USE OF EXTENDED FOCUS-TO-FILM-DISTANCE TECHNIQUE FOR DOSE REDUCTION IN THE DIAGNOSTIC EXAMINATION OF THE PELVIS

BY

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DECLARATION

I hereby declare that: the work in the thesis entitled ‘Use of Extended Focus to film Distance Technique for Dose Reduction in Diagnostic Examination of the Pelvis’ has been performed by me in the Department of Physics under the supervision of Professor T.C. Akpa and Professor S. P. Mallam.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

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CERTIFICATION

This thesis titled "**Use of Extended Focus to film Distance Technique for Dose Reduction in Diagnostic Examination of the Pelvis"** by Simon, Maduakonam Nwafor meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to the Almighty God who kept me through it all by his grace, my lovely wife who stood by me while it lasts and my wonderful children, Fortune and Victory.

ACKNOWLEDGEMENT

I would like to express my profound and sincere gratitude to all those in various capacities that contributed to the success of this study. I am greatly indebted to my supervisor Prof. T C Akpa who worked closely with me on nearly daily basis for his calm, criticism and suggestions throughout this work. I would also want to express my appreciation to Prof. S. P. Mallam for his good advice and provision of useful materials. Their contribution arising from deep wealth of research experiences and love for me contributed immensely to the success of this study.

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I appreciate my entire family, my beloved wife, Nonye and my two children, Fortune and Victory for their love, patience and understanding throughout the course of this work. Above all, I am very grateful to God Almighty who gave me life, strength and knowledge to this end.

ABSRACT

It is essential to reduce the radiation exposure in diagnostic radiology as much as possible because of their inherent danger. This is kwon as ALARA principle. The process of reaching the balance between dose and image quality is optimization. This work is aimed at finding if there are reductions in dose to the pelvis due to a change in focus to film distance (FFD) with the condition that a diagnostic image of the pelvis is obtained. The different examinations involving the direct irradiation of the gonads were studied for the period of six months in the Radiology Department of Ahmadu Bello University Teaching Hospital, Zaria to determine the contributions of pelvic exposure to patient's radiation hazards. It was found that examinations' involving the pelvis contributes about 24% of the total collective detriment to the patients. Entrance skin doses were measured using patients and a constructed pelvic phantom by thermoluminescent dosimeters (TLD). Dose to the pelvis was measured at varied FFD from 100–145cm. Optical densities were measured at positions of the ovaries and the result showed no significant difference. The radiographs obtained at varying FFDs were found to be of good quality after their assessment by clinicians. The increase in FFD showed dose reduction of 8.95% and 6.30% for fixed and varying collimation settings respectively. The backscatter factor was found to be constant and the percentage reduction in dose due to air attenuation was shown to be significant.

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CHAPTER ONE

INTRODUCTION

1.1 General Perspective

In recent years there has been increasing concern amongst patients and radiological workers that unnecessary high levels of radiation are being delivered for common x-ray examination. Once an examination has been justified, it is important that the subsequent imaging process is optimized by ensuring that the radiation dose delivered is as low as reasonably achievable (ALARA) and consistent with an image of high diagnostic quality. This ensures that the clinical objective of the examination is met with lowest possible risk to the patient, Brennan *et al*. (2004).

The dangers of ionizing radiation have been appreciated for many years and the levels of risk from high doses (e.g. nuclear explosions and therapeutic use) are well established (ICRP 60). It has been more difficult to estimate the danger from the much lower levels encountered in diagnostic radiology and one certain fact remains that there is

no safe level of exposure below which adverse effects cease to occur, hence the need to reduce the dose as much as possible by use of all manner of techniques applicable without compromising the quality of the radiographs.

It is worthy to note that the commonplace investigations such as lumber spine views, hips, pelvis, hysterosalpingography (HSG), retrograde urethrogram (RUG), intravenous urography, barium enemas and micturating cystourethrograms all results in significant levels of exposure to the pelvic organs. Public concern about the harmful effects of low level ionizing radiation received during a radiographic investigation has prompted the evaluation of techniques in the use of diagnostic equipment that will further reduce dose. Patient dose surveys have been to provide information on doses in different hospitals for comparison that gives an indication of whether the techniques used in our own are optimized in terms of dose (Robinson and McLean, 2001).

Pelvis is a relatively high-dose examination and contributes significantly to collective dose, making it a useful examination to test any dose-reducing procedure. Patient doses in radiography primarily depend on the entrance skin exposure, the size of the x-ray beam and the sensitivity of the organs and tissues that are irradiated during the radiographic examination. The patient effective dose takes into account the dose to all the organs that are irradiated during a radiological examination, as well as their sensitivity to radiation. The patient effective dose is also (approximately) proportional to the exposed area of film and to the total number of films generated. The body region being examined is another important factor for determining patient dose with the trunk of the body being most radiosensitive. The extremities are the least radiosensitive with the head having a sensitivity that falls between the two extremes.

Many dose-reducing methods have been considered in recent years. These include the use of rare-earth filters, fast film-screen combinations and low attenuation materials in cassettes. Although research has demonstrated the effectiveness of these and other methods for minimizing dose, there are often cost implications to imaging departments, and in the current climate of finite resources, resultant application appears limited. It is therefore, important to consider dose-reducing measures with little resource implications, Brennan *et al*. (2004). Increasing the distance between the patient and the x-ray tube focus (focus-to-film distance, FFD) is one such method. Due to the inverse square law, it is evident that the radiation dose at the patient's entrance surface will be greater than at the image receptor.

1.2 Statement of Research Problem

It is a well known fact that radiation doses from the use of ionizing radiations and radionuclide in medical diagnosis and treatment are the largest contribution to the collective dose from all man-made (artificial) sources of radiation, occupying about 15% of the total collective dose, and rapidly increase over the world due to their relatively high frequency, Park (1998).

From this, it is obvious that medical use of ionizing radiation should be of major concern for radiation protection. It is also well known that one of the risks associated with ionizing radiation is cancer induction. It is assumed from all research models to date that there is no threshold dose below which radiation exposure does not cause cancer. Health physicists have devoted many efforts to the minimization of patients' doses in diagnostic radiology. Through these efforts, substantial reductions in radiation doses to patients resulting from radiographic procedures have been achieved in many countries. A useful background for such efforts is the knowledge of radiation doses to the patients.

This has led to surveys of patients doses in diagnostic radiology in many countries, (Manning, 2004).

The unavailability of anthropomorphic phantoms is a problem resulting in construction of a perspex water phantom.

1.3 Aims and Objectives

The aim of this study is to ensure better service delivery in Radiology Department of Ahmadu Bello University Teaching Hospital (ABUTH) to contribute to the health of the patients who come to the department for x-ray examinations.

The major objective is to study methods of dose reduction in the radiology department of ABUTH. The other objectives are:

i). to construct water in perspex phantom that simulates an average adult pelvis in Ahmadu Bello University Teaching Hospital, Shika.

ii). to determine the effects of increasing FFD and enhance dose using perspex water phantom .

iii). to evaluate the film density and determine the optimal density.

iv). to determine combined effect of collimation and changes in FFD on dose to the patients.

v). to evaluate the backscatter factor for varying FFD.

