± 00	Not sighted	Not sighted
Archive	Not sighted	0.10 ± 00	Not sighted
Toilet	0.10 ± 00	0.10 ± 00	0.17 ± 00
Behind x-ray room	0.10 ± 00	0.10 ± 00	No access

4.2.1 kV_p accuracy and reproducibility

Table 4.3A shows kV_p accuracy on the Shimadzu x-ray machine in facility I. The machine shows a maximum variation of +7 % at 100 kV_p and minimum variation of +3% at 70 kV_p. A maximum variation of < ±5.00% is accepted. Variation greater than the < ±05.00 will produce is higher radiation exposures than the kV_p selected; thereby increasing the radiation dose to the patient by causing repeat of exposures.

kV_p station	Measured kV_p						
	kV_p meter readings			Mean	SD (σ)	Error (%)	Tolerance (%)
60	64.60	62.80	62.60	63.33	1.10	+ 05.56	< ± 05.00
70	72.20	72.20	71.90	72.10	0.17	+ 03.00	< ± 05.00
80	82.70	82.90	82.90	82.83	0.11	+ 03.54	< ± 05.00
90	95.00	94.90	95.30	95.07	0.21	+ 05.63	< ± 05.00
100	107.50	107.00	108.20	107.57	0.60	+ 07.56	< ± 05.00
Mean kV_p variation or error (%)						+ 05.06	

Table 4.3B shows kV_p reproducibility on Shimadzu x-ray machine. This shows a reproducibility variation of 0.003 which is below the acceptable variation of 2%. Therefore, the machine will produce similar radiation exposure when same factors are selected in the future; this by implication will reduce repeat exposures.

kV_p station	Measured kV_p							
	kV_p meter readings					Mean	SD (σ)	Error (%)
70.00	72.20	72.20	71.90	71.70	71.90	71.98	0.22	0.003
Acceptable Variation or Error (%)								< ± 02.00

Table 4.4A shows the kV_p accuracy on Siemens x-ray machine in facility I. This shows a maximum variation at 60 kV_p and minimum variation at 100 kV_p. Therefore, mean variation is within acceptable limits.

kV_p	Measured kV_p

station	kV_p meter readings			Mean	SD (σ)	Error (%)	Tolerance (%)
60	64.50	64.70	64.80	64.67	0.15	+07.78	< ±05.00
70	71.60	70.60	71.00	71.07	0.50	+01.52	< ±05.00
80	80.50	80.20	79.60	80.10	0.46	+00.13	< ±05.00
90	88.30	88.10	89.80	88.73	0.93	-01.41	< ±05.00
100	101.40	100.30	100.30	100.30	0.64	+00.67	< ±05.00
Mean kV_p variation or error (%)						+01.74	

Table 4.4B shows kV_p reproducibility on Siemens x-ray machine. This shows that the variation of 0.012 % which is within the 2 % acceptable variation or error limits.

kV_p station	Measured kV_p							
	kV_p meter readings					Mean	SD (σ)	Error (%)
70.00	71.60	70.60	71.00	71.60	71.70	71.30	0.48	0.012
Acceptable variation or error (%)								< ±02.00

Table 4.5A shows kV_p accuracy on DM- 105N x-ray machine in facility II. This shows a maximum kV_p variation of 17% at 100 and minimum variation of 4.33% at 60 kV_p. Therefore, mean variation is greater than the minimum acceptable variation or error. This implies that more radiation exposure is emitted than expected at selected kV_ps of 70, 80,90 and 100.

kV_p	Measured kV_p				
Station	kV_p meter readings	Mean	SD (σ)	Error (%)	Tolerance (%)

60	61.90	62.70	63.20	62.60	0.54	+04.33	< ±05.00
70	65.50	65.00	65.20	65.23	0.21	- 06.81	< ±05.00
80	72.00	71.40	71.70	71.70	0.24	- 10.38	< ±05.00
90	78.50	77.90	78.70	78.37	0.34	- 12.93	< ±05.00
100	82.70	83.00	83.00	83.00	0.14	- 17.10	< ±05.00
Mean kV_p variation or error (%)						- 08.58	

Table 4.5B shows the kV_p reproducibility of DM- 105N x-ray machine. The x-ray machine has a reproducibility value of 0.005 which is below the maximum accepted error of < ±02.00. Therefore, the x-ray machine has passed the kV_p reproducibility test; this implies that if a certain kV_p is selected in the future; similar radiation exposure would be produced.

kV_p station	Measured kV_p							
	kV_p meter readings					Mean	SD (σ)	kV_p reproducibility (%)
70.00	65.50	65.00	65.20	65.30	64.90	65.18	0.24	0.005
Acceptable variation or tolerance (%)								< ±02.00

