INTENSITY OF SECONDARY SCATTERED X-RAYS DURING X-RAY DIAGNOSTIC PROCEDURES IN SELECTED DIAGNOSTIC CENTRES IN UGANDA

BY
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DECLARATION

I, Bonaventure Byaruhanga, do hereby declare that this dissertation entitled “Intensity of Secondary Scattered X-rays during X-ray Diagnostic Procedures in Selected Diagnostic Centres in Uganda” is my original work and has not been submitted to any University or Institution for an academic award.

Signed:....................................

Date: 31/01/2014

APPROVAL

This is to certify that this research entitled "Intensity of Secondary Scattered X-rays during X-ray Diagnostic Procedures in Selected Diagnostic Centres in Uganda" was carried out under our supervision. The report is now ready for submission to the Graduate School and the Senate of Kyambogo University with our due approval.

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Date: February 4th 2014

DEDICATION

To my dear parents, Mr. Bibutsohoze Barnabas and Mrs. Katalina Nyiramahane (RIP).

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I sincerely thank the Almighty God for enabling me to undertake this study and successfully complete the work.

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ABSTRACT

The purpose of the study was to investigate the intensity of secondary scattered X-rays when different body regions; the chest, the abdomen and the lower limbs were exposed to X-rays during radiography.

The study used experimental design where the secondary scattered X-ray dose from three diagnostic centres in South Western Uganda were measured using TLDs that were worn at the back of the radiographer. The cards were then read monthly and the process repeated for a period of six months. The number of patients exposed to X-rays for each procedure for the same period was also noted.

From the study, it was found that the limb exposures constituted the highest proportion of the patients X-rayed (42%), followed by the chest (35%) and finally the abdomen (23%). In addition, it was found that the chest exposures generally lead to the highest intensity of secondary scattered X-rays to the radiographers which was 2,670 mSv, 2,756 mSv and 2,505 mSv for Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre respectively. The limbs contributed the second highest intensity of secondary scattered X-rays (2,442 mSv) at Mutolere Hospital, though generally the abdomen contributed the second highest secondary scattered X-rays (1,712 and 1,294 mSv for Goodwill and Mbarara Diagnostic Centre respectively). The limbs contributed the lowest intensity of secondary scattered X-rays in Goodwill and Mbarara Diagnostic Centre i.e 1,578 and 1,236 mSv respectively.

In relation to the safety standards set by the International Atomic Energy Agency (IAEA, 2002), the predicted cumulative annual dose to radiographers from Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre are 13,704, 11,964 and 10,692 mSv respectively. These values are below the annual dose limit of 20 mSv for radiation worker as recommended by IAEA (IAEA, 2002). This means that the radiographers from the three diagnostic centres are at a low risk of developing stochastic health effects. However, the annual dose from the diagnostic centres could be dangerous if radiographers are exposed over many years in a lifetime.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

X-rays are a part of the electromagnetic spectrum occupying a narrow band between ultra-violet waves and gamma rays. They have very short wavelengths ranging approximately between 10^{-11} m and 10^{-8} m (Crawford, 2001) and hence have a high energy. This property of short wavelength enables X-rays to penetrate matter to a high degree. They can pass through a thin sheet of metal depending on the X-ray energy and the density of the metal. For example X-rays generated by 75 kV tube voltage can penetrate aluminium of thickness 1 mm and can be stopped by lead of thickness 1 mm (Victor, 1985; Avison, 1983).

X-rays were discovered by Roentgen in 1896 (Sternhem, 1991) when he noticed that an unknown radiation was produced when fast moving electrons were generated thermionically in discharge tubes and then decelerated by matter. Further studies showed that the production of X-rays requires the following: a hot cathode for production of electrons, a high voltage for accelerating the electrons at a high speed and a target for the accelerated electrons to interact with. In modern technology, X-rays are produced by directing a stream of high energy electrons at a target material such as tungsten, with a high atomic number. When the electrons are slowed or stopped by the interaction with the atomic particles of the target, X-rays are produced. High atomic number metals such as tungsten are used as the target to avoid melting of the target due to the excess heat generated by the impact of the electrons on the target (Fuller, 1985).

X-rays differ from other electromagnetic waves such as radio-waves and infra-red not only in terms of their high penetrating power but also in their ability to ionize. They have enough energy to eject tightly bound electrons from atoms leading to formation of ions. Non-ionizing radiation such as radio-waves and infra-red have low energy which only causes atoms to vibrate but do not remove electrons from atoms (Sowby, 1985; Jerrold, 2002).

Owing to their high penetrating power, X-rays are used for scanning luggage and cargo at the airports. The X-ray scan helps in checking for the presence of objects such as weapons and drugs. Scanning luggage is called backscatter. Originally magnetic fields were used for scanning luggage but these would only detect metallic objects (Sprawls, 2002). X-rays replaced the use of magnetic fields because all details of all objects in luggage could be established using X-rays. The energy of X-rays can be varied so that they can pass through all luggages and an image formed on a screen showing details of all objects in the luggage. In industry, X-rays are used to detect structural problems like cracks and flaws in welded joints (Sprawls, 2002).

X-rays also have the ability to penetrate the human body and this is the reason they are used in radiography. In radiography X-rays make it possible for one to examine internal body structures due to the fact that X-rays can penetrate matter to a reasonable extent. The thickness or depth of the body penetrated depends on the X-ray energy and the region of the body irradiated. The range of penetration of the human body by X-rays also depends on the density of the organs irradiated. (Wen, 1974; Kurtus, 2008). The greater the density of the tissues, the less the penetration by the less energetic X-rays. This is because for higher density materials there is a high atomic number and hence there are many electron transitions that occur as the photons impart their energy in the material (Bennet, 1983).

The use of X-rays in diagnostic medical procedures is as old as the discovery of the X-rays (Sternhem, 1991). The use of X-rays to study the internal body structures started before the end of 1895, barely a year after their discovery by Roentgen. During the First World War, X-rays were used for locating bullets in the soldiers' bodies without carrying out an operation (Shapiro, 2002; Walter, 2004). Today, X-rays are widely used in medicine for examining broken bones, and detecting and killing some cancerous cell growths (radiotherapy).

During medical procedures that use X-rays, a collimated beam of X-rays is directed to the target area of the body. X-ray pictures of organs in the affected areas are then taken for analysis and subsequent medical management (Pattison, 1999). In this case, low intensity X-rays are used and the radiation hazard to the patient is minimal (Moores, 1989).

Though widely used in medicine, X-rays have associated health effects. As early as 1920, cases of cancer were reported among people that were continuously exposed to X-rays (Hendee, *et al,* 2005). Other cases of radiation induced sicknesses were reported by Robert Johnstone in a database collected from various countries right from 1930's. The health effects of X-rays are discussed in Sections 1.1.2 and 1.1.4. Radiologists and radiographers are protected from the effects of X-rays by using a lead shield and lead aprons to reduce on absorption of X-rays into their bodies since they are frequently exposed to the X-ray radiation (Blettner, 2005).

In hospitals, X-rays are produced from X-ray machines or X-ray generators. The properties of X-ray beam produced in this case can be described in terms of beam quality and beam intensity. Beam quality is the ability of the beam to penetrate an object. It is controlled by the voltage applied to the X-ray machine or kilo voltage peak (kVp) control. A high quality beam is generated by a high X-ray generator voltage. The 125 kV peak voltage across X-ray generator produces X-rays that can penetrate 1,5 mm thickness of lead (Avison, 1983).

Beam intensity is the number of X-ray photons in the beam and is controlled by the current through the filament of the X-ray tube. Beam intensity reaching the patient is also controlled by filtering. In this case unwanted weak X-rays are eliminated using a filter. Filtering of X-rays means passing the X-rays through a material that absorbs X-rays of low frequency and allows X-rays of high frequency to pass (Hendee, *et al*, 2005).

Although the beam is filtered and collimated, X-rays are attenuated by the human body leading to scattering as they interact with the body of the patient. Scattering in X-ray rooms is characterized as primary and secondary scattering. Primary scattering occurs when the primary beam of X-rays interacts with the body of a patient. Secondary scattering occurs when the primary scattered photons interact with other objects in the X-ray room such as walls, roof and furniture. The theory of scattering is discussed in details in Chapter 2.
Secondary scattered X-rays constitute the radiation exposure to the radiographers as well as the non-occupationally exposed members of the public such as patient attendants and the receptionists at the diagnostic centres during X-ray diagnostic procedures (Dyson, 1981;

Sprawls, 2002). These weak scattered X-rays have cumulative health effects similar to any other ionizing radiation. X-rays cause injury to living tissues as a result of transfer of energy to atoms and molecules in cellular structure. X-rays, being a form of ionizing radiation cause atoms in cells to be excited and ionized. Excitation and ionization by X-rays can lead to breakage of chemical bonds, production of free radicals and finally damage molecules that regulate vital cell processes.

Damage to cells comes from direct and indirect action of the X-ray radiation. Cell damage due to direct action occurs when the X-rays directly irradiate the cell's essential molecules such as ribonucleic acid (RNA). The radiation energy may damage cell components such as the cell walls or RNA. RNA is found in every cell and determines all cell functions. Therefore when RNA is irradiated, the cell dies, or becomes a different kind of cell, possibly even cancerous. This occurs mainly when the body is irradiated with a single dose of 0,05 – 0,10 mSv (Sternhem, 1991).

Indirect cell damage occurs when radiation interacts with water molecules in the cell, which constitute about 80% of the cell composition. The energy absorbed by the water molecules may split the water molecules resulting into formation of free radicals, the hydroxyl ($^{\cdot}OH$) groups. Free radicals are groups with unpaired electrons and are highly reactive and react to form compounds such as hydrogen peroxide.

$$^{\cdot}OH + {}^{\cdot}OH \rightarrow H_2O_2.$$

The hydrogen peroxide formed initiates harmful chemical reactions within the cells which interfere with vital biochemical cell reactions which lead to disruption of biological reactions that can cause cell damage.

The cell changes depend on the dose levels. At low dose levels cells can repair themselves. A single dose of about 20 mSv may cause cell death because at such high doses, cells cannot be replaced quickly and tissues fail to function (Daniels, 2005). Hence the effects of X-rays range from immediate deaths of people to neo-plastic conditions (cancer) and finally long term genetic mutations (Bennet, 1983). The effects of radiation are divided into stochastic and non-stochastic health effects which are discussed in the following sub-sections.

1.1.1 Stochastic Effects

Stochastic health effects are random effects associated with long-term, low-level (chronic) exposure to radiation ("Stochastic" refers to the likelihood that something will happen). Continuous exposure to low levels of X-ray radiation e.g up to 20 mSv annually makes these health effects more likely to occur, but do not influence the type or severity of the effect (Daniels, 2005). Stochastic effects are likely to affect radiographers since they are frequently exposed to X-ray radiation during their work (i.e radiographers are occupationally exposed).

Cancer is considered as the primary health effect caused by radiation exposure. In simple terms, cancer is the uncontrolled growth of cells. Ordinarily, natural processes control the rate at which cells grow and replace themselves. Damage occurring at the cellular or molecular level, can disrupt the control processes, permitting the uncontrolled growth of cells. This is what is called cancer. Ionizing radiation such as X-rays cause atomic excitations where valence electrons are raised to shells not originally occupied. These electron transfers interfere with the chemical forces which bind atoms together inside molecules creating different species that disrupt the bodies' natural control processes. This is why the ability of X-rays to break chemical bonds in atoms and molecules make them such a potent carcinogen (Hendee, *et al*, 2005).

Cancer appears many years after exposure to ionizing radiation. For example tumors may begin to show after ten years from the time of exposure while leukemia may manifest itself after a period of two years from the time of exposure. Different cancerous syndromes have different latent periods i.e the time between exposure and the time for the effect to occur. These biological effects that occur after several years have some common features (Hendee, *et al*, 2005).

(i) The probability of occurrence increases with increase in dose.

(ii) The severity of the effect is just a matter of chance.

(iii) There is no definite threshold below which it can be said with certainty that the effect will not occur.

Other stochastic effects that occur include changes in DNA, what is referred to as mutations. The mutations can be teratogenic or genetic. Teratogenic mutations are caused by exposure of a fetus to ionizing radiation and affects only the individual who was exposed. This can cause the birth of babies with several defects such as brain malformation. Brain malformation results into mental retardation. For this reason pregnant mothers should not undergo X-ray examinations. Genetic mutations affect the gametes before fertilization and are passed on to off springs (Dendy, 1999). This causes a change in a gene pool at population level. Therefore there is need to protect gonads during radiography.

Human lens opacity is another stochastic effect of radiation. According to the International Atomic Energy Agency Draft Safety Standard (IAEA, 2002), a dose of radiation of 150 mSv per year will cause the human eye to develop cataracts whereby the lenses form blurred images and this leads to defocussed vision. The latent period for these defects to manifest is about 8 years from the time of exposure (Rehan, 1994). Radiation workers are continuously exposed to these low levels of X-rays and therefore should ensure proper eye shielding (Daniels, 2005).

Stochastic effects depend on the body organs exposed to X-rays because different tissues and organs have different radio-sensitivities (relative susceptibility of the tissues or organs to undergo damage due to radiation). Radio-sensitivity of organs or tissues is directly proportional to the rate of cell division and inversely proportional to the degree of cell differentiation. Hence organs with actively dividing cells are most at a risk of radiation damage. Highly radio-sensitive tissues include testis, ovaries, blood and bone marrow while tissues with low radio-sensitivity include muscle, kidneys, spinal cord and the thyroid (Rubin and Casarett, 1968).