1.4 Justification of Study

The beneficiaries of this study include radiographers, department, government and literature. The patients will benefit from this study by the fact that less radiation will be administered to them thereby minimizing dose and risks effect of ionizing radiation. It is evident that radiographers/staff also receive some appreciable amount of radiation

during examinations especially as they are occupationally exposed in their everyday service. It therefore implies that low dose to the patients will invariably be applicable to the staff. In view of the financial implications in acquisition of newer improved equipment and accessories, the department will spend less by adopting this method of dose reduction and putting it into practice. The government will spend less in purchase of drugs for the treatment of persons affected by radiation exposure since public exposure will be highly minimized.

Data from this study will serve as a useful baseline against which measurement at individual x-ray departments may be compared to and also as an investigation of the possibility of further reduction in patients' doses. In order to provide refined assessment of world wide exposures, UNSCEAR (2000) has recommended further reviews of global practice. The review according to this document will involve systematic compilation of new national survey data. Hence, the doses reported in this work will also be useful for this kind of review by both local and international organizations.

1.5 Scope and Limitations

This study is limited to the measurement of radiation doses to the pelvis in diagnostic examinations using conventional radiographic techniques with special attention to the extended focal-film distance efficacy on dose reduction.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Production of X-Rays

2.1.1 Energy Lost by Electrons

X- rays are produced when high velocity electrons give up energy by either one of the two processes: the deceleration of a fast-moving electron resulting in conversion of some of its kinetic energy into x- rays (bremsstrahlung) or the movement of an electron between two inner shells in an atom with the difference between the binding energies of the two shells being radiated as an x-ray photon (characteristic radiation). These two processes occur in the target of an x-ray tube (Hay and Hughes, 1986).

2.1.2 The Principles of Operation of an X-Ray Tube

In a modern x-ray tube, which is sometimes called Coolidge tube after the inventor, electrons are released from heated filament by thermionic emission. The electrons are then accelerated across the tube by a high voltage applied between the filament and the anode. When the electrons reach the anode, they are traveling at a high velocity, therefore they have high kinetic energy and this is converted into x- rays and heat as the electrons interact with the atoms of the tungsten target.

The filament that is usually a spiral of tungsten wire (so that it will have a larger surface area from which it emits electrons) is heated by passing an electric current through it from a low voltage supply. Electrons are then released from the filament by thermionic emission. Tungsten is used because it produces appreciable thermionic emission at temperature below its melting point, Hay and Hughes (1986).

A high voltage supply is connected between the filament, which acts as the cathode, and the target that is part of the anode of the tube. The targets of x-ray tubes

used in medicine are usually made up of tungsten, which has a high melting point, adequate thermal conductivity, and a high atomic number, which increases the efficiency of x-ray production. The anode is specially designed considering that: the electron bombardment gives rise to a great amount of heat (99%) and only a small proportion of x radiation (1%). X-ray tube must be capable of producing images which are sharp in outline and the beam must therefore originate from a small source, and the kinetic energy gained by the electrons from the filament is released as they are accelerated to high velocity by the positive voltage applied to the target. The electron then gives up this energy by interactions with the target (Hay and Huges, 1986; Ball and Moore, 1986).

The glass envelope and the vacuum: A high vacuum exists in the tube so that there is no gas present to produce electron by ionization energy. The tube envelope is made up of hard heat resistance glass that serves and supports the electrodes and maintains the vacuum. It is required that the envelop should be able to withstand heat and mechanical stress, serve as an electrical insulator able to withstand high voltage and be capable of being sealed to the electrodes with a vacuum tight, heat proof seal. The envelope is normally of a thinned window (Thompson and Ashwort, 1970).

A shield or focusing cup mounted near the filament forms part of the cathode assembly. This protects adjacent parts of the tube wall from damage by electron bombardment and is so shaped that it produces an electric field that focuses the electrons onto a small area of the target known as the focus or focal area. It is from the focal areas that the x -rays emerges (Chesney and Chesney, 1985).

The tube shield is to the casing in which the glass x-ray tube is contained. The metal case protects people against (i) radiation risk and (ii) electrical risk. Because it gives radiation protection, it is said to be ray-proof and shock proof because it gives

electrical protection. The tube shield or housing is made of steel firmly earthed to provide electrical protection hazards and it is lined with lead to provide radiation hazard protection. The main features of x-ray tube are shown in fig. 2.1.

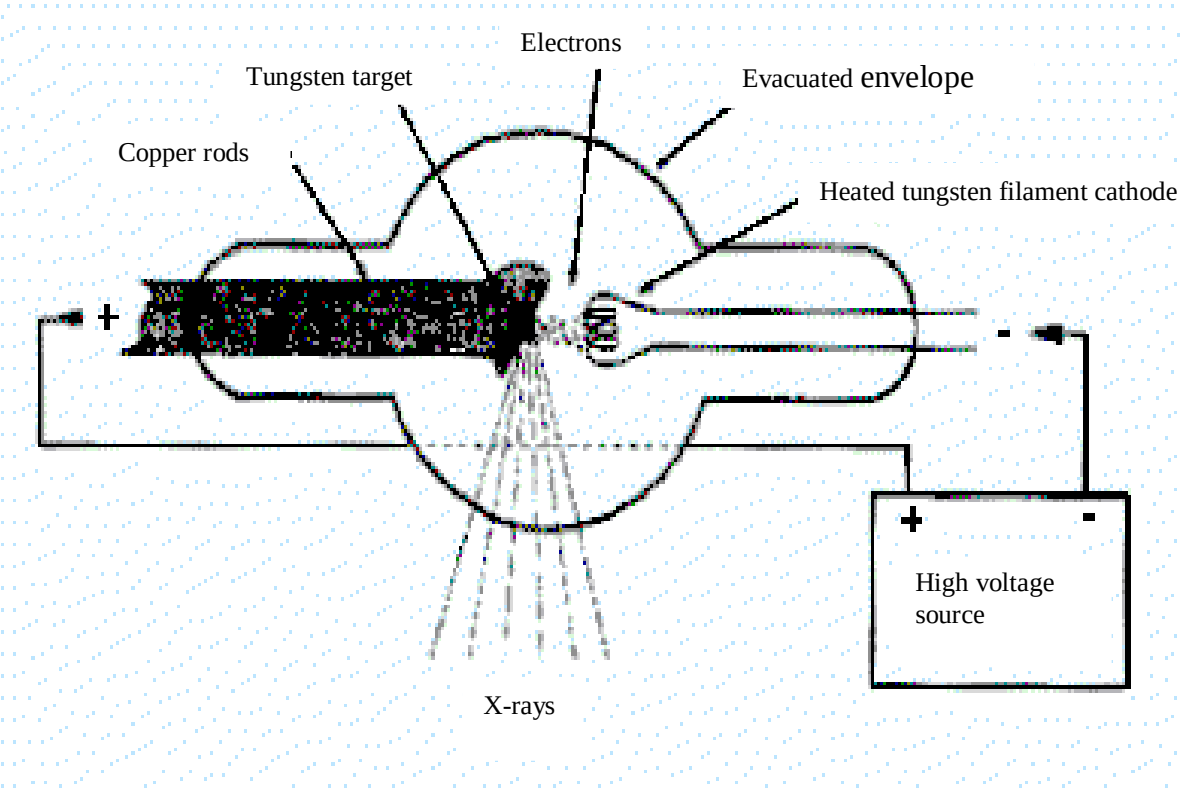


Fig. 2.1: Sketch of an X-Ray Tube

2.2 Interaction of Radiation With Matter

Interaction involves transfer of energy from the radiation to the matter with which it interacts. Matter consists of atomic nuclei and orbital electrons. Radiation may interact with either or both constituents of matter. Interaction probability and penetrating power of any radiation depends on certain factors that include: type of radiation, energy of the radiation and the nature of the absorbing medium.