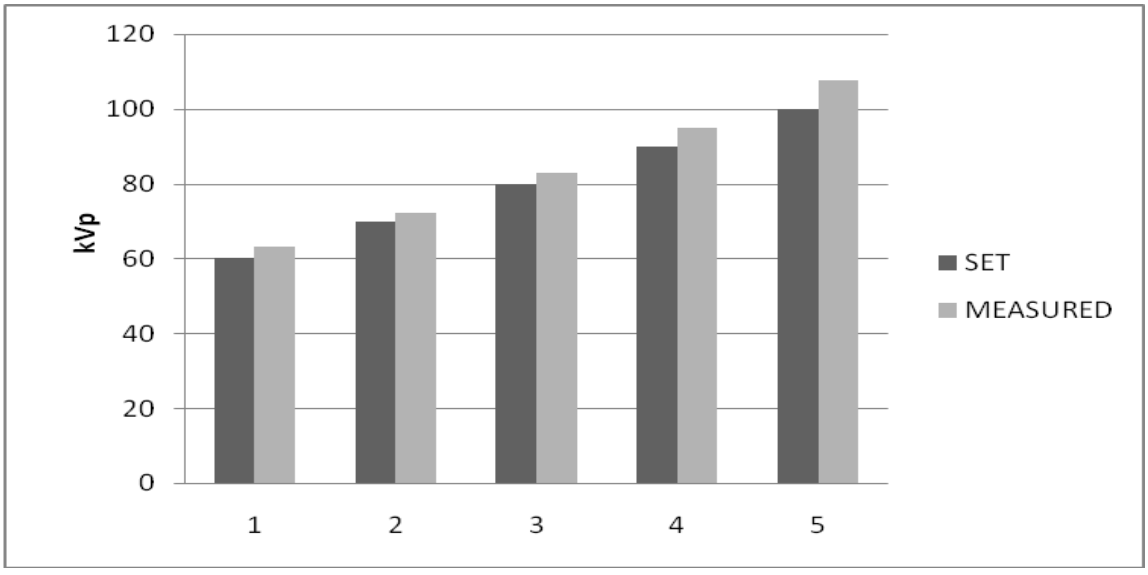


Figure 4.1 shows a comparison between the set kV_p on unit A (Shimadzu) and the kV_p recorded by the kV_p meter afterradiation exposure. The maximum variation is at $100kV_p$.

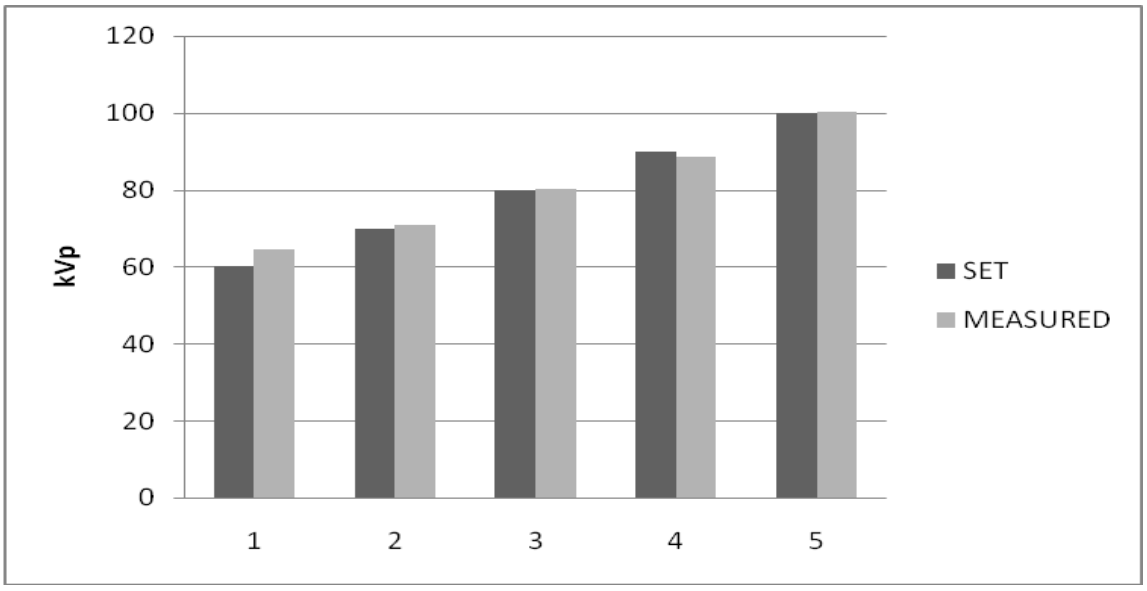


Figure 4.2 shows kV_p a comparison between the set kV_p of x-ray unit B (Siemens) with the kV_p recorded by the kV_p meter. The maximum variation is at the 60 kV_p.