Stochastic effects have no threshold values above which they occur but the probability of the stochastic effects to occur in any individual depends on the frequency of exposure to ionizing radiation. The occurrence of stochastic effects such as leukemia may happen 10 years after the exposure. Hence it is important to note that any cumulative X-ray dose can be harmful. According to a report by the International Atomic Energy Agency, annual doses should not exceed certain limits known as "dose limits" for each category of people (Draft Safety Standard, 2002). Exceeding these limits means that these stochastic health effects are likely to occur in an individual. The dose limits are set to different categories of individuals depending on their likelihood of exposure, shielding and age. For example in terms of age, the dose limit for children below 5 years should not exceed 0,5 mSv per year because children have rapidly multiplying cells that are very radiosensitive. Exposure of the embryo or fetus to some level of ionizing radiation could increase the risk of leukemia, mental retardation and congenital malformations in infants. It is important to note that these dose limits are not considered as acceptable levels but rather maximum levels that should not be exceeded. The dose limits are set as follows (IAEA Draft Safety Standard, 2002).

(i) Occupational exposure to anybody working with ionizing radiation such as radiographers should not exceed 20 mSv per year.
(ii) People aged between 16 and 18 years should not exceed a dose of 6 mSv per year.
(iii) Members of the public (not occupationally exposed) should not exceed a dose of 1 mSv per year.

Occupational limit is higher than that of the other members of the public because radiographers and radiologists are much aware of the safety measures and must always ensure shielding while at work. However, realistically there are no safe doses but rather limits that should not be exceeded for safety.

1.1.2 Deterministic Effects

These are immediate health effects due to exposure to high levels of radiation in a short time, and become more severe as the exposure dose increases. Short-term, high-level exposure is referred to as "acute" exposure. However, these effects are uncommon in many medical X-ray procedures, except that they can be possible in fluoroscopy and computed tomography (CT) if the high energy X-rays that are used miss the target organs. Non-stochastic health effects are characterized by a threshold dose limit below which they do not occur. Hence non-stochastic effects have a clear relationship between the exposure and the effect.

Many non-cancerous health effects of radiation are non-stochastic. Unlike cancer, health effects from "acute" exposure to radiation usually appear quickly. Acute health effects include burns and radiation sickness. Radiation sickness is also called "radiation poisoning". Examples of non-stochastic effects include erythema (skin reddening), skin and tissue burns, cataract formation, sterility and even death. If the dose is fatal, death usually occurs within few hours to two months (See Table 1.1). The symptoms of radiation sickness include: nausea, weakness, hair loss, skin burns or diminished organ function (US Environmental Protection Agency Report, 2000).

Patients receiving radiation treatment (e.g radiotherapy and CT) often experience acute effects, because they receive relatively high "bursts" of radiation during treatment. The high doses such as 0,05-0,1 Sv in a single dose cause changes in blood chemistry and doses of up to 20,0 mSv in single dose causes death immediately (Table 1.1).

Effects of ionizing radiation increase with the duration of exposure. The effects also depend on the region of the body exposed to the radiation (since different organs have different radio-sensitivities). Radiation effects decrease with increase in the distance from source of radiation. Exposure to small doses causes effects that are difficult to immediately detect biologically. Hence, patients should be concerned about these cumulative effects depending on the frequency of the examinations they undergo.

It is therefore necessary to reduce dangers caused by radiation exposure to minimum proportion. This is referred to as ''as low as reasonably achievable'' or ALARA (Avison, 1983). There are three standard ways to limit exposure:

(i) Decreasing the duration of exposure:

All people are exposed to the natural background radiation. However, if a person is exposed to other sources of radiation, limiting or minimizing the exposure time will reduce the dose from the radiation source. The X-ray generator should be switched off if not under use.

Table 1.1: Threshold values of X-ray doses for some deterministic effects and the time taken for the effect to manifest (Adapted from Sternhem, 1991)

Exposure (Sv)	Health effect	Time to manifest without treatment
0,05-0,10	Change in blood chemistry	About 2 weeks
0,50	Nausea	2 – 6 hours
0,55	Fatigue	2-4 hours
0,70	Vomiting	8 hours
0,75	Hair loss	2-3 weeks
0,90	Diarrhea	About a week
1,00	Hemorrhage	Within two months
4,00	Possible death	Within 2 months
10,00	Destruction of intestinal lining, death	1-2 weeks
20,00	Damage to central nervous system ,death	About 20 minutes

(ii) Increasing the distance to the source of the radiation:

Radiation intensity decreases with increase in the distance from the source. The intensity of the X-rays from the source decreases according to the inverse square law i.e

$$I \propto \frac{1}{d^2} \quad \text{......................................} (1.1)$$

where I is intensity of radiation, d is distance from the source to the exposed individual. Hence keeping at a large distance from the source of X-rays reduces the exposure.

(iii) Shielding:

This is the act of placing a barrier between the radiation source and the individual to reduce on exposure. Air or skin can be sufficient to substantially attenuate low-energy alpha and beta radiation. Barriers of lead, concrete, or water give effective protection from electromagnetic radiation such as gamma rays and X-rays. Lead and concrete are by far the most commonly used materials for shielding against X-rays. Lead has a high density (11340 kg m^{-3}) and a high stopping power due to a large atomic number. Lead is used in form of aprons that are worn by the radiologists for protection. Concrete is used for walls to shield X-rays that are scattered from the X-ray room from reaching the surroundings.

The maximum range of penetration of energetic radiation such as X-rays in matter depends on the energy of radiation, density and the thickness of the material irradiated. The thickness of the lead used for shielding depends on the energy of the X-rays. As mentioned earlier, the energy of the X-rays depends on the voltage applied to accelerate the electrons in the X-ray generator. Hence different energies of X-rays require different lead thickness for shielding (See Table 1.2).

The thickness of lead required to achieve about 95% attenuation of X-rays increases almost linearly with the X-ray generator voltage. From Table 1.2 it therefore means that different medical procedures (radiography, computed tomography and fluoroscopy) use different X-ray energies, and so the lead material used for shielding should be of varying thickness. Increasing the X-ray energy reduces on the attenuation of the X-rays for a constant thickness of lead as shown in Table 1.3.

Table 1.2: X-ray generator peak voltage and minimum lead thickness required to achieve 95% attenuation of X-rays generated (From Avison, 1983)

X-rays generator peak voltage (kV)	Minimum thickness of lead (mm)
75	1,0
100	1,5
125	2,0
150	2,5
175	3,0
200	4,0
225	5,0
300	9,0
400	15,0
500	22,0
600	34,0
900	51,0

Table 1.3: Percentage attenuation of X-rays by different Lead thicknesses (From Nicholas, 2009)

Lead thickness (mm)	Percentage (%) attenuation of X-rays from different X-ray tube voltages		
	50 kVp	75 kVp	100 kVp
0,25	97	65	50
0,50	99,8	88	75
1,00	99,9	99	93

1.2 Statement of the Problem

The studying and observing of internal body structures for the purpose of identifying disorders involves the use of X-ray radiography, computed tomography (CT) and ultra-sound scans (Camphausen, 2008). The most commonly used procedure is the X-ray radiography.

X-ray radiography is associated with primary scattering of the radiation by the patient's body. The primary scattered beam further undergoes secondary scattering into different directions by other objects in the X-ray room such as the walls, roof, floor and furniture. In everyday diagnostic practice, secondary scattering of X-rays is ignored by the radiographers. This is shown by the radiographers wearing lead aprons that cover only the front part of their bodies to protect their vital organs such as gonads from the X-ray radiation scattered from the patients but leaving the back exposed to secondary X-ray radiation scattered by the objects in the X-ray room. The low energy secondary X-ray radiation has the same effects as those of the primary scattered radiation. It can eventually lead to cancer and mutations in the body cells irrespective of the direction from which it enters the body. There is little known data about the intensity of the secondary scattered X-rays from different diagnostic procedures. Therefore the likelihood of the effects it can cause cannot be predicted.

1.3 Purpose of the Study

To determine the intensity of secondary scattered X-ray dose in some selected diagnostic centers in Uganda.

1.4 Objectives of the Study

(a) To measure the secondary scattered X-ray dose when the following parts of a patient are exposed

(i) Chest
(ii) Abdomen
(iii) Lower limbs

(b) Compare the secondary scattered X-ray levels for the above three X-ray diagnostic procedures to the dose limit set by the Uganda Atomic Energy Council.

1.5 Scope of the Study

The study was limited to the determination of secondary scattered X-rays when the chest, abdomen and lower limbs were exposed to the X-rays. Three hospitals in South Western Uganda were chosen for the study and these are Mutolere Hospital in Kisoro District, Mbarara Diagnostic Centre and Goodwill Imaging Centre both found in Mbarara town in Mbarara District.

Measurement of secondary scattered X-rays in the selected diagnostic centres was carried out by the use of Thermo Luminescent Dosimeter (TLD) badges which were provided to each radiography department in each of the selected centres. Each radiography department in each of the selected diagnostic centres was provided with three TLD cards. Each of the radiography procedures perfomed (i.e the chest, the abdomen and the lower limbs) was assigned a labeled TLD card. The TLD cards were worn at the back of the radiographer each time the radiographer X-rayed patients. In this way, the cards were exposed to secondary scattered X-ray dose when the radiographer exposed the mentioned body parts to X-rays.

The duration of exposure of the cards to secondary scattered X-rays was for a period of one month after which the cards were collected and read or annealed. The process of data collection lasted six months.

1.6 Significance of the Study

The study has revealed that the most prevalent X-ray procedures involve the exposure of the limbs, followed by the chest exposures and finally the abdomen exposures. In addition the study has found out that the secondary scattered X-rays in X-ray rooms in the three diagnostic centres is less than the annual dose limit set by the IAEA. According to the study, chest exposures led to the highest intensity of secondary scattered X-rays, among the body regions used in the study.

The findings have provided quantitative data on which to assure personnel (radiologists and radiographers) about their safety during X-ray diagnostic procedures because none of the diagnostic centres used in the study leads to an over-exposure of radiographers to X-ray radiation. In addition the results of the study enable the radiographers to know the number of patients they can X-ray annually without the radiographers being at a risk of developing radiation health effects.

The findings of the study also provide information for policy formulation in regard to monitoring and administration of X-ray diagnostic procedures.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

This study is concerned with the propagation of X-rays especially secondary scattering of X-rays. The determination of secondary scattered X-rays is important because of the associated health effects which X-rays cause to human beings, if they are not controlled. Of particular interest in this study was the intensity and likely effect of secondary scattered X-rays to radiographers and the non-occupationally exposed members of the public. The review of the related literature in this study covered the theory of scattering of X-rays, and results of similar studies carried out earlier especially in X-ray rooms.

2.2 Theory of Interaction of X-rays with matter

The interaction of X-rays with matter begins with irradiation of an object with X-ray photons. When X-rays are directed onto matter three possible things can occur to the propagated X-ray beam. When there is minimum interaction between the material and the photons, the photons pass through the material without substantial effect on the material. The X-ray beam can also be completely absorbed by the material where the X-ray photon energy is completely absorbed into the material. In diagnostic procedures, this constitutes the dose absorbed by the patients. There can also be partial absorption with scatter where there is partial transfer of energy to the material, the resulting X-rays being scattered into different directions. The scattered X-rays have less energy than the incident X-rays and follow a different trajectory.

X-rays being part of the electromagnetic waves, they undergo the processes of reflection, refraction and diffraction. Refraction and diffraction are accompanied by attenuation and absorption of the X-ray beam (Lehman, 2005). The reflection and refraction effects are generally observable at high X-ray energies, and the atomic spacing of the materials irradiated must be comparable with the wavelength of the X-rays used. Since most of the materials have uneven spacing of particles and high densities, these effects cannot be observed in common materials.

The diffraction equation which relates the X-ray wavelength and the distance of the irradiated material from the X-ray source assumes small changes in refractive index when X-rays move from air to an object and is given by

$$L << \frac{\delta^2}{2\lambda}$$ ....(2.1) (Lehman, 2005),

where L is distance from the illuminated face of the object under evaluation to the detector, λ is wavelength of X-rays and δ is feature size of the atomic spacing of the object. If L is significantly larger than the ratio on the right hand side of the equation, diffraction effects will be observed. Diffraction results into scattering of X-rays.

2.3 Scattering of X-rays

When a material is irradiated by X-rays, part of the X-ray photons are scattered. Scattering of X-ray radiation is the deviation of photons by materials irradiated by the X-ray beam. Scattered X-ray radiation does not serve any useful purposes in medical practice. Instead, it contributes to the dose to radiographers and the patient (Gaines, 1980). The scattered beam of X-rays has a longer wavelength than the incident beam (this is discussed in sub-section 2.3.2).

X-rays incident on matter undergo both elastic and inelastic scattering depending on whether the material is crystalline or non- crystalline (Victor, 1985). In elastic scattering energy of outgoing photons is the same as that of the incoming photons, while in inelastic scattering outgoing photons have less energy than incoming photons i.e wavelength of outgoing photons is longer than that of incoming photons (Krane, 1996).