During an interaction, the atoms of the absorber are either excited or ionized depending on the degree of energy transfer from the interacting radiation. Energy transferred is usually dissipated as heat (Cember, 1989 and Hay and Huges, 1986).

X-ray interactions are important in diagnostic examination for many reasons. For example, the selective interaction of x-ray photons with the structure of the human body produces the image; the interaction of the photons with the receptor converts an x-ray or gamma image into one that can be viewed or recorded (Sprawls, 1993).

2.2.1 Attenuation and Scattering

When a beam of x- and gamma- rays pass through matter, their intensity is reduced. The beam is attenuated and some of the energy that is originally contained is taken up, or absorbed by the irradiated material. The other energy is simply deflected out of the beam to travel on in some new direction and is called scattered radiation. Each of this plays an important part in radiology. Different attenuation in different tissues produces the radiographic pattern: absorption produces the radiograph and biological effects needed in radiotherapy, whilst scattered radiation brings problems to both diagnosis and radiotherapy (Meredith and Massey, 1986).

2.2.2 The Absorption of Energy

The absorption of energy in matter from the basis of radiology and radiotherapy implies that when a beam of x-rays or gamma rays passes through matter, the interaction result in a reduction in the intensity (i.e. the energy per unit area per unit time) of the beam. Some of the energy is absorbed by the medium and some scattered out of the beam. The energy, which is absorbed by the medium, causes the changes that we observe in the medium e.g. chemical and biological changes. The energy is absorbed by various processes and is converted initially into kinetic energy of electrons in the medium. The

electrons then move in the medium producing ionization and excitation of atoms and molecules resulting in turn in chemical change (Hay and Hughes, 1986).

2.2.3 Photoelectric Absorption

This occurs when an incident photon has energy equal to or greater than the binding energy of an electron in an atom of the medium. In this case, the photon can ionize the atom by ejecting an electron from a shell. The incident photon gives up all its energy to the atom. The electron, called secondary electron or photoelectron, is ejected with kinetic energy equal to the energy of the incident photon minus binding energy. The outer electrons move in to fill the gaps in the inner orbit produced by the radiation. This transition is accompanied by the emission of characteristic x radiation in the form of a secondary photon. The photoelectrons ejected by the radiation are emitted with a velocity υ determined by the equation

$$h\upsilon = \frac{mv^2}{2} \qquad 2.1$$

Where W is the energy required to remove the electron from its position in the atom and m is the electron mass. The characteristic x radiation is identical in nature to that generated in the target of x-ray tube. In this process, no scattering occurs because the incident photon gives up all its energy and ceases to exist. Energy is absorbed and is present in the medium initially as the kinetic energy of the photoelectron, (Meredith and Massey., 1986 and Young, 1970).

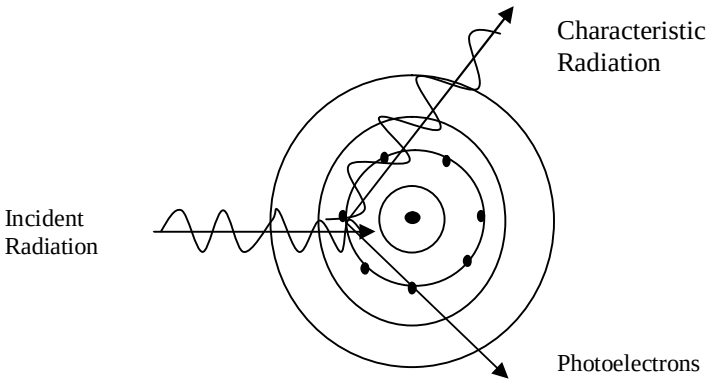


Fig. 2.2: The Photoelectric Effect

2.2.4 The Compton Scattering

Compton scattering is an interaction of photons with ″free″electrons, which can be visualized as billiard-ball-like collisions. The photon hands on some of its energy to the electron and itself continues in a new direction but with reduced energy and hence with increased wavelength. As shown in Figure 3, the electron recoils with the energy lost by the photon.

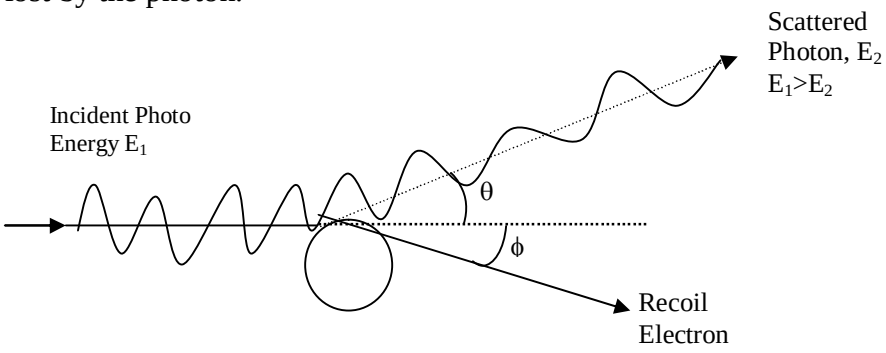


Fig 2.3: The Compton Scattering Process

It will be noted that the wavelength change depends only upon the angle through which the radiation is scattered. Compton process results in both attenuation and absorption. The result of Compton process is that the energy of the initial photon is shared between the scattered photon and the recoil electron. Most of the energy is

absorbed with the high-energy radiation, whereas at low energies, most of the photon is scattered. The recoil electron is called the secondary or Compton electron (Meredith and Massey, 1986 and Young, 1970).

2.2.5 Pair Production

When a photon whose energy is in excess of 1.02 MeV passes close to the nucleus of an atom, the photon may disappear, and in its place, a positive and a negative electron appear. Mass is produced from energy whilst the total amount of charge remains unchanged by the simultaneous production of equal positive and negative charges.

$$E = mc^2 \qquad 2.2$$

Where E = the energy associated with a mass m c is the velocity of light. The mass of either a positive or a negative electron is equivalent to 0.51 MeV of energy. The minimum energy at which it occurs is 1.02 MeV. This is because positrons are very rare and have no permanent place in its scheme of things, the created positron links up with another negative electron and they ″annihilate″one another changing back into two photons each of 0.51 MeV energy. Of the energy (E) originally removed from the beam, the amount absorbed is (E-1.02 MeV) (Meredith and Mersey, 1986 and Young, 1970).