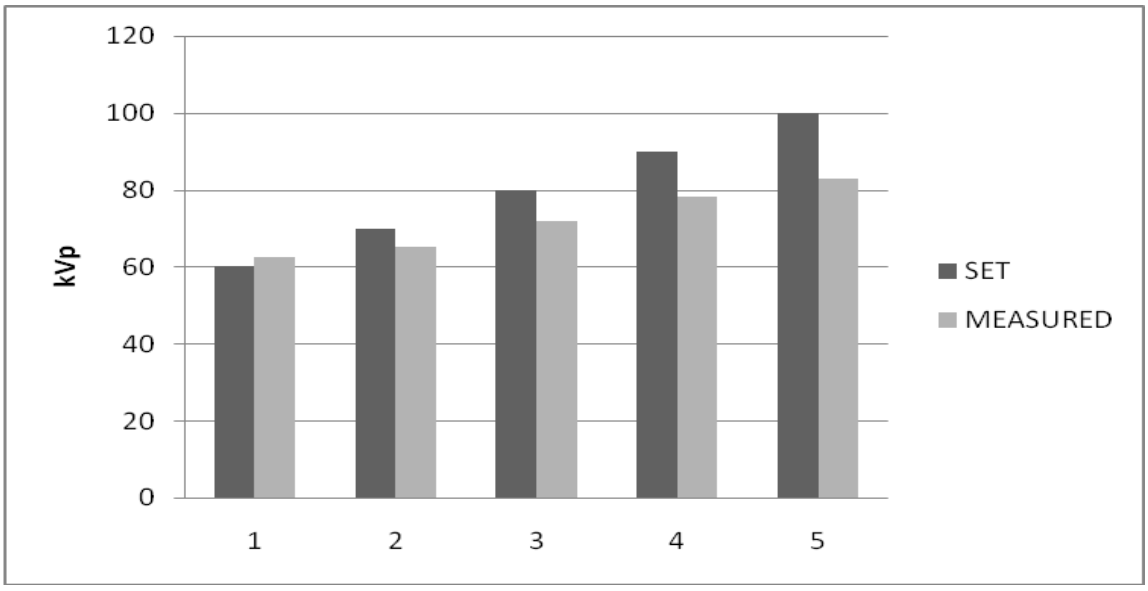


Figure 4.3 shows a comparison between the set kV_p on x-ray unit C (DM-105N) and the kV_p measured the kV_p meter. The maximum variation was recorded at 100 kV_p where the measured kV_p is below 100 kV_p as set on the control panel of the machine. This implies that for a certain kV_p value needed, a higher kV_p has to be set on the machine in order to compensate for the large kV_p drop.

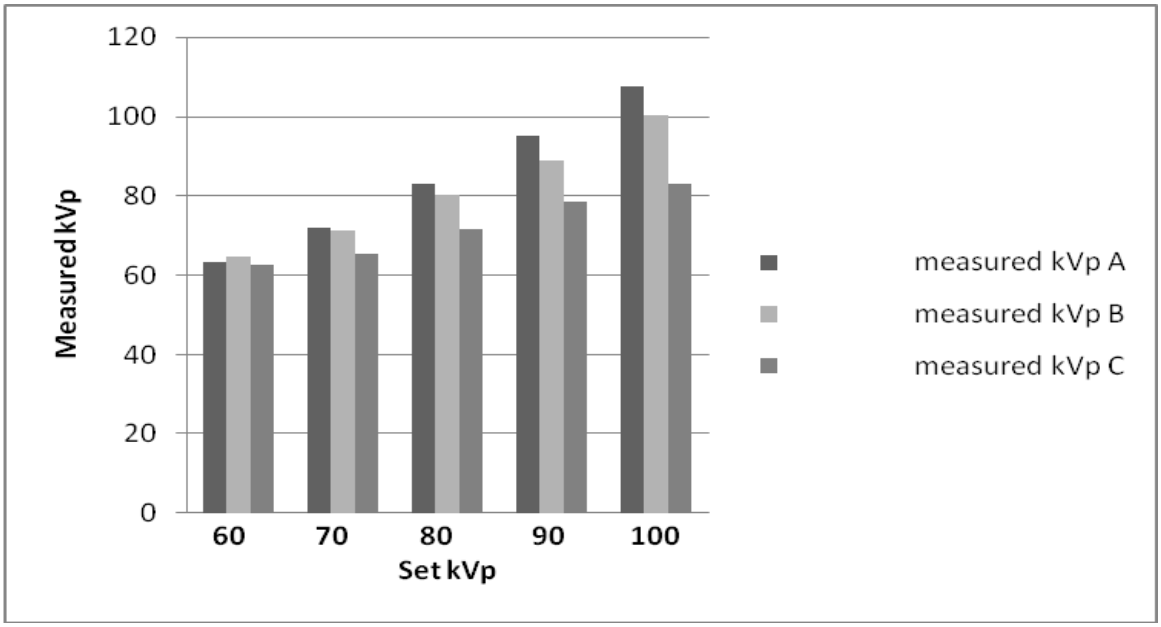


Figure 4.4 shows kV_p variation comparism for the different x-ray machines A – C against the set kVp. mm

Table 4.6 shows comparing the kV_p errors between the different x-ray machines. The highest kV_p error is - 17.10 % by x-ray unit at 100 kV_p while the least kV_p 0.13 % by x-ray unit B.

Set kV_p		60	70	80	90	100
Errors (%)	A	+ 05.56	+ 03.00	+ 03.54	+ 05.63	+ 07.76
	B	+ 07.78	+ 01.52	+ 00.13	- 01.41	+ 01.74
	C	+ 04.33	- 06.80	- 10.38	- 12.93	- 17.10

4.2.2 Filtration and Half Value Layer (HVL)

Table 4.7 shows filtration values for HVL estimation. This shows the various measurements at different thickness of aluminium. The measurements are plotted against the several thickness of aluminium.