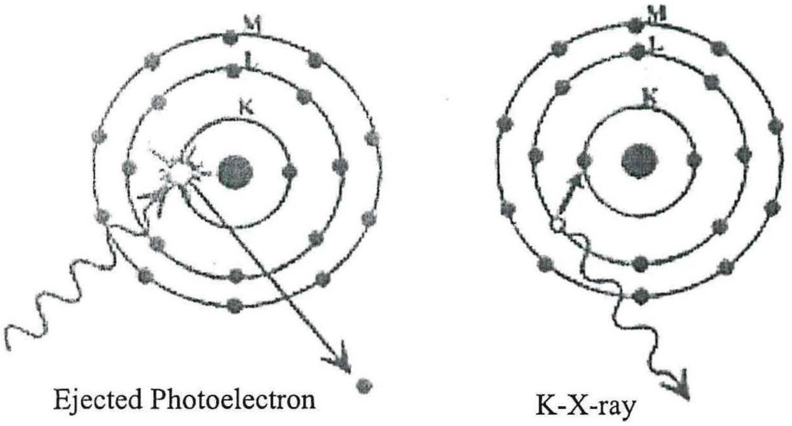
When a beam of X-rays passes through a material, its intensity reduces. Reduction in intensity results from the X-rays imparting part of their energy in excitation, ionization and heat to the absorbing material. The process of reduction in intensity of X-rays is called attenuation. Attenuation is the property of X-rays that accounts for scattering of X-rays. Lower energy X-rays are more attenuated than high energy X-rays because the atomic spacing of most objects is comparable to the wavelength of low energy X-rays. A general rule states that the higher the peak voltage used to generate the X-rays, the more the scatter of X-rays. Attenuation of X-rays occurs the X-rays pass through matter as they undergo the two processes of photoelectric absorption and Compton scattering (Sharpe, 1964).

2.3.1 Photoelectric Absorption

Photoelectric absorption occurs when X-rays transfer all their energy to an electron to one of the atomic shells, normally K or L and the electron is removed from its shell or from the influence of the nucleus (ionization). The resultant vacancy in the K-shell can be filled by an electron from another shell as indicated in Figure 2.1. The ejected photoelectron has energy E_x given by

$$E_x = E_\gamma - E_k \quad \text{.............} \quad (2.2)$$

where E_k is the binding energy of the electron and E_γ is the energy of the scattered photon . The atomic system is left in excited state and returns to the ground state by X-ray emission which is given out coincidentally with the photoelectron. These X-ray photons are captured in the medium to produce further electrons. During radiography, photoelectric absorption accounts for part of the dose to the patients because some energy of the X-rays is absorbed into the patient's body. Imparting of energy partly explains why X-rays cause damage to the body. The electrons produced will dissipate their energy in the absorbing medium (Dyson, 1981). The lowest energy of X-rays for photoelectric effect to occur is 0,03 MeV.



Ejected Photoelectron   K-X-ray

Figure 2.1: Illustration of Photoelectric absorption (Adapted from Knoll, 2000)

The transfer of energy by photons during photoelectric emission is a two-step process i.e transfer of energy to the electron is the first process followed by dissipating of energy into the absorbing medium (Sprawls, 2002). Photoelectric interaction usually occurs with electrons that are firmly bound to the atom, that is, those with a high binding energy but whose binding energy is slightly less than the energy of the incoming X-ray photons (Knoll, 2000).

2.3.2 Compton Scattering

The other method of X-ray interaction with matter is Compton scattering. This process occurs when high energy X-rays (200 KeV-10 MeV) are deflected from their original path by interaction with an electron. The electron is ejected from its orbital and X-ray photon loses its energy but continues to travel in a different direction i.e it is scattered. In Compton interaction, part of the energy of the photon is absorbed and the scattered photon emerges with a reduced energy. In Compton scattering, the scattered photons travel in different directions at an angle θ to the direction of incident photons (Figure 2.2) with different wavelengths and different frequencies, depending on density of scattering material (Dwiggins, 1984).

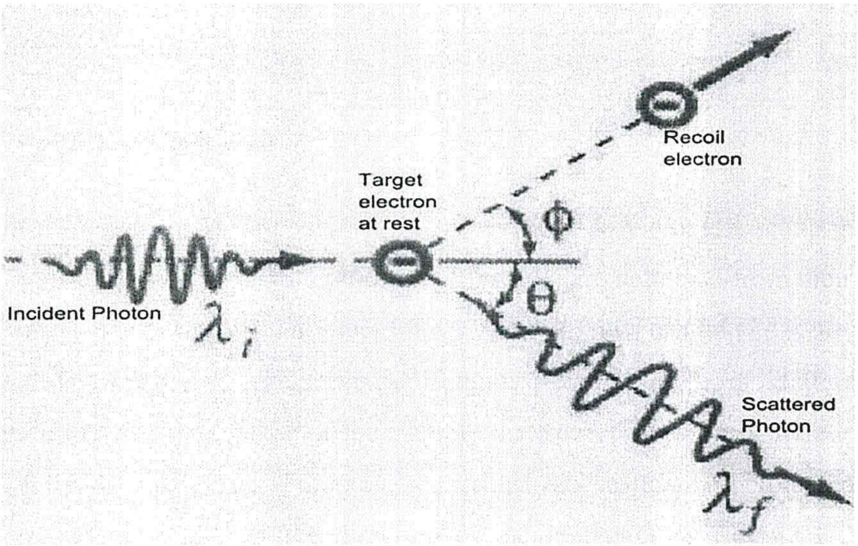


Figure 2.2: Illustration of Compton Scattering (Adapted from Sharpe, 1964).

The probability of Compton scattering per atom of the absorber depends on the number of electrons available (scattering targets) and therefore it is directly proportional to the atomic number (Knoll, 2000; Paul and Ralph, 2008).

The scattered X-rays have a longer wavelength than the incident photons and the change in wavelength of the scattered X-ray photon is given by the following Compton formula

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.3)$$

where λ is the wavelength of incident X-ray, λ' the wavelength of scattered X-rays, h Plank's constant, m_e the mass of electron at rest, c the speed of light and θ the scattering angle from the horizontal direction of incident photons and it which depends on the density of the object. The more dense the object with which the X-rays interact, the more the value of θ (Knoll, 2000). Increase in wavelength of the scattered X-rays is a result of the incident X-rays losing part of their energy as they interact with electrons of atoms of the absorbing material. More dense materials offer greater resistance to X-ray penetration because they absorb more of the energy of the X-rays. Hence more dense materials scatter more X-rays (Sharpe, 1964; Sproull, 1964). The quantity $\frac{h}{m_e c}$ is called Compton wavelength (h_c) and has a value of $1{,}426 \times 10^{-12}$ m. Any radiation whose wavelength is greater than this value suffers a small fractional change in wavelength on interaction with matter while those with lower wavelength than the Compton wavelength suffer a high fractional change in wavelength on interaction (Dyson, 1981; Born, 1962).

2.3.3 Pair Production

At very high X-ray energies i.e 10 MeV and above, the prominent interaction that occurs is pair production. This process occurs when the energy of the X-rays exceeds the rest mass of an electron (exceeds 1,02 MeV). Practically the probability of occurrence of this interaction is low until X-ray energy approaches several MeV and is only confined to high energy X-ray medical procedures such as fluoroscopy, angiography and computerized tomography (Knoll, 2000). It therefore does not occur during radiography of for example the chest and abdomen that use X-ray energy which is less than that of X-rays that undergo pair production interaction.

If photons are assumed to be particles, then the conservation of energy principle equates the sum of the energies before and after scattering as shown in equation 2.4.

$$E_y + E_e = E_y^{'} + E_e^{'} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.4)$$

where, E_y is the energy of incident photons, E_e the energy of electron in orbit, $E_y^{'}$ the energy of scattered photons and $E_e^{'}$ the energy of the recoil electron. Assuming that photons have momentum (are particles) then the principle of conservation of momentum of the photon and the photoelectron can be expressed as:

$$P_y = P_y^{'} + P_e^{'} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.5)$$

where P_y is the momentum of the incident photons, $P_y^{'}$ the momentum of the scattered photons and $P_e^{'}$ the momentum of the recoil electron (Fig. 2.1). The momentum of the electron at rest is zero (Sharpe, 1964).

X-rays are scattered in a Bragg-like diffraction pattern by crystalline structures. This means that a parallel incident beam gives parallel diffracted beam. Scattering in non-crystalline structures like the human body gives scattered beam in different directions (Fuller, 1985). In both cases, the scattered beam has a longer wavelength than the incident X-ray beam.

In order to study scattering of X-rays whose energy is suitable for chest, limb and abdominal radiography, materials of low atomic number such as beryllium, boron and carbon are used. This is because the intensity of the X-ray beams needs to be reduced to match that used for the above radiography procedures. Otherwise atoms with large atomic number require high energy X-rays because of the high energy required to cause electron transitions in the many orbitals of the atom. Such high energy X-rays are suitable for procedures like radiotherapy and not chest, limb and abdomen radiography (Knoll, 2000).

From the discussion of both photoelectric and Compton interactions, patient dose is contributed by both interactions. This is because X-ray energies used during radiography lies within the range of photon energies that undergo the interactions. Increasing the X-ray tube voltage (kVp) raises the average energy of photons so that there is a significant decrease in the photoelectric effect making the additional photons available to contribute to film contrast.

Again, scattered X-rays, exiting the patient increase with increase in the tube voltage (kVp). At higher kVp, patient dose decreases because of the reduction in the photoelectric effect, but causes an increase in the Compton scattering which increases the dose to the radiographer (due to scattered X-rays). The decrease in photoelectric effect and increase in Compton scattering as kVp of the X-ray generator increases are shown in Table 2.1 (Sprawls, 2002).

Table 2.1: Percentage interaction of X-rays through 10 cm of soft tissue
(From Sprawls, 2002).

Energy (kVp)	**Percentage occurrence of Photoelectric effect**	**Percentage occurrence of Compton effect**
50	79	21
70	60	40
90	36	60
120	19	71

In traversing a thin slab of matter, the absorbed intensity of the X-ray beam, I is given by

$$I = I_0 e^{-\mu x} \qquad (2.6)$$

where I_o is the incident intensity, x the thickness of the material, and μ the linear attenuation coefficient of a material. Linear attenuation coefficient describes the fraction of a beam of

X-rays that is absorbed or scattered per unit thickness of the material irradiated. An alternative form of equation 2.6 is

$$I = I_0 e^{-M\rho x} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.7)$$

where $\mu = M\rho$. The quantity M is mass attenuation coefficient, which depends on the density, ρ, of the scattering material i.e

$$M = \frac{\mu}{\rho} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.8)$$

Mass attenuation coefficient of a material is given by the expression

$$\frac{\mu}{\rho} = \frac{\tau}{\rho} + \frac{\sigma}{\rho} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.9)$$

where $\frac{\tau}{\rho}$ is the absorption coefficient and $\frac{\sigma}{\rho}$ is the scattering coefficient. τ is the absorption ratio of the material while σ is the scattering ratio of the material (Shankland,1960). The relative occurrence of photoelectric effect, pair production and Compton scattering when different atomic numbers of absorber materials are plotted against different X-ray photon energies is illustrated in Figure 2.3.

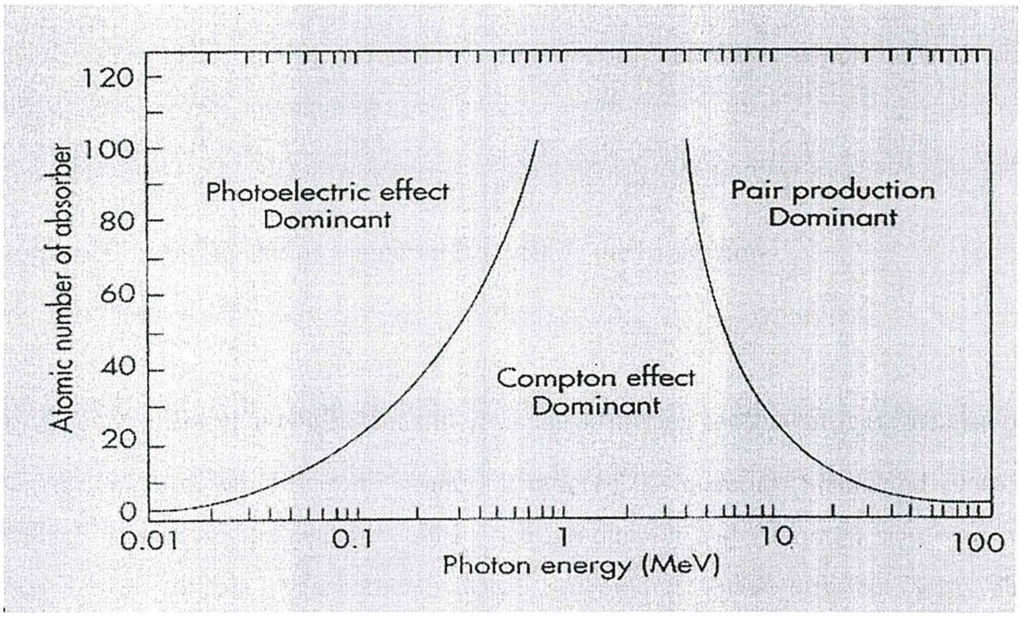


Figure 2.3: A graph of atomic number of absorber materials versus photon energies for the different photon interactions with matter (From Knoll, 2000).