2.3 Radiation Measurements and Detection

2.3.1 The Bases of the Measurements

The measurement of quantity of x-ray or gamma radiations can be based on any of the effects produced by radiations, for example, ionization, chemical change, and photographic effects. Some effects are readily measurable only if large quantities of radiation are involved and some depend very much on the quality of the radiation producing them. The effect that is most suitable for general use over a wide range of

qualities is the ionization produced in air by the radiation known as exposure. The amount of ionization produced is related to the energy absorbed by the air and is measured by collecting the ions formed and this is particularly useful as it gives a measure of the energy (dose) absorbed by soft tissue exposed to radiation. This is because air and soft tissue have approximately equal effective atomic numbers (7.6 and 7.4 respectively) and hence similar attenuation coefficients; therefore, the energy absorbed per unit mass is the same for equal exposures.

2.3.2 Absorbed Dose

A human body absorbs most of the radiation energy delivered to it. The portion of an x-ray beam that is absorbed depends on the penetrating ability of the radiations, the size and density of the body part exposed. In most clinical situations, more than 99% is absorbed.

Absorbed dose is the fundamental quality that describes the effect of radiation in a tissue or organ. It is the energy deposited in a small volume of matter (tissue) by the radiation beam passing through the matter divided by the mass of the matter. Absorbed dose is measured in terms of energy deposited per unit mass of tissue or matter. The SI unit is the joule per kilogram (J kg^{-1}) and is given the name gray (Gy); (Sprawls, 1993).

2.3.3 Equivalent Dose

Equivalent Dose (H) is the quantity commonly used to express the biological damage or impact of radiation on persons receiving occupational or environmental exposures. Personnel exposure in a clinical facility is often determined and recorded as a dose equivalent. It is used as a measure of the biological effect of a particular type of radiation on organs or tissues. It is calculated by multiplying the absorbed dose to an organ or tissue by a dimensionless factor called the radiation-weighting factor (W_R)

$$H_{TR} = D_{TR} \times w_R \qquad 2.3$$

Where H_{TR} is the equivalent dose to an organ or tissue T delivered by radiation type R. D_{TR} is the absorbed dose in an organ or tissue delivered by radiation type R and W_R is the radiation-weighting factor for radiation type R. The conventional unit for dose equivalent is the rem, and the SI unit is the Sievert (Sv). 1 Sv = 1 J kg $^{-1}$, 1 Sv = 100 rem (Sprawls, 1993).

2.3.4 Effective Dose

Some tissues and body organs are more sensitive to radiation than others are and an equivalent dose in one organ may be more hazardous than the same equivalent dose in another organ. The International Commission on Radiological Protection (ICRP) recommends tissue-weighting factors, which are applied to the specific body organs. The tissue-weighting factor takes into consideration the different radio sensitivities of the different organs and tissues. The effective dose (E) is the sum of the tissue equivalent doses multiplied by the appropriate tissue-weighting factor for those organs and tissues.

$$E = \sum_T \left(H_T \times w_T \right) \qquad 2.4$$

Σ_T indicates the sum for each organ or tissue type T, E is the total effective dose to all exposed organs and tissue, H_T is the equivalent dose to an organ or tissue T and w_T is the tissue-weighting factor for an organ or tissue type, T.

The risk of cancer induction from an equivalent dose depends on the organ receiving the dose. The effective dose is used to compare the risks when different organs are irradiated. The effective dose by definition is an estimate of the uniform, whole body equivalent dose that would produce the same level of risk for adverse effects from the non-uniform partial body irradiation (Sprawls, 1993). The SI unit is the Sievert (Sv).

2.3.5 Collective Dose

This is the product of the average dose and number of persons exposed in a given practice.

$$S = \int_0^{\infty} EP(E)dE \qquad 2.5$$

Where P(E)dE is the total number of persons receiving an average effective dose, E from a practice. The collective dose is a measure of total detriment to a population or group from a practice. In this work the detriments associated with pelvic examination was qualified using collective dose estimation for the period under study.

2.3.6 Mechanisms used for Detecting Radiation

Since our bodies and senses cannot detect ionizing radiation, we rely on the detection of changes produced by the radiation when it interacts with materials. Radiation detectors operate by detecting a change in the absorbing medium that is caused by the transfer of energy from the ionizing radiation to this medium. There are two basic types of instruments used for its detection: particle counting instruments and dose measuring instruments

Particle Counting Instruments

Particle counting instruments are used to determine the activity of a sample taken from the environment, to measure the activity of body fluids and can be used as a portable survey instruments for contamination monitoring. The detector in a particle-counting instrument can either be a gas, solid or liquid. Passage of an ionizing particle through the detector in most cases, results in energy dissipation in the form of a burst of ionization. This burst of ionization is converted into an electrical pulse that activates a readout device such as a scalar or a rate meter to register a count. Examples are ionization

counters, proportional counters, Geiger Muller counters (gas filled), Scintillation counter (crystals, plastic, or liquid), (Hay and Hughes, 1986).

Dose Measuring Instruments

To measure dose, the instrument's response must be proportional to the energy absorbed from radiation. Efficiency for different types of radiations and energy must be taken into account to effectively measure dose. Pocket dosimeters, film badges and personal thermoluminescent dosimeters are all used to measure personal dose. They are based on the effects of accumulated irradiations in the material inside the instrument. Change in the detectors material can be stored for later reading of the results.

Electrical dosimeters are also used for direct reading of dose .for work in high radiation fields. Survey meters are particle-counting instruments that have been calibrated to measure dose. They are highly specialized and can only be used for the type of radiation (x-rays, gamma rays and neutrons) for which they have been calibrated.

2.3.7 Thermoluminescent Dosimeter

This makes use of the properties possessed by the certain crystalline powders such as lithium fluoride (LiF) calcium fluoride (CaF2) lithium borate etc to emit light when heated after having been exposed to radiation. They are called thermoluminescent crystals. Absorption of energy from the radiation excites the atoms in the crystals, which result in the production of free electrons, and holes in the thermoluminescent crystal. These are trapped by impurities or imperfections in the crystalline lattice thus locking the excitation energy into the crystal that are released on heating as light. Heating the crystals releases the excitation energy as light.