Thickness of aluminium (mm)	Mean digital dosimeter readings (R/min)		
	(A) Shimadzu	(B) Siemens	(C) DM- 105N
01.00	0.324	0.533	0.154

02.00	0.257	0.445	0.127
03.00	0.205	0.388	0.102
04.00	0.169	0.334	0.083
05.00	0.150	0.299	-

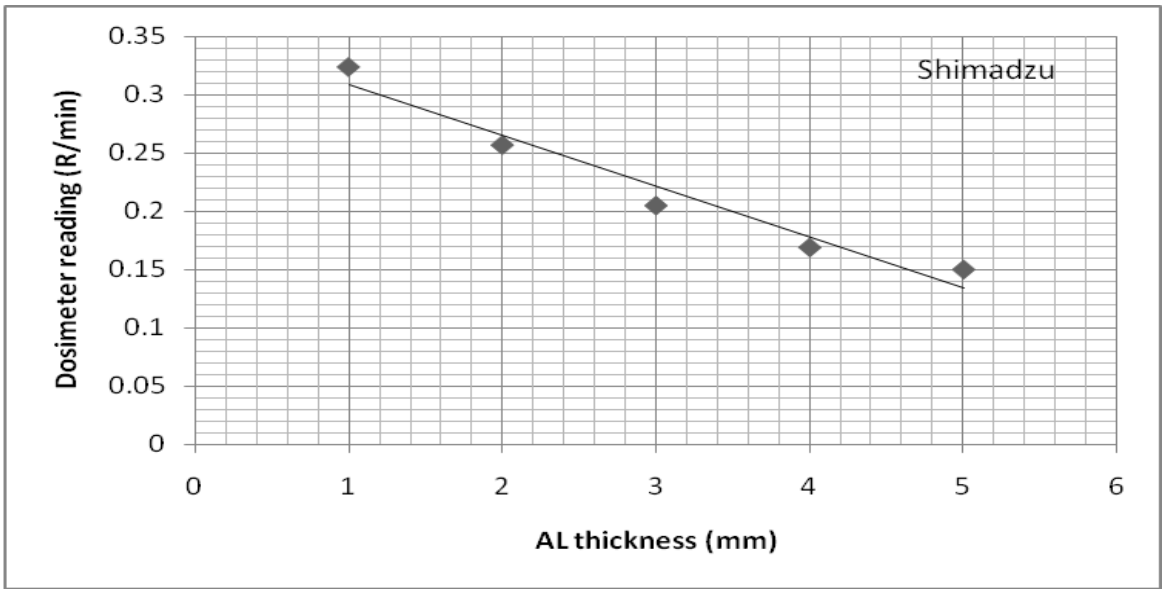


Figure 4.5 shows HVL graph for Shimadzu (x-ray unit A) and this shows a HVL of about 4.4mm at 80 kV_p. This means that the tube has passed the minimum recommended HVL of 2.3mm at 80 kV_p. Therefore the machine filters out the soft x-rays adequately.

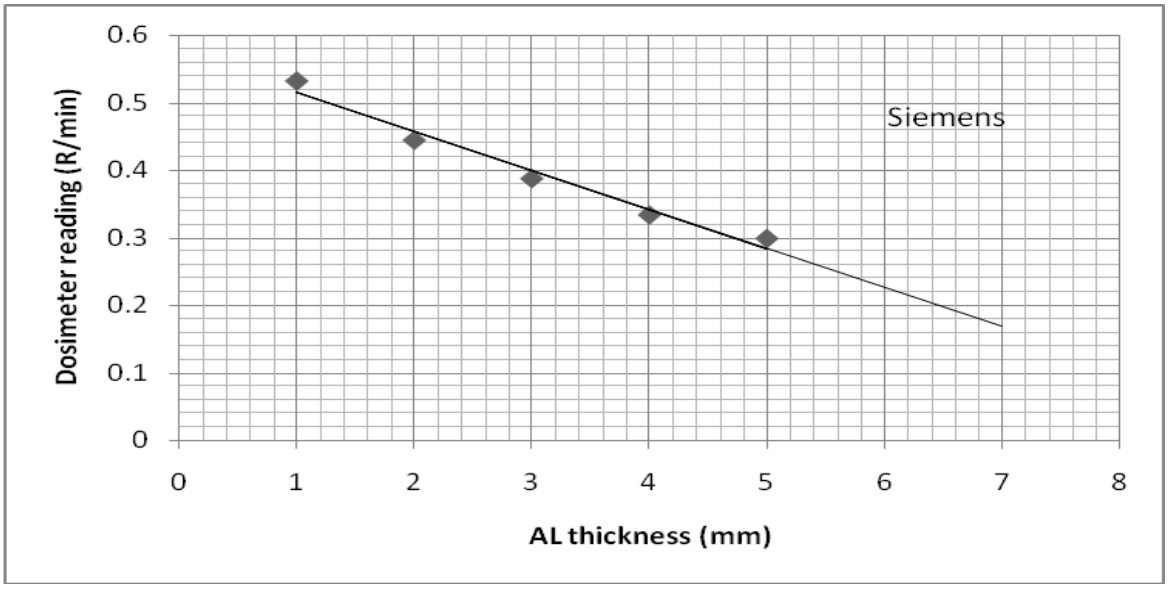


Figure 4.6 shows HVL graph for Siemens (x-ray unit B). This shows a HVL of about 5mm at 80 kV_p. This means that the tube has passed the minimum recommended HVL.