From Figure 2.2, it is clear that photoelectric effect is dominant at lower energy of X-rays (in the region of 0,01 to 0,5 MeV) and increases with increase in the atomic number of the absorber. This means that photoelectric effect is likely to occur in radiography because of the X-ray energy used (Table 2.1). As earlier mentioned, photoelectric effect contributes to the patient dose (Knoll, 2000).

For intermediate X-ray energy (0,8 MeV to about 5 MeV), Compton scattering is dominant and is the most common interaction during radiography because radiography uses this energy range. For this reason, radiography leads to X-ray scattering due to the Compton effect. This is the cause of the dose to the radiographers against which the radiographers must be shielded (Knoll, 2000). Pair production is dominant at higher energy X-rays which are not used during chest, limb and abdominal radiography.

2.3 Coherent Scatter

In this form of interaction, an incoming X-ray photon causes an electron in an atom to vibrate. The electron subsequently emits an X-ray photon with the same energy as that of the incoming photon, but exactly in the forward direction. Therefore there is no ionization as is the case with Compton scattering and photoelectric effect. The process occurs with very low X-ray energies not used in diagnostic radiography.

When X-rays interact with the human body during medical procedures, they undergo primary scattering (Muller, 1928). As mentioned earlier, the amount of scattered X-rays depends on the density of the body tissue and the energy of the incident X-rays. Scatter of X-rays increases with increase in energy of primary X-rays from the X-ray tube which in turn depends on the tube voltage (kVp). It also depends on the patient size (Shigeru, *et al*, 2004). For the human body, the intensity of scattering depends on the region of the body (for constant kVp) since different regions of the body have different tissues with different densities. More dense tissues such as bones scatter more X-rays than less dense tissues because more dense tissues contain a large proportion of calcium and phosphorus. These elements have a higher atomic number and hence a large energy difference between electron orbitals. This favours absorption of photons.

Measurements for the scatter of X-ray radiation from concrete block barriers were made, basing on the assumption that the blocks absorb most of the radiation falling on them (Kenneth and Goran, 1983). The interest of the study was to compare absorption and scatter of radiation by concrete since most X-ray rooms are constructed using concrete. The study established that about 50% of the radiation falling on the concrete inside the X-ray room is scattered in different directions.

In a study conducted by Moores, scattered X-ray radiation around the bed during a chest X-ray procedure was measured to determine the safe distance for the staff to stand in order to minimize exposure (Moores, 1987) . The study revealed that scattered X-rays can be detected at a distance of up to two metres from the bed of the patient being examined (International Commission on Radiological Protection, 1988). The study emphasizes wearing of a lead apron in front of the radiographer to safeguard the radiographer against the primary scattered radiation from the patient. There are some cases where patients undergoing chest X-ray examination remain standing and the beam directed to the patient is scattered in different directions. However, the study did not consider the secondary scattered radiation.

Muhogora and Kondoro carried out an assessment of secondary radiation of X-ray diagnostic facilities that provide general X-ray services (Muhogora and Kondoro, 1992). The study used thermo luminescent dosimeters (TLDs) to measure the amount of radiation received by the radiologist (shielded) at different angles from the X-ray tube and the direction of the patient. The results of the study revealed that the amount of X-rays scattered in the direction facing the patient was much higher than the radiation in the direction remote from the patient. However, the direction remote from the patient received a significant dose (about 50% of the radiation dose in the direction of the patient). This significant dose received from the side remote from the patient indicates that the primary scattered radiation is further scattered by the walls to the other side of the radiographer i.e it undergoes secondary scattering. The study recommended a thinner protective gear to the radiologist on the other side away from the patient since it receives secondary scattered radiation.

Measurements for scattered radiation in four X-ray rooms (chest X-ray room, general purpose X-ray room, skull and neck X-ray room and X-ray CT room) using optically stimulated luminescence dosimeter for a period of three months (Iida, 1998). The study found that the secondary X-ray dose scattered in the room where the skull and neck are X-rayed room was less than 1,3 mSv for three months and the highest dose of scattered (primary and secondary) X-ray radiation (48mSv for three months) was measured in the CT room near the walls and floor. The study revealed that the little amount of X-rays recorded for the three months of the study is a result of the low frequency of the skull and neck procedures. This study supports the earlier view that high energy X-rays are more scattered than low energy X-rays. This is seen from the amount of scattered X-rays measured in the CT room for the three months.

It was reported (Karabut, 2002), that if a patient is placed on a protective lead material of thickness 2 mm and a primary source of X-rays from the X-ray tube directed to the patient for diagnostic procedure, no X-ray radiation detected behind the lead material. However, radiation was detected behind the X-ray tube though the primary beam of X-rays from the machine is collimated. Karabut's study revealed that the amount of radiation detected behind the X-ray tube is a result of scattering (McEwan, 2008).

A study in the X-ray rooms (McVey and Weatherburn, 2002), revealed that the scatter of X-rays from diagnostic X-ray rooms can be detected outside the X-ray room if the material of the wall is not thick enough. The study was based on the amount of scatter of radiation inside and outside the X-ray room. The scatter of radiation inside the X-ray room was measured for the secondary scattering objects in relation to the primary beam scattered by the patient, against which the radiologists are shielded in front of their bodies. The results gave a difference in the primary and secondary scattered radiation. The same study showed that there is multiple scattering of radiation in X-ray rooms due to surrounding materials in the

X-ray room. Their findings were confirmed by the fact that removal of most of the furniture from the X-ray room reduced on the amount of scattered X-rays recorded.

A study by Shymko revealed that secondary radiation in X-ray rooms accounts for about 50% of all the scattered radiation in the X-ray room, (Shymko, 2002). He suggested that radiologists should be aware of secondary radiation from walls of X-ray rooms. The study emphasized protective wear against primary and secondary radiation. The study also emphasized on the thickness of the material used to construct the X-ray room e.g 1,0 mm thickness of lead (equivalent to 30,0 cm of concrete) in shielding X-rays generated by 75 kilo voltage machine. The study further revealed that due to the inevitability of primary and secondary scattering of X-rays, the design of the X-ray rooms should be of concern to the standards and regulatory organs of any country.

In a study by Date, it was observed that the chest and abdominal X-rays are the commonest X-ray examinations sought in developing countries (Date, 2005). Measurement of primary and secondary scattered X-rays to the patient and radiographer is essential. This is because scattered X-rays reduce image brightness and contribute to the dose to the radiographer. The study by Date revealed that both chest and abdominal X-ray procedures result into scattering of X-rays which should be shielded from both patients (region not being examined) and radiographers. The study recommends a front lead apron for shielding and also proposes further study on secondary scattering from other objects in the X-ray room. The study is also supported by the study of Blettner, (Blettner, 2005) which proposed a thinner protective material at the back of the radiographer.

Manuel Fernandez observed that primary X-ray scattering properties of tissues and tumors of the breast reveal information about the densities of the tissues (Manuel, 2006). The study revealed that X-rays change their direction within the tissues due to primary inelastic scattering (Chatterje, 2009). The study revealed that the phenomenon of scattering is unnecessary to radiography because it affects the quality of the image and is dangerous to the radiographers i.e it contributes to the radiographers' dose (Suric, *et al*, 2001). Again the study recommended that further studies be carried out to determine the intensity of secondary scattered radiation since the study hypothesized that the secondary scattered radiation depends on the intensity of the primary scattered radiation.

During X-ray diagnostic procedures a beam of X-rays from the X-ray machine is directed to a specific region of the body. The X-ray machine is the primary source of the X-rays. As mentioned before, the human body scatters the X-rays in different directions and hence the part of the body of the patient that is irradiated with the primary beam is a secondary source of X-ray radiation (Figure 2.4).

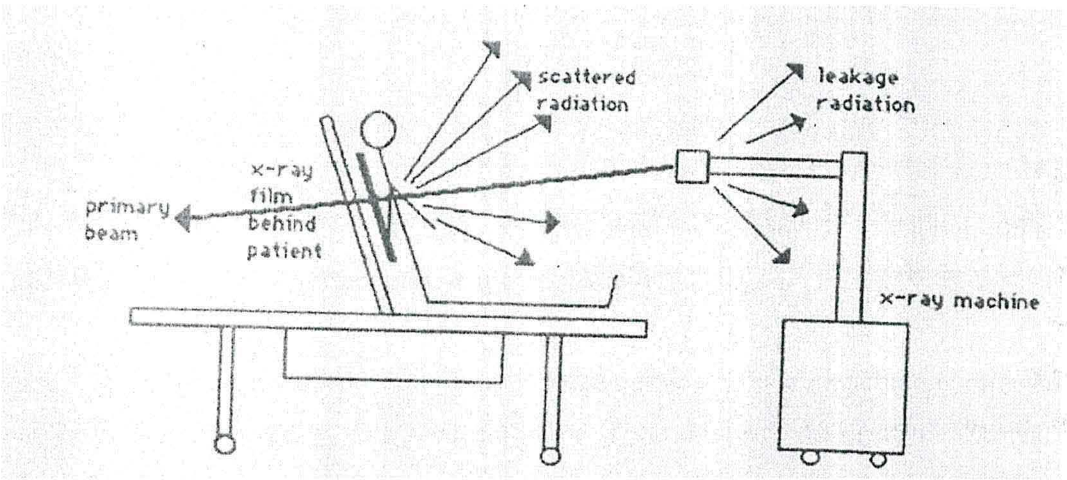


Figure 2.4: Propagation of X-rays During Chest X-ray Examination (Adapted from Hart and Jones, 1996).

The scattered radiation that proceeds from the patient has two effects:

(i) The photons that proceed in the forward direction reaching the X-ray film decreases the quality of the image i.e decreases the contrast on the image.

(ii) The scattered radiation in different directions is a source of radiation exposure to the radiographers conducting the examination and undergoes further scattering by the objects in the X-ray room such as the roof and walls.

Studies were carried out in hospitals (Morrish and Goldstone, 2008) using a phantom to measure the scattered X-rays from the patient to the radiographer. The phantom represented a patient and the position of the radiographer (inside the cabin) was measured and found to be about 2m from the patient. The different regions of the phantom were X-rayed i.e the chest and the limbs. These procedures account for about 30% of all X-ray examinations. The study of Morrish and Goldstone found that all regions around the patient have varying amounts of scattered X-rays depending on the X-ray tube voltage. The results of the study showed that the radiographer is in a radiation field and this radiation has health implications to the staff carrying out the examinations.

So basing on the above studies, there is clear evidence that secondary scattering of X-rays occurs in X-ray rooms during radiography. There is, however, no available quantitative data on the amount of secondary scattered X-rays in the X-ray rooms and therefore the likely health effects that can arise from the secondary scattered X-rays cannot be predicted. This study therefore presents quantitative data about secondary scattered X-rays in some diagnostic centres in Uganda.

The theory and method used in measurement of X-rays and other ionizing radiation is discussed in the following sub-section.

2.5 Process of Measurement of X-ray dose

Measurement of radiation dose is known as dosimetry. One way of measuring radiation dose is by observing the amount of ionization that the radiation produces in matter. Measurement of X-ray radiation (and other forms of ionizing radiation) is done using a dosimeter which records the total dose received by an individual (Gfirtner, 1992). Different types of dosimeters are used to measure ionizing radiation and these include gas ionization counters, scintillation counters, semi-conductor counters and Thermo-Luminescent Dosimeter (TLD) depending on the nature of the radiation (Sharpe, 1964).

The principles of radiation dosimetry depend on the absorbed dose i.e the average energy imparted to a quantity of matter per unit mass of the substance. Absorbed dose received by a material that is located in a radiation field depends on the density of the material. Some basic dosimetry methods are:

(i) Calorimetric method which uses temperature rise measurements to determine the amount of energy imparted into the material by the radiation.

(ii) Chemical dosimetry method that uses measurements of chemical changes that are induced by radiation.

(iii) Luminescence method which involves measurement of intensity of light that is produced by some materials when irradiated by the ionizing radiations

(iv) Physical dosimetry method that uses effects such as change in semiconductor properties of materials.