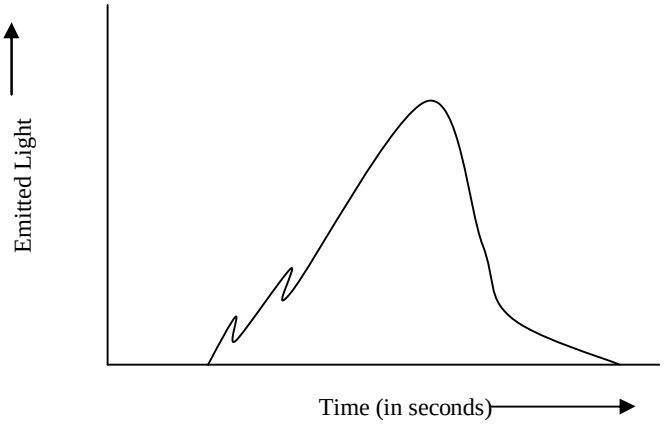


Figure 2.4: Sketch of a Glow Curve

The area under the curve in Fig 2.4 is proportional to the total exposure. The Figure above shows a characteristic glow curve for LiF obtained by heating the irradiated crystal at a uniform rate and measuring the light output as the temperature increases. The total amount of light is proportional to the number of trapped, excited electrons, which in turn is proportional to the amount of energy absorbed from the radiation. The intensity of light emitted from the thermo luminescent crystals is thus directly proportional to the radiation dose (Cember, 1989).

Thermoluminescent dosimeters respond quantitatively to x-rays, beta rays, electrons and protons .Lithium fluoride dosimeters are approximately tissue equivalent since the effective atomic number of the LiF phosphor is 8.1, while the effective atomic number of soft tissue is about 7.4. TLDs are available in various forms powder, chips, rods and ribbons. They are very sensitive to thermal treatment, ultraviolet exposure, chemical contaminations and physical handlings amongst others and these can produce variation in sensitivities or a reduction in the thermoluminescent signal over a course of time (Barke and Sutton, 1997).

Of all TLD materials, LiF has proved the most popular because of its almost negligible fading at room temperature and its low average atomic number that does not differ greatly from that of air or tissue. The minimum sensitivity of LiF is about 100 μGy and the signal remains linearly related to dose up to about 10 Gy (Knoll, 1988).

2.4 Harmful Effects of Low Level Ionizing Radiation

Ionizing radiation, the sort found in x-rays or gamma rays is defined as radiations that have sufficient energy to displace electrons from molecules. Free electrons in turn can damage human cells. One challenge to understanding the health effects of radiation is that there is no general property that makes the effect of man-made radiation different from those of naturally occurring radiation. Still another difficulty is that of distinguishing cancers that occur because of radiation, from cancers that occur because of other causes. These facts are some of the many that makes it difficult to characterize the effects of ionizing radiation at low levels. There is substantial evidence that exposure to high levels of ionizing radiation can cause illness or death, mental retardation in children, heart disease and stroke.

Health effects of low levels of low linear energy transfer (LET) ionizing radiation deposits less energy in the cell along the radiation path and is considered less destructive per radiation track than high-LET radiation. Examples of low LET include x- and gamma rays. Health effects of concern include cancer, hereditary diseases and other effects such as heart disease. When ionizing radiation interacts with living tissues, it is the absorption of radiation energy in the tissues that cause damage. Whenever radiation is absorbed, chemical changes are produced virtually immediately and subsequent molecular damage follows in a short space of time (seconds to minutes). It is after this, during a much longer

time spasm of hours to decades that the biological damage becomes evident (BEIR, 2001).

2.4.1 Chemical and Cellular Effects Of Radiation

When x-ray is absorbed in a biological medium, a chain of events is initiated .The photon creates a fast moving electron with sufficient energy that can completely remove an orbital electron resulting in ionization. The biological effects of radiation are produced by direct and indirect effects, the letter mediated through the production of radicals such as oxygen, water and hydroxyl (OH) radical. The critical molecules for radiation damage are believed to be the proteins (such as enzymes) and nucleic acid (principally deoxyribonucleic acid (DNA). Radiation damage results in the breaking of chemical bonds within DNA disrupting the reproductive integrity of the cell. Cellular death is therefore mitotically linked in that the cell dies after it attempts to divide. Radiochemical lesions in DNA are the results of the direct actions of charged particles of the indirect effects of free radicals produced by ionization of cellular water. A free radical has a lifetime of 10 to 15 seconds, and it is estimated that about two thirds of the damage caused by x-rays or gamma rays is the result of the actions of free radicals. The component of damage caused by free radicals is amenable to modification by the presence or absence of oxygen or chemical compounds. Direct damage cannot be modified. single or double strand breaks may occur in DNA when irradiated.

The repair of these DNA double-strand lesions is largely error prone and is an important determinant of dose, dose rate and radiation quality effects in cells (UNSCEAR, 2001). Damage to the DNA may kill the cell or prevent proliferation, or if the modified cell is still reproductively viable, may promote a complex series of changes

leading to cancer. Consequently, the loss of function in a tissue or organ is the result of cell death or inability of the cell to reproduce (NATO, 1996).

2.4.2 Deterministic Effect

Cells in an organ or tissue are injured or killed by the radiation, resulting in a loss of tissue function. A certain threshold dose has to be exceeded before the effect is seen and above these thresholds, the severity of the effect is dose-related (the severity of the effect is a function of the dose). Skin damage and cataract formation are two types of damage with a deterministic effect. Radiation may injure the cornea, conjunctiva, iris and the lens of the eye. In recent years, several reports have been published describing acute skin damage from radiation. The ICRP report 85 covers this issue in detail (Geijer, 2001).

2.4.3 Stochastic Effect

Instead of being killed, the irradiated cell may be modified and continue to reproduce, potentially causing malignancy. There is no threshold level known and the probability of the effect is linked to the radiation dose. The shape of the function is conservatively assumed linear. If the initial damage is to the germ cells in the gonads, hereditary effects may occur instead.

In diagnostic radiology where radiation doses are very small and deterministic effect should not occur, the somatic effects of real concern are the stochastic effects. Besides the exposure to the patient, there is also a radiation exposure to staff mainly in interventional radiology. The source of this radiation to staff is mainly scattered radiations from the patient. In the context of radiation, the main stochastic effects are cancer and genetic effects, which are effects that result from low level chronic exposure to radiation, the type that can be incurred over a long time in an environment (Geijer, 2001).

2.4.4 Genetic or Hereditary Effects

Genetic effects of radiation occur if the irradiated cell is a germ cell whose function is to transmit genetic information to the descendant of the exposed individuals. The damage arises from radiation-induced mutations in the germ cells of the ovary and testis that must be transmitted. The exact processes by which mutations occur are not known, but they involve chemical changes in the DNA that carries the hereditary information in cell nucleus. The hereditary diseases that mutations may cause range from serious defects, which may cause early death or severe mental retardation, to the trivial such as skin blemishes and minor disorder of metabolism.

Mutation can occur in human population in a seemingly spontaneous manner, but radiation of natural origin may contribute to the number. It is difficult to assess the genetic risk in humans, as even the descendants of those exposed at Hiroshima and Nagasaki have shown no additional genetic or cytogenetic effects (BEIR, 2001).

2.5 External Radiation Protection

Human beings have significantly benefited from the use of devices utilizing ionizing radiation materials. As a result, both the workers and the public are exposed to radiation that involves some levels of risk. Radiation protection standards are put forward to strike a balance between the use and control of ionizing radiation. The standards are included to protect health workers and the public while deriving maximum benefit from the application of ionizing radiations (ICRP, 1991).