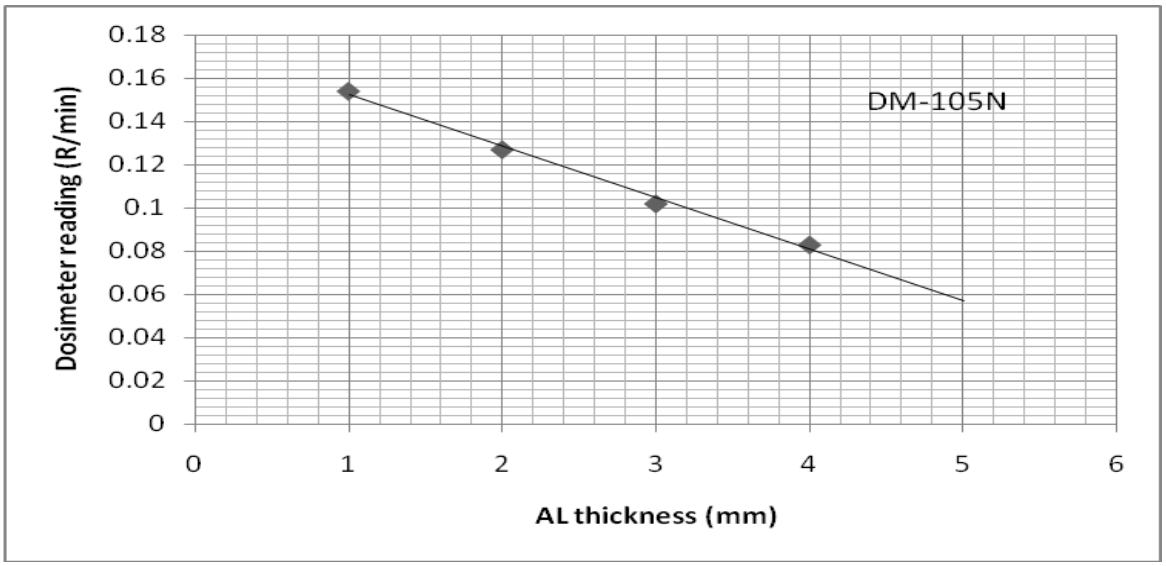


Figure 4.7 shows HVL graph for DM-105N (x-ray unit C). This shows that a HVL value of about 4mm at 80 kV_p. This means that the tube has passed the minimum recommended HVL.

4.2.3 mAs / timer linearity and reciprocity

Table 4.8 shows mAs / timer linearity for Shimadzu x-ray machine. he variations are within acceptable limits.

mAs linearity of Shimadzu x-ray machine

	Exposure (mR)				
Exposure factors	1st	2nd	3rd	Mean	$\frac{mR}{mAs}$
200mA,20mAs,70kV_p	0.111	0.110	0.110	0.110	0.0055
400mA,40mAs,70kV_p	0.224	0.225	0.224	0.224	0.0056
Linearity variance or error (%): 0.0045					
Acceptable error (%): < 0.1 (10%)					

Table 4.9 shows mAs linearity for Siemens. The mAs linearity is within acceptable limits.

mAs linearity of Siemens x-ray machine					
	Exposure (mR)				
Exposure factors	1st	2nd	3rd	Mean	$\frac{mR}{mAs}$
80mA,40mAs,70kV_p	0.0034	0.0035	0.0035	0.0035	0.141
160mA,80mAs,70kV_p	0.0026	0.0025	0.0026	0.0026	0.210
Linearity variance or error (%): 0.074					
Acceptable error (%): < 0.1 (10%)					

.**Table 4.10**shows mAs reciprocity of Shimadzu x-ray machine

mAs reciprocity of Shimadzu x-ray machine					
	Exposure (mR)				
Exposure factors	1st	2nd	3rd	Mean	$\frac{mR}{mAs}$
160mA,125ms,80kV_p	0.146	0.145	0.145	0.145	0.00725
200mA,100ms,80kV_p	0.137	0.137	0.136	0.137	0.00685
400mA,50ms,80kV_p	0.147	0.147	0.147	0.147	0.00735

Reciprocity variance or error (%): 0.0166

Acceptable error (%): < 0.1 (10%)

Table 4.11 shows mAs reciprocity of Siemens x-ray machine

mAs reciprocity of Siemens x-ray machine					
	Exposure (mR)				
Exposure factors	1st	2nd	3rd	Mean	$\frac{mR}{mAs}$
20mA,0.70ms,80kV$_p$	0.010	0.009	0.011	0.010	0.0007
40mA,0.33ms,80kV$_p$	0.091	0.090	0.090	0.090	0.0064
80mA, 0.18ms,80kV$_p$	0.298	0.300	0.300	0.300	0.0214
Reciprocity variance or error (%): 0.36					
Acceptable error (%): < 0.1 (10%)					

4.2.4 Radiation output reproducibility

Table 4.12 shows radiation output reproducibility test, this shows that all the three x-ray machines have a radiation out reproducibility values within the acceptable limits. The Siemens shows higher variation of 0.037 followed by DM-105N with 0.013.

Dosimeter reading (R/min)			
Shimadzu	Siemens	DM-105N	Exposure factors
0.140	0.155	0.038	kV$_p$: 80
0.139	0.144	0.038	mA: 100
0.141	0.155	0.037	Time(s): 0.2
0.140	0.149	0.037	mAs: 20

	0.140	0.152	0.037
Variance or error (%):	0.007	0.037	0.013
Acceptable error: <0.05 (5%)			

4.2.5 Beam misalignment test

Table 4.13 shows light field and the radiation beam misalignment. The Siemens machine has the highest value of 0.6 cm length while DM-105N has 0.5 cm in width. Meanwhile, all the three x-ray machines passed the test as the misalignment is within the acceptable limits in both length and width of the radiation field.