2.5.1 Thermoluminescent Dosimeter (TLD)

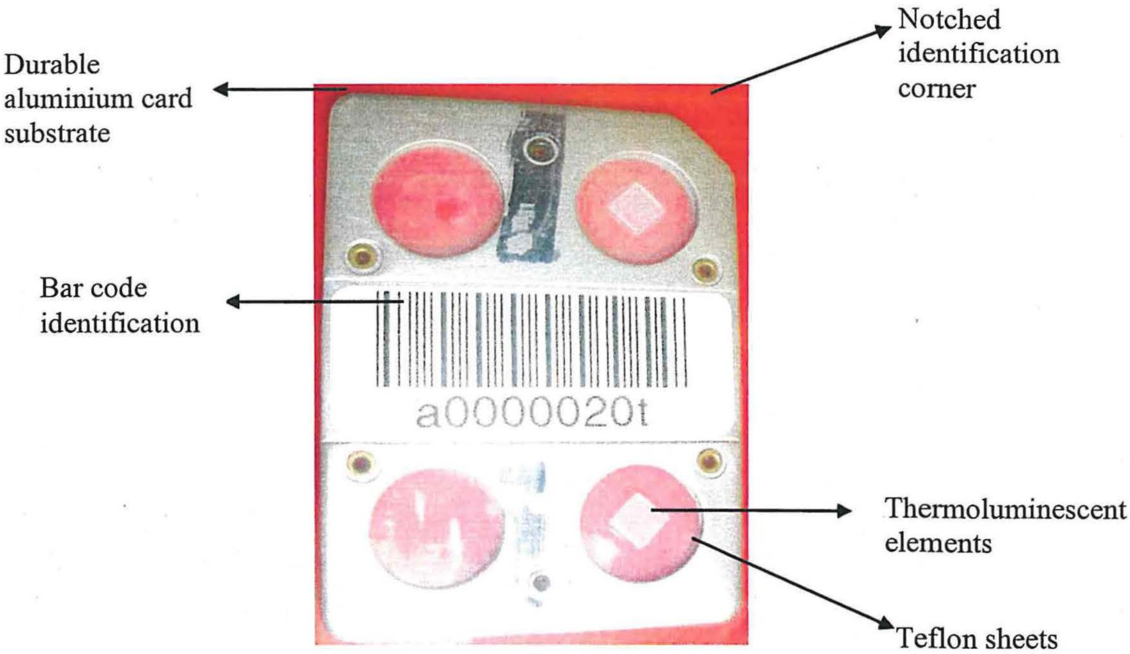


Figure 2.5: A Typical Dosimeter Card

This is one of the commonest dosimeters used for measuring scattered X-rays in hospitals and it absorbs the total accumulated dose of the X-ray a person receives over a period of time (Dominian, 1935). The TLD badges are sealed in polyethene packets and held near the breast pocket for measuring the primary scattered X-rays and just above the waist on the back of the radiographer to measure secondary scattered X-rays.

The major parts of the thermo luminescent dosimeter (Figure 2.5) are:

(i) Identification number (ID): This is presented in numeric and barcode formats. It is used for the identification of the card for the purpose and place it is used.

(ii) Thermo luminescent elements: These are thermo luminescent crystals such as calcium sulphate, lithium fluoride, calcium fluoride and aluminium oxide (Sharpe, 1964). Thermoluminescent crystals have a high sensitivity to radiation and respond to different amounts of radiation when heated (Chatterje, 2009). The crystals absorb radiation and later release light when the TLD card is heated in an analyzer. TLD have at least two thermoluminescent chips so as to discriminate the X-ray doses. The chip in a thin window is used to detect shallow skin dose while the chip in a plastic cover detects deep tissue dose or whole body dose.

(i) Notched identification corner: This is used to fit the card into the TLD reader.

The major advantages of the TLD as a personnel dosimeter over other dosimeters are (Kwaku, 1994; Horowitz, 1984):

(i) It can be re-used several times.

(ii) It can be put on by the radiographers without much care.

(iii) It is highly sensitive in measuring exposure to radiation ranging from a few millisieverts to several sieverts.

Thermoluminescent dosimeter works on the principle that absorption of energy from the radiation excites the electrons from the valence band to the conduction band within the atoms of the crystals. This results in the production of free electrons and holes in the crystal (Figure 2.6 shows illustration of thermo luminescence). The electrons and holes are trapped by impurities or imperfections in the crystalline lattice and thus locking the excitation energy into the crystal (Hendee, *et al*, 2005).

Reading a TLD is aided by hot nitrogen gas found in an analyzer. When a TLD card is inserted in the analyzer and the analyzer switched on, the crystals in the card are heated. Heating the crystals causes the crystal lattice to vibrate, releasing the trapped electrons in the process. Released electrons return to the original ground state, releasing the captured energy from ionization as light i.e shows luminescence.

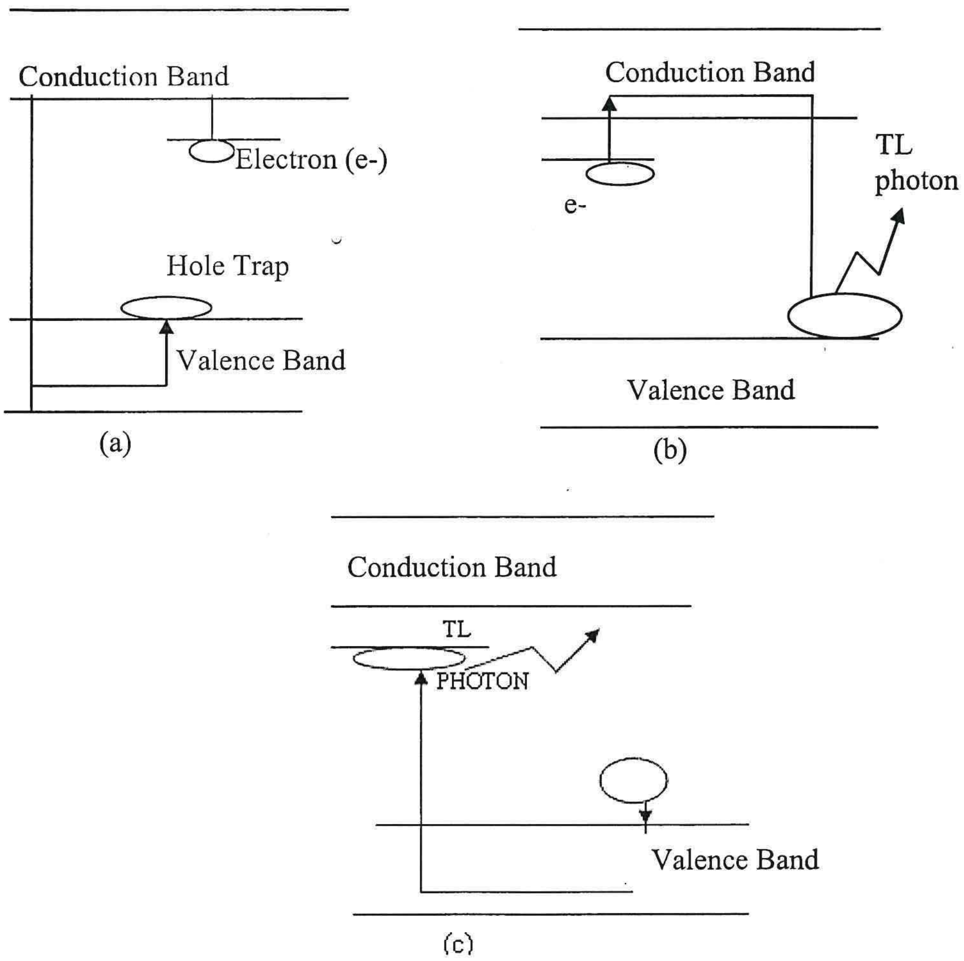


Figure 2.6: Thermo luminescence process: *(a) Exposure of crystal to ionizing radiation. (b) Heating the thermo luminescent crystal causes the electron trap to become less stable. The hole trap becomes the emitting centre.(c) Alternatively during heating, the hole trap becomes less stable and the electron becomes the emitting centre (*Adapted from Kwaku, 1994).

The total amount of light is proportional to the number of trapped excited electrons in the crystal and hence the absorbed dose. The light is directed to a photo-multiplier tube to generate an electric signal which is proportional to the energy originally deposited in the crystals by the radiation. Detection and amplification of this signal (in nanocoulombs or microcoulombs) yields a measure of the absorbed dose in the crystals (Kwaku, 1994).

The intensity of the luminescence after amplification is supplied to a computer monitor for read out in sieverts (Hanna, 1981). The whole process of TLD readout is computer generated and the reading obtained is a measure of all the radiation absorbed for the whole period for which the TLD badge was exposed to radiation.

Generally the amount of light released when TLD crystals are heated also depends on other factors like temperature to which the crystals are heated and the time taken during the heating, in addition to the energy absorbed from the radiation. Hence the temperature and the time for all the cards must be kept constant for uniformity. The heating temperature for each card is 300^0C (anneal temperature) and the process of heating each card takes 2 minutes. TLD measurements are first calibrated using dose from known radiation before being used to measure unknown radiation dose (Hendee, *et al*, 2005).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The purpose of this study was to investigate the intensity of secondary scattered X-rays from some X-ray diagnostic procedures in selected diagnostic centres in South Western Uganda. This was done in three diagnostic centres as discussed in the following section.

3.2 Research Sites

Three diagnostic centres were chosen for the study and they were Mutolere Hospital, Mbarara Diagnostic Centre and Goodwill Imaging Centre all located in South Western Uganda. Mutolere Hospital is located in Kisoro District. It is a Mission founded referral hospital in Kisoro District and the surrounding districts of Kabale and Kanungu. The hospital also handles cases of people from neighbouring countries of Rwanda, Democratic Republic of Congo (DRC) and Northern Tanzania who live near the border with Uganda and find it convenient to seek radiography and other health services from Uganda. Mbarara Diagnostic Centre and Goodwill Imaging Centre are found in Mbarara Town in Mbarara District. Mbarara Diagnostic Centre and Goodwill Imaging Centre are referral clinics that specialize in radiography and handle many cases of radiography referred from health centres which do not have radiography department. They handle cases from the districts of Mbarara, Kiruhura, Ibanda, Ntungamo, Bushenyi, Buhweju, Sheema and Isingiro. The diagnostic centres also deal with cases of people from neighbouring Tanzania and Rwanda that get radiography services conveniently in Uganda. The above diagnostic centres have properly working X-ray machines as indicated from the inspection reports of Atomic Energy Council at the start of the study. Each centre also has trained radiographers.

The above three centres serve a large population. The population from the catchment area engages in many activities some of which involve travelling on bad roads. In addition to this there is use of motorcycle transport and over-loading small cars with passengers yet they are not meant for public transport. This exposes the people to road accidents that cause them to have fractures such that they must seek X-ray services to examine the extent of the damage. Also the rural setting of the population that engages in vigorous manual labour activities like agriculture and brick making makes the people develop chest complications later in their lives. In addition, there are many complications associated with the chest such as tuberculosis. This therefore causes a big section of this population to seek X-ray diagnostic examinations regularly.

Because of the large volume of work handled by each of the above named diagnostic centres, the radiographers in those diagnostic centres may be more susceptible to the dangers of occupational exposure to X-rays compared to the radiographers from other regions whose population may not seek X-ray services regularly (especially if shielding standards are not considered). Again in areas where there are many diagnostic centres there is a likelihood of the patients being distributed to the centres. This reduces the average number of patients X-rayed per radiographer hence reducing the amount of secondary scattered X-rays to the radiographers.

3.3 Data Collection

The secondary scattered X-ray dose were measured during the study. The X-ray dose was measured using TLD badges. These badges were provided to the radiographers in the selected diagnostic centres to absorb the secondary scattered X-rays by different body regions. The body regions of interest were the chest, abdomen and lower limbs. The chest, abdomen and the limbs were chosen for the study so as to compare the relative intensity of the scatter of radiation by each of the regions of the body. In addition, the chest, abdominal and limb X-ray procedures are frequently sought because these body regions are associated with many health complications (Date, 2005).

During the process of measuring the secondary scattered X-ray dose, the TLD badges were located near the trunk at the back of the radiographer. The TLD near the trunk absorbed the X-rays that are scattered to the vital organs such as the gonads that have cells that are very sensitive to ionizing radiation. Different TLD badges were used for different body region exposures.

The patients were irradiated with X-rays either while lying on the bed or standing at some distance from the X-ray tube. The position of the TLD was at the back of the radiographer who was inside the radiographer's cabin during all procedures (Fig 3.1). The primary scattered X-rays were blocked from reaching the radiographer by the cabin walls. The TLDs only stored energy from X-ray radiation due to multiple scattering from the roof, floor and walls of the X-ray room which cause a radiation field in the X-ray room. Since the three diagnostic centres sampled were all using old X-ray machines, the kVp and mAs of the X-ray machine were set before each procedure was performed since both kVp and mAs settings determine the energy of X-rays reaching the patient and hence the degree of film blackening. For example, the settings for the chest and abdomen are 75 kVp and 20 mAs, while settings for the limbs are 53 kVp and 40 mAs. These settings are also adjusted depending on patient weight. The settings are obtained from a chart which is found in each diagnostic centre.