2.5.1 Sources of the Hazard

External radiation hazards emanates from sources of radiation outside the body. The sources include x-ray machines, devices specifically designed to produce radiation

and radioisotopes. The external radiation hazard to which protection is required include beta particles (β), gamma rays (γ), x-rays and neutrons all of which penetrate to the sensitive organs of the body. The philosophy inherent from any radiation protection program is to reduce the absorbed dose, whether internal or external, to a minimum achievable. For external radiation source, the total dose one receives in a given radiation may be controlled by concurrent application of one or more of the following three techniques:

i Minimizing exposure time
ii Maximizing distance from radiation source
iii Shielding the radiation Source

2.5.2 Minimizing Exposure Time

The dose accumulated by workers in a given radiation field is directly proportional to the amount of time spent by the worker in the area. Limiting the time the worker spends in the area can control the dose.

$$Dose = Dose\ rate \times Exposure\ Time \qquad 2.5$$

This equation implies that the longer one remains in radiation field, the greater will be the dose received. At times especially during emergencies, work must be performed in a strong radiation field. In this case, the work procedure should be carefully planned so that minimum amount of time is spent to complete the job. If the time required for one man to complete the job would result in all over exposure beyond the prescribed limits, then a team of workers should be employed. This would mean a small exposure for several people instead of a large exposure to an individual (ICRP, 1991).

2.5.3 Maximizing Distance from Radiation Source

For an isotropic source i.e. one which emits radiation uniformly in all directions, the flux is inversely proportional to the square of the distance (r) from the source. $\phi \propto 1/r^2$ this is inverse square law. Since radiation is directly proportional or related to flux, it therefore follows that the dose and dose-rate also obey the inverse square law i.e.

$$D \propto \frac{1}{r^2} \qquad 2.6$$

In radiation protection, the technique is to keep the source as far away as possible (Martin and Harbison, 1988).

2.5.4 Shielding the Radiation Source

Radiation hazard can be reduced by placing a suitable material, or combination of materials between the source and the worker. The choice and or thickness of the material (Shield) will depend upon the type and energy of the radiation. A shield is a medium of such a thickness that will stop or effectively attenuate radiation to non-hazardous level. The effectiveness of the Shield is determined by the interaction between the incident radiation and the atoms of the absorbing medium. The interactions that take place depend mainly upon the type of radiation (α, β, x, and γ.), the energy of radiation and the atomic number of the absorbing material. In choosing a shield material, the first consideration must be personnel protection. Other factors that may influence the choice of material include economics, weight, space and structural strength. Lead is commonly used as a shielding. The attenuation of radiation is given by:

$$I = I_o e^{\mu x} \qquad 2.7$$

Where I_o is the intensity before passing through the shield, I is the intensity after passing through the shield, μ is the attenuation coefficient and x is the thickness of the shield. For quick shielding estimate, multiples of tenth-value or half-value layers can be used. A half-value layer is defined as the thickness of a material that reduces the radiation to one-half of its initial value (ICRP, 1991).

2.6 Reciprocity Law Failure

If perfect, a film will record both exposures with the same density on a given film if the illumination level remains the same. Nevertheless, we are not in a perfect world and in reality, the longer an exposure, the slower the film becomes. This is known as reciprocity law failure. Photographic emulsions are most sensitive when the intensity of exposing radiation is such that an exposure time between 0.01 and 10 seconds is required to produce a medium film density. Decreased Sensitivity may occur at higher or lower intensities (Suzuki, 2003).

2.6.1 Silver Halides

Silver Chloride and Silver bromide crystals are one kind of solid-state device called “indirect gap semiconductors”. These photosensitive crystals react with photoelectron to form small silver specks on or in the crystals. These silver specks are amplified during development process to image-forming silver grains. In typical silver halide materials for negative images, various chemical sensitizers are use to improve latent image formation and developability of latent silver specks. When light is absorbed by silver halide crystal, photo carriers consisting of free electrons and holes are generated. The desired photographic effect is obtained by allowing the free electrons to react with silver to form silver catalytic center or latent images (LI), Suzuki (2003).

2.6.2 Latent Image and Development

Upon absorption of light, electrons and holes are generated in the silver halide. Both of this can take one of three states: free or mobile, trapped and atom. The actual distributions of electrons and holes in these states are considered to be in equilibrium. Formation of latent image is a reaction between a free electron and a silver atom. Absorption of two photons is necessary to initiate latent image growth. The Ag_1 state ("electron at atom") after absorption of the first photon is unstable because its electron is at equilibrium among free, trapped and atom states until one more photon is absorbed to proceed to the Ag_2 state and this is one cause of low intensity reciprocity law failure (LIRF). The LIRF needs to be considered for medical radiography because the film loses sensitivity selectively in shadow regions of the image while maintaining the normal speed in highlights (Suzuki, 2003).

2.7 Image Characteristics and Quality

To human observer, the internal structures and functions of the human body are not generally visible. However, by various technologies, images can be created through which the medical professional can look into the body to diagnose abnormal conditions and therapeutic procedures. The medical image is a window to the body. No image window reveals everything. Different medical imaging methods reveal different characteristic of human body, Sprawls (1993).

The five major components are the patient, imaging system, the system operator, the image itself and the observer. The visibility of specific anatomical feature depends on the characteristics of the imaging system and the manner in which it is operated. Most medical imaging systems have a considerable number of variables that must be selected

by the operator. There can be changeable system components, such as intensifying screens in radiography, transducer in sonography or coils in magnetic resonance imaging. However, most variables are adjustable physical quantities associated with the imaging process. The values selected will determine the quality of the image and the visibility of specific body features.

2.7.1 Image Quality

In the diagnostic radiographic process, several factors must coincide to reach a correct diagnosis:

- The radiologist in cooperation with the referring clinician must choose a suitable examination.
- The image quality should be adequate to show the pathology.
- The observer must be able to see and recognize the pathology.
- The result of the procedure should be beneficial to the patient.

Furthermore, the quality of a medical image is determined by the imaging method, the characteristic of the equipment and the imaging variables selected by the operator. Image quality is a composite of the following: contrast, blur, noise, artifacts and distortion as shown above. The image quality goals are thus just one part in this long chain but this goal should be reached without subjecting the patient to unnecessary radiation exposure.

2.7.2 Image Contrast

Contrast means difference. In an image, contrast can be in the form of different shades of gray, light intensities, or colours. Contrast is the most fundamental characteristics of an image. An object within the body will be visible only if it has sufficient physical contrast relative to surrounding tissue. The physical contrast of an

object must represent a difference in one or more tissue characteristics. When a value is assigned to a contrast, it refers to the difference between two specific points or areas in an image. The interest is the contrast between a specific structure or object in the image and the area around it (Sprawls, 1993).

2.7.3 Blur and Visibility of Detail

Structures and objects in the body vary not only in physical contrast but also in size. Objects range from large organs and bones to small structural features such as trabecula patterns and small classifications. The small anatomical features add detail to a medical image. Each imaging method has a limit as to the smallest object that can be imaged and thus on the visibility of detail. Visibility of detail is limited because all imaging methods introduce blurring into the process. The primary effect of image blur is to reduce the contrast and visibility of small objects or detail. The amount of blur in an image is quantified in units of length (Sprawls, 1993).