	Misalignment		
	Length (cm)	Width (cm)	Direction
Shimadzu	0.1	0.4	Away from the cathode (-)
Siemens	0.6	0.1	Towards the cathode (-)
DM-105N	0.3	0.5	Away from the cathode (-)
Acceptable misalignment: < 2cm (2% of 100cm) in length and width			

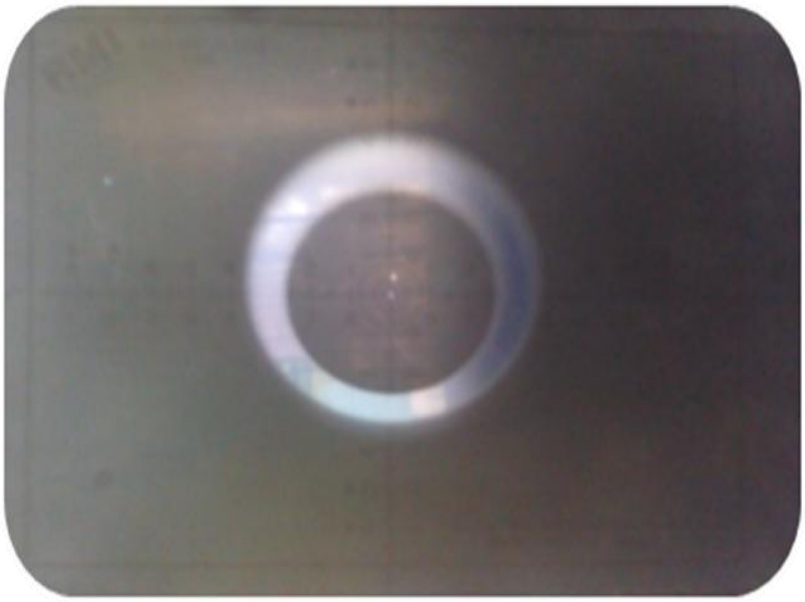


Figure 4.8 shows SHIMADZU light field – radiation misalignment, the displacements are 0.1 cm and 0.4 cm in length and width respectively.

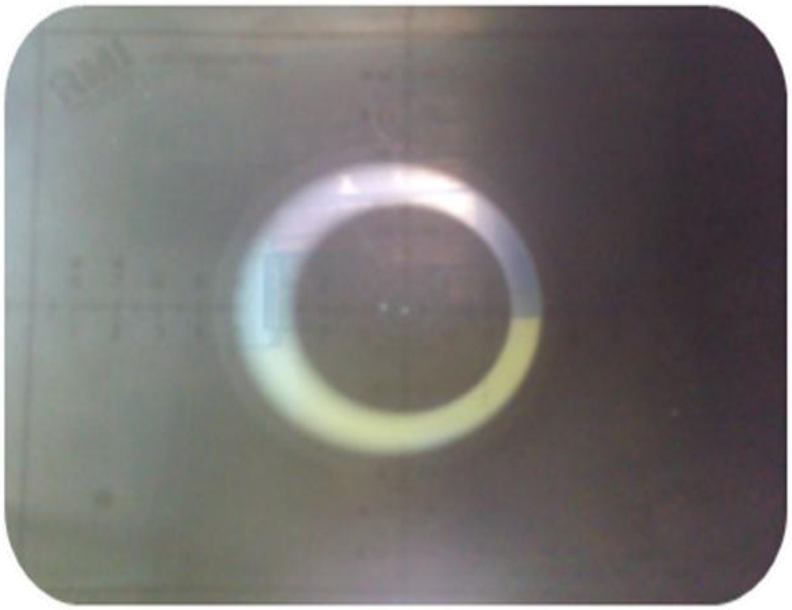


Figure 4.9 shows SIEMENS light field – radiation misalignment, the displacements are 0.6 cm and 0.1 cm in length and width respectively.

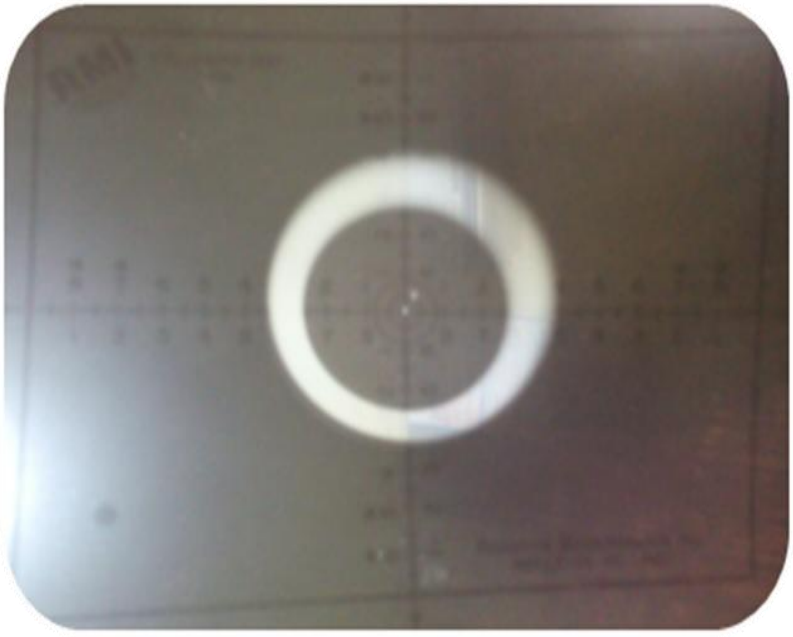


Figure 4.10 shows DM-105N light field – radiation misalignment, the displacements are 0.3 cm and 0.5 cm in length and width respectively.