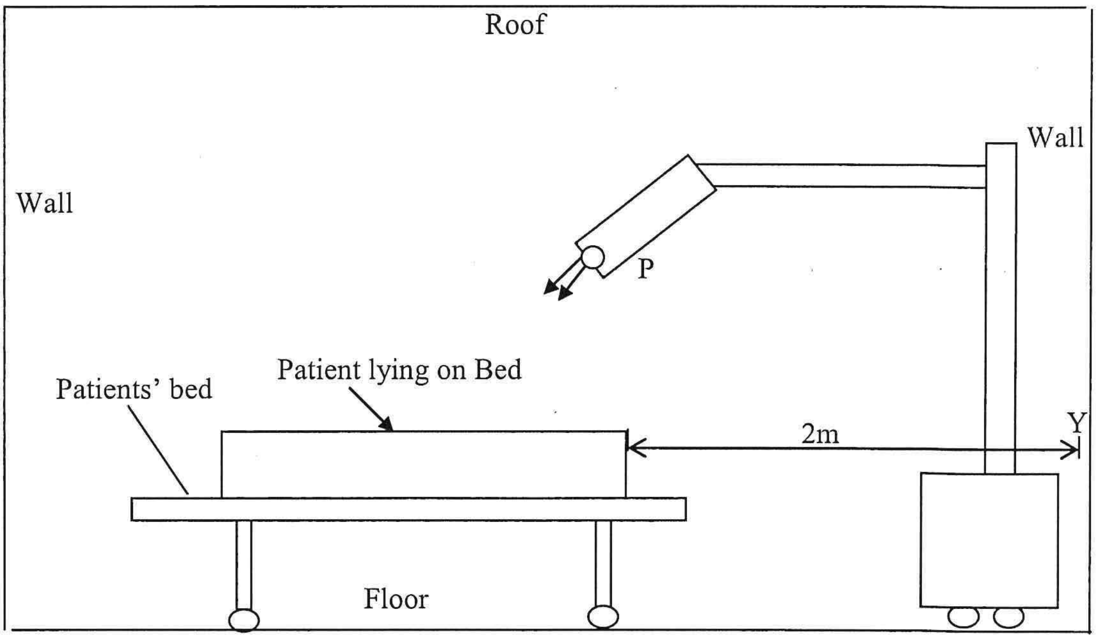


Figure 3.1: Schematic diagram of the X-ray room layout. *Y is location of back of the radiographer in the cabin and P is the casing of the X-ray tube and contains the gun where X-rays are generated.*

Three TLDs were provided to each diagnostic centre every month after which they were collected and read in a Harshaw analyser shown in Figure 3.2. This process was done for a period of six months. The number of patients whose chest, abdomen and limbs were X-rayed during the period of the study was recorded at the diagnostic centres. Mean secondary scattered X-rays per patient and mean monthly number of patients were determined. These were then extrapolated to obtain the annual secondary scattered X-ray dose.

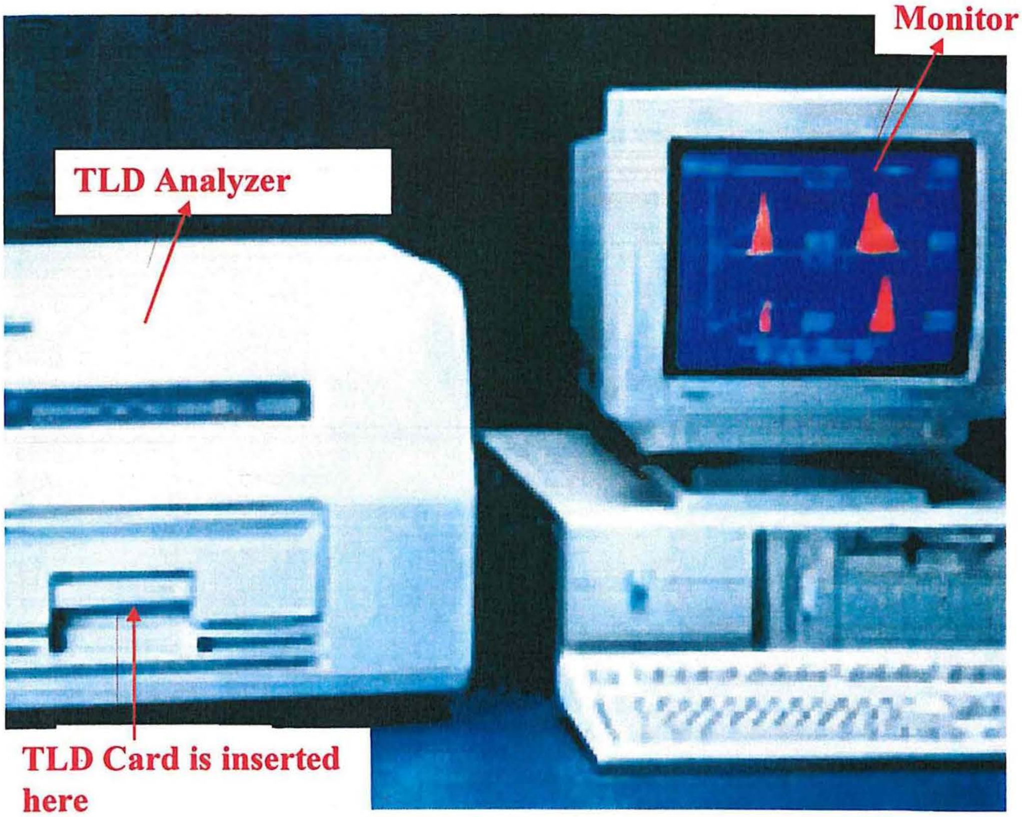


Figure 3.2: Harshaw 4500 Analyzer System

3.4 Calibration and Reading of a TLD Card

A TLD card was first annealed by heating it in the Harshaw 4500 analyser (Figure 3.2) to remove all the energy trapped from any radiatin e.g background radiation. The TLD card was then exposed to a collimated beam of a known source of radiation (the radiation from the known source is expressed in roentgens (1 roentgen= 0,01 sieverts). During this process, the scattered X-rays were absorbed and stored by thermoluminescent elements in the TLD.

The TLD card was again placed in the TLD Harshaw 4500 analyzer where it was heated. As the crystals in the card were exposed to increasing temperatures, light was emitted (Luo, 2006). The intensity of the emitted light is plotted as a function of temperature and a glow curve (Time Temperature Profile, TTP) is obtained as shown in Figure 3.3.

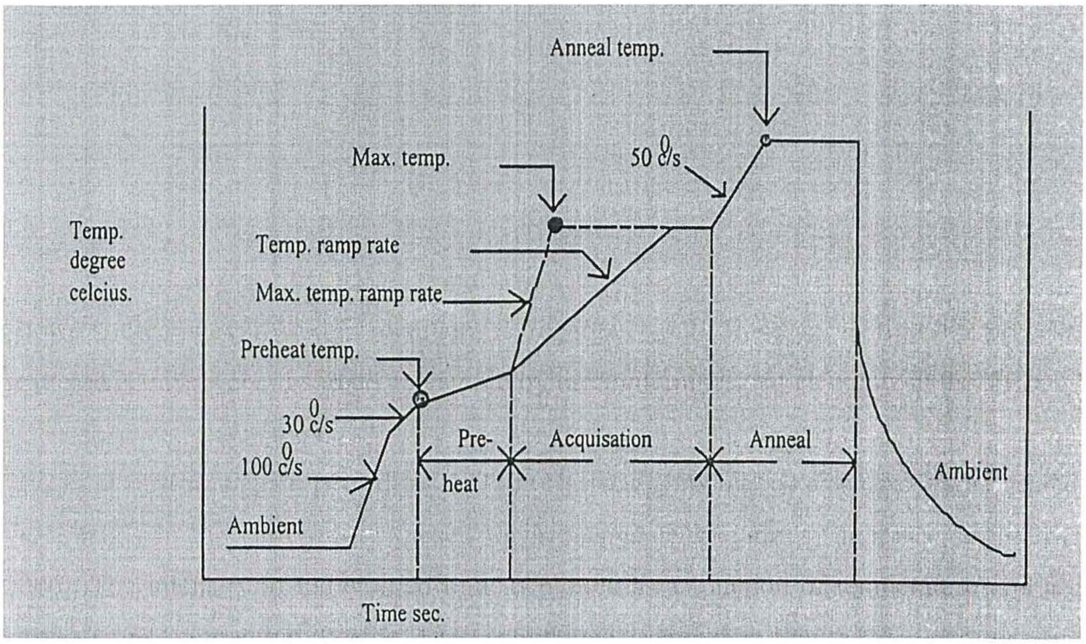


Figure 3.3: Time Temperature Profile curve for reading a TLD card (Kwaku, 1994)

The height of the glow curve is directly proportional to the energy of the radiation. The height of the curve is expressed in form of electric charge in microcoulombs or nanocoulombs. The nanocoulombs are converted to millisieverts by the equation

$$R = \frac{6Q}{1000} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.1)$$

where R is the X-ray dose, measured in mSv, Q is the electric charge in nanocoulombs. Equation 3.1 is called a conversion factor (Kwaku, 1994). When the calibrated TLD is exposed to radiation of unknown dose for example scattered X-rays in X-ray rooms, and then heated in the analyzer, the electric charge obtained on the glow curve can also be compared to that of the known source to obtain the radiation dose in sieverts.

During the reading of a TLD, a glow curve of electric charge versus temperature (Figure 3.4) as generated by the Harshaw Analyzer is obtained.

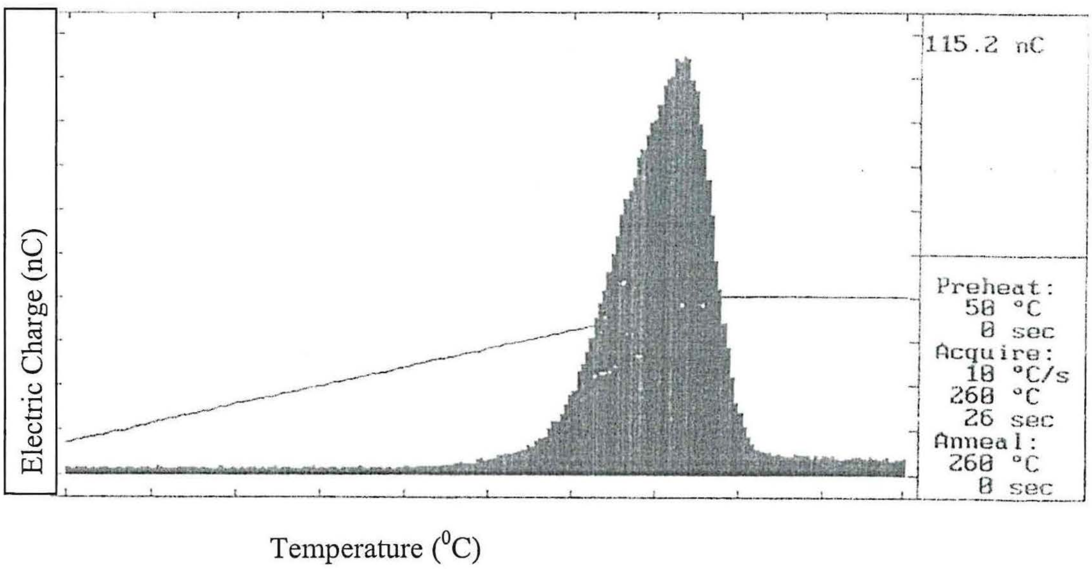


Figure 3.4: Glow curve for reading a TLD card.

From the Figure 4.2, 50 ^{0}C was the pre-heat temperature of the analyser; 10 ^{0}Cs^{-1} was the acquisition temperature per second (initializing to read) while 260 ^{0}C is the anneal temperature of the analyser. Annealing occurs for 26 s and then the card cools to its original temperature. The glow curve shown in Figure 4.2 gave an electric charge of 115,2 nC. Using equation 3.1 the secondary scattered X-rays in this case was obtained to be 0,691 mSv. This procedure was done for all the TLD cards each time they were read.

The TLD has an error of up to ±5% for high doses of $\geq$ 10 mSv absorbed in less than one hour. In the case where it is used to store and record low doses (<10 mSv) over a long time such as six weeks, each reading has an error of about ±1%. This small error may or may not be neglected in general calculations for the cumulative dose (Hendee, et al, 2005).

3.5 Data Analysis

The data obtained was analyzed statistically and also expressed graphically using computer software, Excel. Excel was used for drawing bar graphs and pie charts from the data.

From the number of patients exposed and the amount of secondary scattered X-rays in six months, the mean secondary scattered X-rays per patient was calculated. This was then used to project the annual cumulative dose to the radiographer.

CHAPTER FOUR: RESULTS OF THE STUDY

4.1 Introduction

The aim of this study was to determine the intensity of secondary scattered X-rays from some X-ray diagnostic procedures. The intensity of secondary scattered X-rays when the chest, abdomen and lower limbs were X-rayed was determined using TLD LiF-100 cards. These cards were worn at the back of the radiographer each time the radiographer was X-raying patients. For each procedure followed, the number of patients was recorded.

4.2 Results

A total number of 1447 patients were exposed to X-rays in the three selected diagnostic centres during the six months period of the study. The total number of patients X-rayed from Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre are shown in Table 4.1. Of the total number of patients exposed to X-rays, 34,6% patients had the chest exposed, 22,6% of the patients had the abdomen exposed while 42,8% of the patients had their lower limbs exposed. The distribution of the patients exposed for each procedure from each diagnostic centre is shown in Figure 4.1.