2.7.4 Image Noise, Artifacts and Distortions

Image noise sometimes referred to as image mottle, gives an image a textured or grainy appearance. In most medical imaging situations, the effect of noise is most significant on the low-contrast objects that are already close to the visibility threshold.

Artifacts and distortions are image features that do not represent a body structure or object. Artifacts can obscure a part of an image or may be interpreted as an anatomical feature. A variety of factors associated with each imaging method can cause image artifacts. A medical image should not only make internal body objects visible, but should give an accurate impression of their size, shape and relative positions. An imaging procedure can, however, introduce distortion of these three factors (Chesney and Chesney, 1984).

2.7.5 The Scattered Radiation

In diagnostic radiography, secondary radiation which is largely Compton scattering of the primary beam within the patient makes no favorable contribution to the image formation and it seriously deteriorates contrast in the radiograph. The scattered radiation is an overall density on the film which is not productive of image detail to any extent and is therefore fog. This can be minimized by use of cones, diaphragms, compression bands and secondary radiation grids, Brateman (1999).

2.7.6 Image Quality Assessment

Before any image was included for assessment, it was required to fulfill the following criteria:

- Symmetrical reproduction of the pelvis
- Reproduction of the necks of the femur without distortion by foreshortening or external rotation
- Visualization of all parts of the pelvis.

The image quality assessment was formulated using European Guideline on Quality Criteria for Diagnostic Image for Analytical Criteria, (CEC guidelines, 1996). The anatomic criteria were based on subjective scoring by three radiographers and three radiologists from the Department of Radiology, ABUTH, Zaria. The criteria were based on visually sharp reproduction of:

Sacrum and its intervertebral foramen
Pubic and ischial rami
Sacro-iliac joints
Femoral necks
Spongiosa and corticalis
Trochanters

Each criterion was scored I for inadequate visualization, 2 for adequate and 3 when perfectly visualized. A total score was calculated for each image by adding all criteria scores. A radiograph demonstrating perfect visualization was used as a reference image. All images were examined using constant illuminator and ambient light conditions throughout the study, time and observer, film distance was unrestricted and all images assessed blindly (Brennan *et al*., 2004).

2.8 Dose Estimation

The dose used in this work is the Entrance Skin Dose which is the dose to the entrance skin or surface of the patient at the central point of the irradiated surface area. It includes backscattered radiation from the patient. Entrance Skin Dose is a point quantity and thus independent of collimation apart from the influence on the backscatter factor (Geiger, 2001). Entrance Skin Dose is regarded as the best indicator of deterministic effects such as skin burns (ICRP, 2000). The entrance skin dose decreases when the focus to skin distance is increased due to inverse square law. The ESD is also calculated using the formulated equation by Kumar *et al.* (1996).

$$Dose = k\frac{(kVp)^n \times (mAs)}{d^2 \times f \times \phi} \qquad 2.8$$

Where mAs is the tube charge, kVp is the applied voltage, d is the focus to skin distance (FSD), f is the total filtration and ϕ is the machine phase. n is a machine factor which is an integer approximately 2 and k is a constant. There are changes in ESD values due to air attenuation and backscatter. The attenuation is calculated using the attenuation coefficient in air for the energy under study and the backscatter is estimated by measuring the factor by which the radiation dose is increased due to scatter base and the body. This factor depends on the energy, patient size and x-ray field (Parry *et al.*, 1999).

Backscatter Factor

The backscatter factor (BSF) depends on the x-ray spectrum, x-ray field size, thickness of the patient or phantom and the distance between the dosimeter and the surface. It is the factor by which the radiation dose is increased by radiation scattered from the body.

$$Backscatterfactor = D_{w-}/D_{w+} \qquad 2.9$$

Where Dw- is the measured dose without water and Dw+ is dose with water. Backscatter factor depend on partially on the energy and field size of the x-ray beam but they are typically in the range of 1.3-1.4.

2.8.1 Dose Reduction Techniques in Radiography

There are many dose reducing techniques that have been considered in recent years. They include: the use of rare-earth filters, fast-film screen combination and the use of low attenuation materials in cassettes. Others are: applied voltage (kVp), milliampere (mA), exposure time, beam collimation, shielding of sensitive organs whenever possible, use of compression bands especially in thick patients, use of anti-scatter grids with lowest grid factors compatible with adequate scatter rejection, use of modern image intensifiers with sensitive photocathode and digital image processing, and many more others, Parry *et al.* (1999).

Beam Energy and Filtration Control

Beam energy primarily depends on the voltage selected the amount of filtration in the beam. If all other variables are held constant, ESD will change as the square of the change in kVp. The selection of the higher peak voltage increases the energy of the x-rays and therefore beam penetrability. As the beam becomes more penetrating, more x-

rays will reach the receptor during the same period. In practice, this may allow for the use of a low tube current or a shorter exposure time, thus reducing the dose to the patient.

Diagnostic radiography units are required by regulations to contain a total filtration (which includes the tube wall and any other added filtration) of at least 2.5mm of aluminum equivalent if they are operated at tube potential above 70 kVp. This filtration preferably absorbs the low energy x-rays in the beam. Absorption primarily takes place with x-rays of less than 40 keV of energy and virtually all x-rays below 10 keV are absorbed. Without filtration, this low energy radiation would most likely be absorbed in the patient. In effect, the added filtration serves to further increase the average energy of the beam in the range of energies of x-rays used in radiodiagnostic radiology, (Parry *et al*., 1999).

Collimation Control

During any radiographic procedure, the areas of the patient exposed to the x-ray beam have to be limited to the area of clinical interest. Tissues inside the primary beam receive doses that are others of magnitude higher than doses received by tissues outside the primary beam. By using collimation, you expose only the area of clinical interest, unnecessary patient exposure can be substantially reduced. Furthermore, by reducing the area covered by the beam, the amount of scattered radiation that reaches the image receptor is also decreased. The resulting images have better contrast (Parry *et al*., 1999).

Film-Screen Combination

Most current radiographic intensifying screens are composed of rare-earth phosphors (terbium-activated oxysulphides, like gadolinium and lanthanum). Previously, calcium tungstate was the most commonly used material. Use of faster film-screen

combination can substantially reduce dose, and modem rare-earth screens up to 600 speeds may be used.

Due to inverse square law, it is evident that the radiation dose at the patients' entrance surface will be greater than that at the image receptor (Brennan *et al*., 2004). As the FFD increases, the ratio between entrance dose and image receptor dose increases and since the dose to the image receptor must remain constant, the dose to the patient must be reduced (Parry *et al.,* 1999).