4.2.6 Radiation leakage

Table 4.14 shows the radiation leakages from all the x-ray machines in the study, the values obtained are below the maximum acceptable value of < 0.1 R/h at100cm. The DM-105N has the highest leakage value as shown below.

Radiation leakage	
	Dosimeter reading (R/min)
DM-105N	0.004
Shimadzu	0.001
Siemens	0.002
Acceptable leakage	< 0.1 R/h

4.2.7 Lead apron test

Table 4.15 e shows that all the lead aprons in facility A are in very good condition while 2 lead aprons in facility B have cracks. The lead aprons are worn by the radiologic staff that performs such procedure, if such damaged the lead aprons are used; it will result in more radiation dose to the staff.

Lead apron test		
	Facility 1	Facility 2
Lead aprons without cracks	4	7
Lead aprons with cracks	0	2
Total	4	9

4.3 HSG Procedure

Table 4.16 shows frequency distribution table according to age showing the exposure factors used during HSG procedure.

Age	Frequency	Mean patients	kV_p	mAs	Mean	Mean

(Years)		thickness (cm)	range	range	kV_p	mAs
20 – 24	10	20.75	83 - 90	22 - 25	87.0	21.8
25 – 29	09	20.67	80 - 85	20	83.3	20.0
30 – 34	11	20.40	85 - 98	20 - 25	89.0	22.0
35 – 39	08	25.00	87 - 90	20 - 25	88.9	23.5
Total	38					

Table 4.17 shows frequency distribution table showing the mean ESD to the patients and the staff who performed the procedure

Age (Years)	Frequency	Mean patient ESD (mGy)	Mean staff ESD (mGy)
20 – 24	10	9.18	0.11
25 – 29	09	14.03	0.18
30 – 34	11	9.00	0.11
35 – 39	08	11.3	0.09
Mean ESD		10.88	0.12

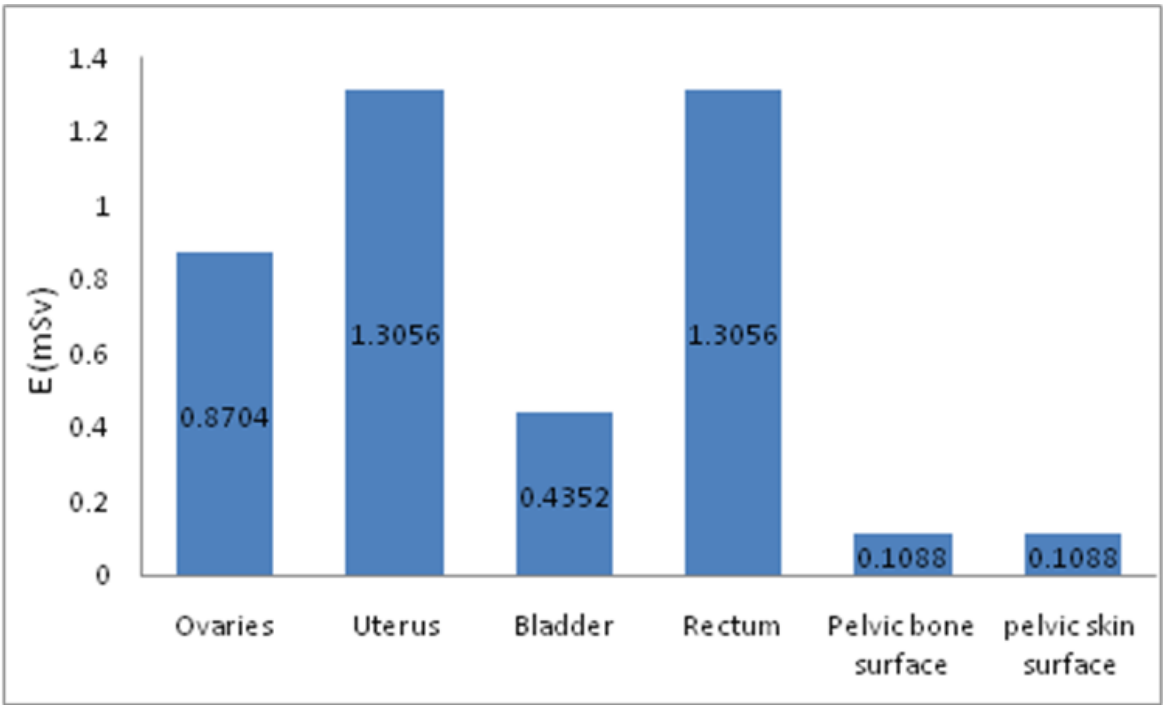


Figure 4.11 shows the effective doses to the various pelvic organs of the patient. The rectum and the uterus have the modal radiation risks (1.31mSv) followed by the ovaries (0.87mSv).