Table 4.1: Numbers of the Patients Exposed for each Procedure from each Diagnostic Centre

Diagnostic centre	**Number of patients**			**Total number of patients**
	Chest	**Abdomen**	**Lower limbs**	
Mutolere Hospital	169	110	315	596
Goodwill Imaging Centre	170	111	198	479
Mbarara Diagnostic Centre	162	106	106	374
Total	**501**	**327**	**619**	**1447**
Percentage	**34,6**	**22,6**	**42,8**	**100**

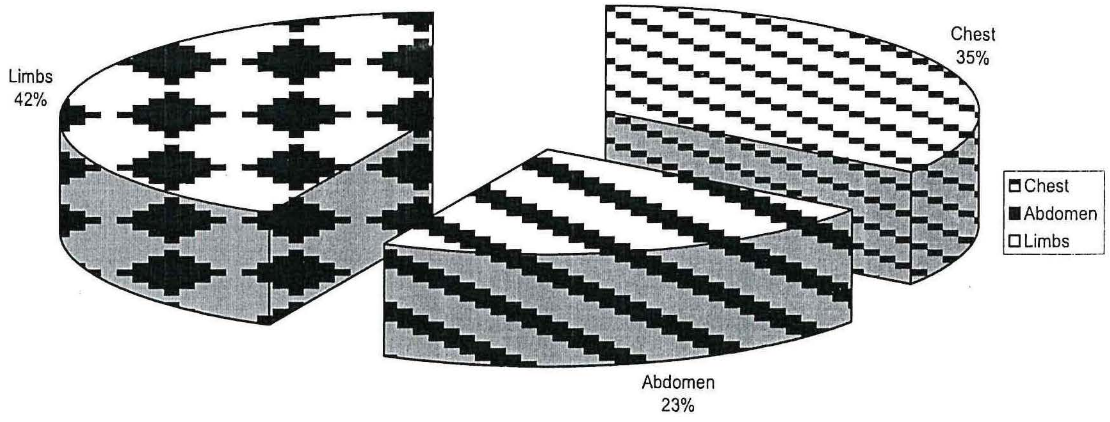


Figure 4.1: Percentage Distribution of Patients for each Procedure

From the results shown in Table 4.1 and also in Figure 4.1 above, the limb exposures constituted the highest number of X-ray exposures. This could probably be as a result of the rampant road accidents resulting from bad roads, over-loading of passengers in cars not meant for public transport and the use of motorcycles for public transport. Most of the cyclists are careless and inexperienced and cause many road accidents. Bad road usage could also lead to accidents. However, this is contrary to the work of Date that the abdominal exposures constitute a higher number of X-ray exposures than the limbs (Date, 2005). It was observed that from the diagnostic centres the limbs instead constituted the highest number of exposures. The chest region constituted the second highest number of X-ray exposures because of the many health complication associated with the chest region.

4.3 Secondary scattered X-rays for each Procedure at each Diagnostic Centre

The error per monthly reading which is ± 1%, was indicated at the top of each reading. The secondary scattered X-rays for each body region and the number of patients exposed for six months are shown in Tables 4.2, 4.3 and 4.4.

Table 4.2: Secondary scattered X-rays and number of patients exposed from Mutolere Hospital

Months	Region of the Body exposed					
	Chest		Abdomen		Limbs	
	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001
September 2011	35	0,480	20	0,273	106	0,330
November 2011	34	0,440	21	0,310	60	0,420
January 2012	21	0,227	17	0,253	19	0,146
February 2012	26	0,505	15	0,240	36	0,425
March 2012	28	0,509	23	0,329	51	0,717
April 2012	25	0,509	14	0,220	43	0,404
Total	**169**	**2,670**	**110**	**1,625**	**315**	**2,442**

Table 4.3: Secondary scattered X-rays and number of patients exposed from Goodwill Imaging Centre

Months	Region of the Body exposed					
	Chest		Abdomen		Limbs	
	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001
November 2011	26	0,440	21	0,279	15	0,179
December 2011	32	0,504	20	0,368	92	0,450
January 2012	36	0,585	17	0,289	36	0,343
February 2012	28	0,345	10	0,200	13	0,146
March 2012	28	0,457	27	0,282	21	0,235
April 2012	10	0,425	16	0,294	21	0,225
Total	**170**	**2,756**	**111**	**1,712**	**198**	**1,578**

Table 4.4: Secondary scattered X-rays and number of patients exposed from Mbarara Diagnostic Centre

Months	Region of the Body exposed					
	Chest		Abdomen		Limbs	
	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001	Number of patients	Cumulative secondary scattered X-rays (mSv) ± 0,001
February 2012	26	0,363	21	0,279	15	0,179
March 2012	30	0,504	28	0,368	19	0,227
April 2012	31	0,585	17	0,289	18	0,215
May 2012	28	0,345	10	0,166	17	0,210
June 2012	27	0,363	14	0,221	16	0,220
July 2012	20	0,345	16	0,294	21	0,236
Total	**162**	**2,505**	**106**	**1,294**	**106**	**1,236**

4.4 Comparison of the Secondary Scattered X-rays for the Procedures at each Diagnostic Centre

Using the results in Tables 4.2, 4.3 and 4.4, the secondary scattered X-rays for each procedure from each diagnostic centre were compared as shown in Figures 4.3, 4.4 and 4.5

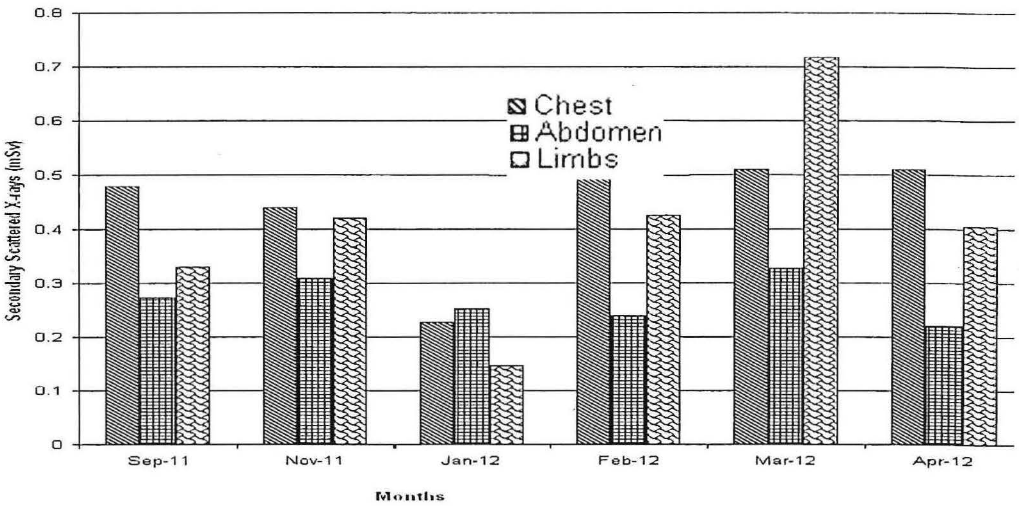


Figure 4.2: Secondary scattered X-rays for six months from Mutolere Hospital

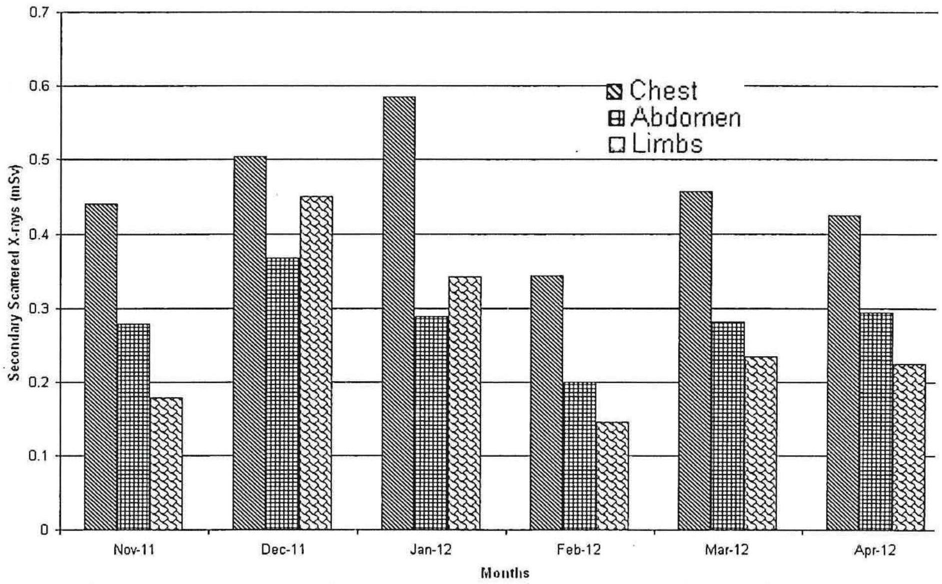


Figure 4.3: Secondary scattered X-rays for six months from Goodwill Imaging Centre

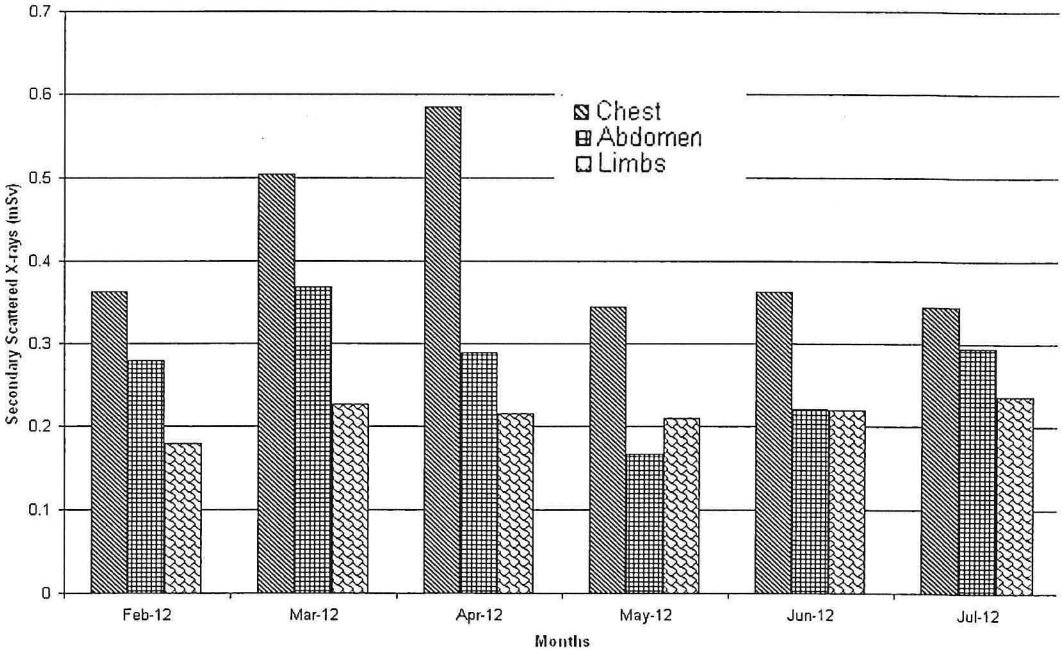


Figure 4.4: Secondary scattered X-rays for six months from Mbarara Diagnostic Centre

Using the results shown in Tables 4.3, 4.4 and 4.5, the mean secondary scattered X-rays per patient for each procedure was obtained by dividing the total cumulative dose for six months by the total number of patients exposed for each procedure during the same period. The mean scatter per patient and the mean monthly number of patients were used to predict the annual dose to the radiographer due to secondary scattered X-rays. This was done by multiplying the mean secondary scattered X-rays per patient by the mean monthly number of patients and then multiplying the result by twelve months. The results obtained are shown in Tables 4.5, 4.6 and 4.7.

Table 4.5: Mean values and projected annual dose for Mutolere Hospital

Body region	Secondary scattered X-rays per patient / (mSv) ± 0,001	Mean monthly number of patients	Predicted annual secondary scattered X-rays (mSv) ± 0,001
Chest	0,016	28	5,376
Abdomen	0,015	18	3,240
Limbs	0,008	53	5,088
Total cumulative dose			**13,704 ± 0,001**

Table 4.6: Mean values and projected annual dose for Goodwill Imaging Centre

Body region	Secondary scattered X-rays per patient (mSv) ± 0,001	Mean monthly number of patients	Predicted annual secondary scattered X-rays (mSv) ± 0,001
Chest	0,016	28	5,376
Abdomen	0,015	19	3,420
Limbs	0,008	33	3,168
Total cumulative dose			**11,964 ± 0,001**

Table 4.7: Mean values and projected annual dose for Mbarara Diagnostic Centre

Body region	Secondary scattered X-rays per patient (mSv) ± 0.001	Mean monthly number of patients	Predicted annual secondary scattered X-rays (mSv) ± 0.001
Chest	0,015	27	4,860
Abdomen	0,015	18	3,240
Limbs	0,012	18	2,952
Total cumulative dose			**10,692 ± 0.001**

From Tables 4.5, 4.6 and 4.7 the predicted annual dose of secondary scattered X-rays for each procedure per diagnostic centre were compared as shown in Figure 4.6.

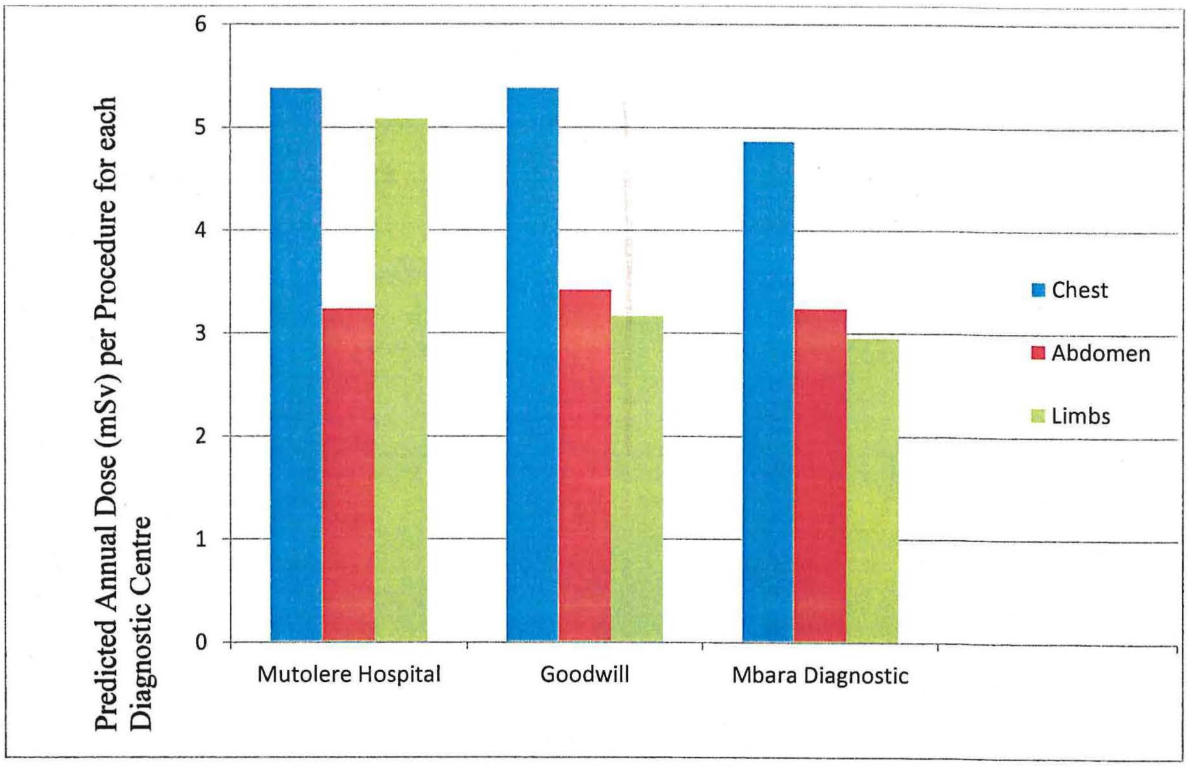


Figure 4.5: Predicted Annual Dose per Procedure for all the Diagnostic Centres

The mean secondary scattered X-rays per patient, $\overline{X}$, were obtained from the equation

$$\overline{X} = \frac{\sum M}{\sum N} \quad \text{...(4.2)}$$

where, $\sum M$ is the sum of the secondary scattered X-rays for all the procedures (i.e chest, abdomen and limb) for a period of six months, while $\sum N$ was the total number of patients that were exposed for all the procedures during the same period of time. The values obtained for the diagnostic centres are 0,011, 0,013 and 0,014 mSv for Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre respectively.

The mean secondary scattered X-rays per patient for all procedures obtained from Equation 4.2 were used to predict the maximum number of patients a radiographer at each diagnostic centre can annually expose without being at risk. Since the dose limit for radiation workers is 20 mSv annually, the maximum number of patients, P, that a radiographer can X-ray annually without being at a risk is obtained from the equation

$$P = \frac{20}{X} \quad \text{...(4.3)}$$

where, X is the secondary scattered X-rays per patient for the three body regions from each diagnostic centre. The results are shown in Table 4.8.

Table 4.8: Mean Secondary Scattered X-rays per Patient for all Procedures and Maximum Number of Patients that a Radiographer can X-ray Annually Without being at a risk.

Diagnostic Centre	**Mean secondary scattered X-rays for all procedures (mSv)**	**Maximum number of Patients that can be X-rayed without radiographer being at a risk**
Mutolere Hospital	0,011	1818
Goodwill Imaging Centre	0,013	1538
Mbarara Diagnostic Centre	0,014	1429

From Table 4.8, the maximum numbers of patients that a radiographer at the diagnostic centres can expose with minimum risk were compared as shown in Figure 4.6. This number of patients should not be exceeded at any time during one year if the radiographers are to minimize unsafe exposures. However, since patients go to diagnostic centres to seek radiography services without being restricted in number, the number of patients X-rayed per radiographer should be properly recorded in order to minimize exposure to radiographers.

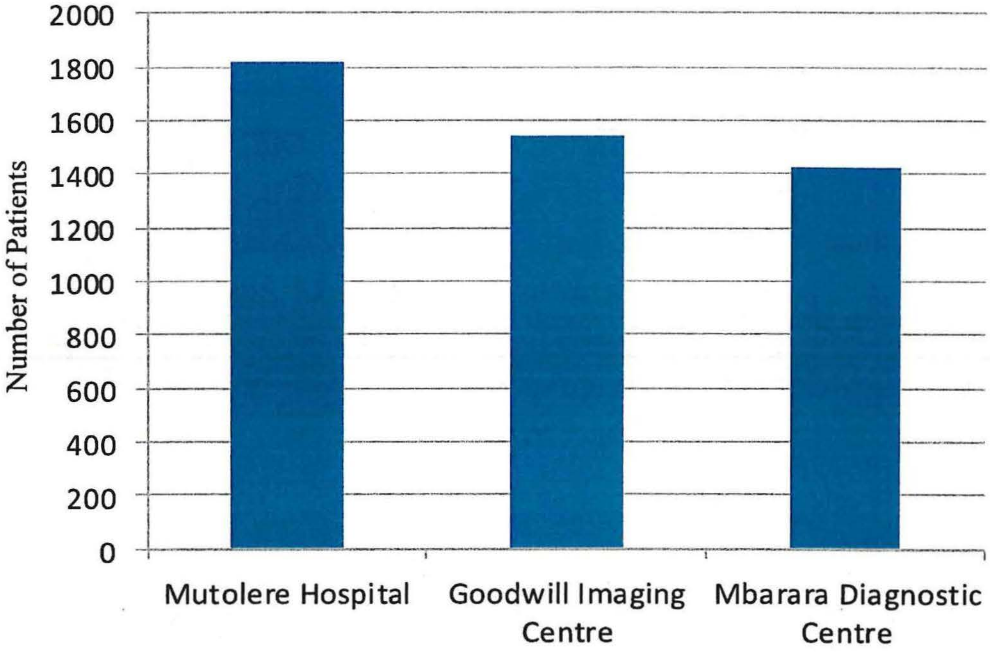


Figure 4.6: Number of Patients per Diagnostic Centre that a Radiographer could Expose Annually without being at a Risk

The maximum number of patients that can be exposed annually per radiographer with minimal risk decreases from Mutolere Hospital to Goodwill Imaging Centre and finally to Mbarara Diagnostic Centre. The reason for this decrease is that for all the three diagnostic centres, there was a small difference in the number of patients whose chest and abdomen were exposed i.e for Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre, the number of patients who underwent chest X-ray exposure were 169, 170 and 162 respectively. Similarly, 110 and 111 and 106 patients underwent abdomen exposure at Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre respectively. However, there was the highest number of patients for limb exposures at Mutolere Hospital (315) than the other two diagnostic centres i.e 198 and 106 for Goodwill Imaging Centre and Mbarara Diagnostic Centre respectively.

CHAPTER FIVE: DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussions

From the three diagnostic centres, the limb exposures constituted the highest number of patients followed by the chest and finally the abdomen. The frequency of each of the procedures depends on the health complications associated with each body region. The rampant road accidents could result into fractures and this could have caused many people to seek limb X-ray examinations. The chest houses vital organs like the lungs and the heart and these vital organs are associated with a variety of complications like tuberculosis which cause many people to seek chest X-ray examination.

From Figures 4.3, 4.4 and 4.5 the chest region generally gave the highest dose of secondary scattered X-rays even when a small number of patients were exposed, except for the month of March-2012 at Mutolere Hospital. This is attributed to two reasons: the chest examination uses a strong beam of X-rays of 75 kV. The higher the tube voltage, the greater the X-ray energy and this leads to greater the scattering. In addition, the chest contains more dense tissues than other body regions. The regions that have a high density have high atomic numbers hence there is more electron transition of X-ray photons causing scattering (Sprawls, 2002; Sharpe, 1964).

Secondary scattered X-rays by the human body depend on the density of the tissues X-rayed (Morrish and Goldstone, 2008: Sharpe, 1964). From Figure 4.3 it can be seen that the secondary scattered X-rays are high when the chest is examined. Therefore this agrees with theory about scatter of X-rays by different regions of the body. The higher the density of the tissues, the greater the scattering of X-rays. The higher scatter from the limbs and chest is a result of the big number of patients exposed. The limbs contributed a higher dose of secondary scattered X-rays than the abdomen because a high number of patients were exposed though the tube voltage used for both procedures was 50 kV.

In all the three diagnostic centres, the abdomen contributed the lowest dose of secondary scattered X-rays due to the fact that the abdomen region has soft tissue and the examination uses low tube voltage. However, the secondary scattered X-rays from limb exposures at Goodwill Imaging Centre is slightly higher than that at Mutolere Hospital for fewer patients. This could have resulted from some cases of multiple exposures e.g on 4th February 2012 when a patient at Goodwill Imaging Centre had both tibia and fibula exposed but this was recorded as one patient i.e this should be recorded as two patients.

By extrapolation basing on the secondary scattered X-ray dose for six months, the annual cumulative doses of secondary scattered X-rays are 13,704, 11,964 and 10,692 mSv respectively for Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre. None of the values exceeds the annual dose limit of 20 mSv for radiographers (IAEA Draft Safety Standards, 2002), though the cumulative dose for Mutolere Hospital is slightly higher than that of the others. However, the radiographers at all the diagnostic centres may develop the stochastic health effects during their life-time. According to Suric, occupational exposure $\geq$ 20 mSv annually poses a health risk to radiographers (Suric, *et al*, 2011). The higher value of the cumulative annual dose at Mutolere Hospital is because of the high numbers of patients were exposed at Mutolere Hospital.

However, according to the IAEA Draft Safety standards of 2002, an annual dose that does not reach or exceed the annual dose limit of 20 mSv for radiographers is not necessarily safe especially if the individual is exposed over many years during a lifetime. Therefore, occupational workers from all the three diagnostic centres should take precaution against this cumulative dose. The likelihood of the stochastic effect depends on how close the annual absorbed dose is to the dose limit (Hendee, *et al,* 2005).

The values of the secondary scattered X-rays for the chest examination for the months of February 2012, March 2012 and April 2012 at Mutolere Hospital (Table 4.2) are higher than those of September 2011 and November 2011 with respect to the number of patients exposed. This anomaly arises from multiple exposures of a single patient. This occurs when the images obtained are not clear, such that the patient is further X-rayed to obtain a clearer image. Each exposure causes scattering of X-rays (Niklason, *et al,* 1981).

5.2 Conclusion

The study found out that generally the limb procedures were the most prevalent and constituted the highest percentage of people who sought X-ray examinations from the three diagnostic centres.

The study found out that the chest generally contributes the highest intensity of secondary scattered X-rays with respect to the number of patients in the three diagnostic centres. The annual secondary scattered X-ray dose was predicted to be 5,376 ± 0,001 mSv, 5,376 ± 0,001 mSv and 4,860 ± 0,001 mSv for Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre respectively. This was followed by the limbs (5,088, 3,168 and 2,952 mSv) and finally the abdomen (3,240, 3,420 and 3,240 mSv) respectively for Mutolere Hospital, Goodwill Imaging Centre and Mbarara Diagnostic Centre. However, for Mutolere Hospital, the limbs contributed exceptionally the highest intensity of secondary scattered X-rays because a very large number of patients were exposed.

None of the diagnostic centres had a projected annual dose near or above the safe dose limit of 20mSv per year for the occupationally exposed persons. From the basic Radiation Safety Standards set by the IAEA for the protection of radiographers against ionizing radiation, none of the diagnostic centres has an over exposure of the radiographers to X-rays while on duty. Nevertheless radiographers should ensure proper shielding due to the cumulative dose.

5.3 Recommendations

It was observed that some rooms being used were not originally designed for X-ray purposes. This was seen in diagnostic centres like Goodwill Imaging Centre where plywood was used to separate the radiation area from the waiting room, though X-rays are highly penetrative. This could have affected the value of the intensity of scattered X-rays that was measured. Therefore the National Regulation Authority, the Atomic Energy Council should ensure proper standards against which construction of X-ray rooms should be based so as to avoid a situation where ordinary rooms are used as X-ray rooms. In addition, a Radiation Safety Officer should be employed at diagnostic centres where ionizing radiation is used in diagnosing and treating diseases. This person helps in ensuring proper safety standards against ionizing radiation. This was found lacking in the diagnostic centres.

A maximum number of patients should be exposed per radiographer annually in order to minimize exposure of the radiographer to up to 20 mSv annually. One way of doing this would be to ensure that Diagnostic centres that administer ionizing radiation should be properly staffed with radiographers such that they work in shifts. This will reduce on the annual dose received by each radiographer since they would not work throughout the year though this does not reduce the collective dose at the diagnostic centres. To reduce the collective dose to radiographers, the X-ray machine should be checked so that it is in good condition and is not leaking. Also radiographers should ensure maximum shielding.

Two other areas for further study were recommended by the study. One could be carried out to determine secondary scattered X-rays in Referral Hospitals since many patients visit these hospitals for X-ray diagnostic services. Also further studies should be carried out to investigate the intensity of secondary scattered X-rays by other parts of the body such as the neck, skull and the lumbar that were not covered by the study. Also the intensity of secondary scattered X-rays by the body parts covered in the study should be investigated over a longer period of time such as two years. This is because the study took a shorter period (six months) due to time constraints.

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