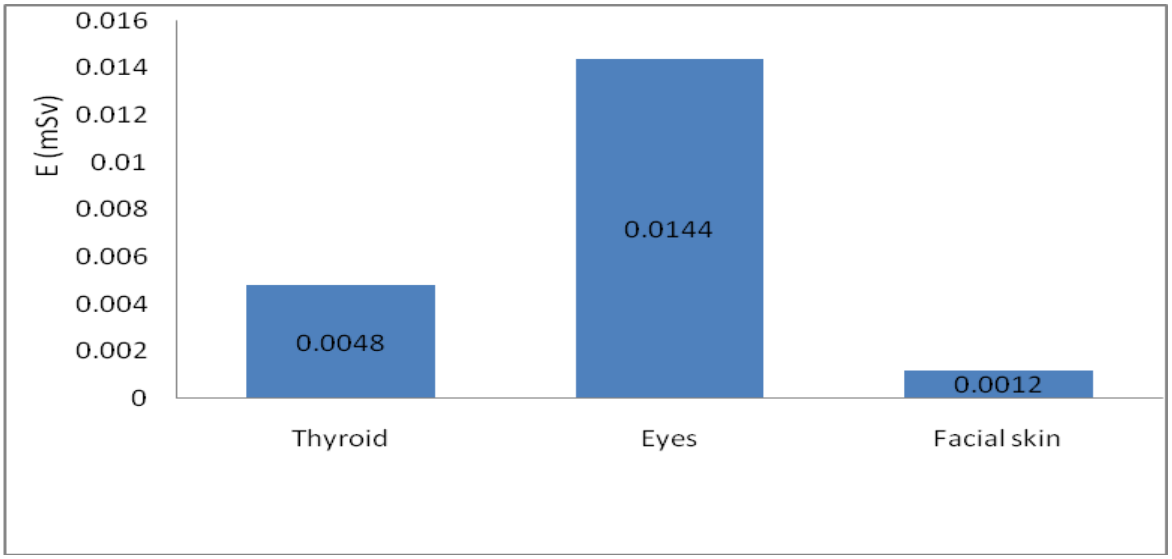


Figure 4.12 shows the effective doses received by staff per HSG procedure. It shows that the eyes have the highest radiation risk followed by the thyroid. The tissue weighting factors used for the calculating the effective dose where according to ICRP 103.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The quality assurance and control tests showed that all the three x-ray machines in the study are in good condition, this is because the x-ray machines have passed most of the acceptable requirements. Also, the mean ESD to the patients' pelvis is 10.88mGy while to staff (the anterior surface of the neck) is 0.12mGy. The total exposed films used were between 4 to 6 films, this implies that the patients' ESD per film is 1.8 to 2.8mGy which is below the IAEA diagnostic reference level of 10mGy for Antero-posterior (AP) projection of the patients' pelvis. The radiation risks to the patient are; ovary (0.87mSv), uterus (1.31mSv), bladder (0.44mSv), rectum (1.31mSv), pelvic bone surface (0.11mSv) and pelvic skin surface (0.11mSv).And to the staff are; thyroid (4.8µSv), eyes (14.4µSv) and facial skin (1.2µSv) which are lower than the occupational dose by ICRP 103. Even though these values seem low, there is need for more optimization of the procedure through proper choice of exposure factors, proper radiation beam collimation and reducing the number of films or exposures made without detriment to image quality and patient care. The result of this study is not un-associated with the quality of staff as there are qualified radiologists, radiographers and x-ray technicians in the various diagnostic facilities.

5.2 Recommendations

- Further studies should be conducted on the quality control of image processor and x-ray cassettes. This is because some repeat patient exposures may result from faults associated with the image processor and/or the x-ray cassettes

- There is need to replace the light beam diaphragm of the x-ray machines with ones that have measuring tape for proper FFD measurement.

- The lead aprons with cracks should be discarded and the periodic quality control tests are advised.

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APPENDIX 1

X-Ray Room Design and Layout

The table below shows the x-ray room layout parameters for the various x-ray units involved in this study

Layout parameter	x-ray facility		
	A	B	C
X-RAY ROOM			
Location	Bungalow	Bungalow	Bungalow
Dimension	20.0m^2	38.5m^2	12.8m^2
WALL			
Type	Cement block	Cement block	Cement block
Thickness	0.27m	0.27m	0.27m
Lead thickness (mm)	2.0	2.0	2.0
Lead lining height (m)	3.3	3.3	2.8
DOOR			
Number	2.0	2.0	1.0
Type	Wooden board	Wooden board	Wooden board
Dimension (m^2)	1.2 x 2.1	0.8 x 2.1	0.8 x 2.1
Lead lining	Yes	Yes	Yes
Lead thickness (mm)	2.0	2.0	2.0
CEILING			
Type	Wooden board	Wooden board	Concrete
Height from the floor (m)	3.3	3.3	2.8
WINDOW			
Number	None	None	None
DISTANCES			
Operator – tube (m)	3.4	3.8	1.5
Operator – chest stand(m)	3.2	4.5	3.1
CONTROL CUBICLE			
Type	Concrete	Concrete	Leaded screen