2.9 Diagnostic Equipment

2.9.1 Overview of Diagnostic Radiology

When Wilhelm Conrad Roentgen accidentally discovered what he called x- rays in 1895, he could have had no idea what an enormous impact his discovery would have on medicine and industry. No hospital today is complete without some form of x-ray equipment. Diagnostic Radiology is the use of x-rays to investigate the structure and function of the human body. The techniques used are many and varied and include plain x-rays (radiography), x-rays of the breast (mammography), continuous imaging (fluoroscopy) and cross sectional imaging (CT) scanning. Those that do not utilize x-rays (noninvasive) are ultrasound (USS) and magnetic resonance imaging (MRI), (Whitehouse and Worthington., 1990).

2.9.2 Radiography

Radiographs are images produced on films by directing a beam from an x-ray tube through a part of a patient and then onto a film cassette. Photographic films are relatively insensitive to x-rays but much sensitive to visible light. The intensifying screens absorb x-rays and emit visible light and it is primarily light from the intensifying

screen, which exposes the film rather than the x-ray themselves. Different parts of the patient are of different density and attenuate the x-rays to different degrees so that an image of different tissues of the patient forms once the film is developed (Whitley *et al.*, 1999).

2.9.3 Digital Radiography

A major revolution took place in the mid 1990s following the introduction of computer Radiography (CR). With CR, the use of film for image generation is eliminated. The film cassette is replaced with a CR plate that contains a fluorescent matrix, which absorbs the x-rays. These plates are different from the screens that are used in standard film cassettes in that they do not fluoresce unless stimulated with a laser.

The second advance was the development of Digital radiography (DR). With DR, the x-rays strike a selenium-based screen that absorbs the x-rays and emits electrons. The electrons are detected by a charge-coupled device (CCD) much as is done in a video camera, and then converted to electronic signals that are then used to reconstruct the digital image (Whitehouse and Worthington, 1990; Whitley *et al.*, 1999).

2.9.4 Fluoroscopy

As with standard radiography, the beam of x-rays is directed through a patient onto a fluorescent screen, but the light produced on this screen is not used to expose a film, instead, it is detected and magnified by a device called an image intensifier and projected on a screen. Any structure within the patient that moves can be seen to move on the screen and the patient position may be changed in order to permit a sort of three-dimensional appreciation of the anatomy being observed (Armstrong and Wastle 1987; Whitley *et al*., 1999).

2.9.5 Computed Tomography

Computed tomography (CT) has become established as an essential radiological technique and one that is applicable in a wide range of clinical situations. Used correctly, the technique is particularly effective in influencing clinical decisions and the management of patients. It is another way of making images using x-rays. The CT image represents a cross-section of the body made up of a matrix of small squares or pixels each representing the attenuation value of the tissue at that point. The cross-sectional display together with sophisticated detector systems and computerized production of the image makes the technique superior to conventional radiography in the demonstration of structures (Sutton 1995; Lanksah and Kazner, 1976).

2.9.6 Mammography

Mammography is a specific type of imaging that uses a low-dose x-ray system for examining the breast. It plays a central part in early detection of breast cancer Diagnostic mammography is used to evaluate a patient with abnormal clinical findings such as breast lump or lumps that have been found by the woman or doctor. The unit is dedicated equipment because it is used exclusively for x-ray examination of breast with special accessories that allow only the breast to be exposed to the x-rays (Roebuck and Blamey, 1990).

2.9.7 Ultrasound Imaging

Ultrasound imaging or sonography is a method of obtaining images from inside the human body using high frequency sound waves. The reflected sound wave echoes are recorded and displayed as a real-time visual image. They can show movement of internal tissues and organs and enable physicians to see blood flow and heart valve functions. The

soft tissue images are produced entirely none invasively and without the need for contrast agents.

USS can also be used to guide procedures such as needle biopsies, evaluate superficial structures such as thyroid gland and scrotum. USS scanners consist of a console containing a computer and electronics, a video display screen and a transducer that is used to scan the body (Fish *et al*., 1992; Palmer 1995).

2.10 Review of Related Works

Robinson and McLean (2001) investigated the effect of increasing FFD from 100 to 176 cm on the entrance skin dose using anthropomorphic phantom for a non-bucky knee radiograph. Results showed that the skin dose reduction was 13.4% at 176 cm FFD with 0.8% due to extra focal radiation variations. This compares to 14.8% (theoretically calculated due to geometric considerations alone) with 3.5% calculated due to air attenuation. This is in contrast to other studies that actually showed an increase in dose as FFD was extended to 150cm, Brennan and Nash (1998). Increasing FFD: an effective dose reductions tool for lateral lumber spine investigations), however that study involved the use of a grid and any variations in mAs were not reported.

Brennan *et al*. (2004) used both anthropomorphic phantom and patients, also studied the dose reducing efficiency of increasing FFD from the traditional 100 to 130cm for pelvic x-ray examination. The results show that increasing FFD results in a reduction in effective dose of 33% with no change in image quality.

Ogundare *et al.* (2004) carried out a survey on 171 patients in three public hospitals in Nigeria undergoing abdomen, pelvis and lumber spine diagnostic x-ray examinations. The technical parameters used are tube potential, exposure time and FFD

using TLD chips to measure the ESD which was found to be within the range of values that has been reported before and comparable with and higher than those from Ghana and Tanzania respectively.

The relationship between FFD and received radiation dose to patients, where the radiation dose to the testes may be significantly lowered whilst still maintaining acceptable image quality was investigated by Dilger *et al.* (1997). He found that increasing FFD to 200cm resulted in 30% decrease in entrance dose to the testes after using anthropomorphic phantom. He suggests that an FFD of 200cm is an effective method of minimizing radiation dose to patients during lumbar radiography.

Grondin *et al.,* (2004) worked on the dose reducing strategies in combination offers substantial potential benefits to females requiring x-ray examination using an adult anthropomorphic phantom aimed to establish an optimized technique for women of childbearing age undergoing antero-posterior (AP) pelvis and AP and lateral lumber spine examinations. Phase one of the work involved introducing the following dose-reducing measures individually. Increased kVp, increased focus-to-film distance, a carbon fiber cassette, a faster film/screen combination of the parameters above the results demonstrated that the optimized procedures reduced effective dose by 77, 62 and 66% for AP pelvis and lateral lumber spine respectively with no significant change in image quality.

Brennan, *et al.* (2004) investigated the dose-reducing efficacy of change in FFD for pelvic x-ray examinations. TLD dosimeter was used for dose measurement using anthropomorphic phantom and patients. The results showed that increasing the FFD results in a reduction in effective dose of 33% with no change in image quality.

Sherman-ray (1986) in his work, teleradiography: extending the focus film distance noted that lengthened focal film distance reduces the radiation burden to the patient and enhance final film result by improved geometric and physical factors. Clinicians possessing adequate radiographic equipment were advised to use a minimum of 150cm FFD and preferably 200cm.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 X-Ray and Imaging Equipment

The diagnostic x-ray machine used in this work is a three phase high frequency (fluoroscopy), prestige SI positioner with MPH 50 generator, 1.6mm focal spot, target angles of 15° and 30° with an aluminum tube filtration of 1.5 mm manufactured by General Electric (GE) MEDICAL SYSTEMS (October 2004) with an automatic exposure control (AEC). This equipment is ISO 9001 and EN 46001 certified (USA) and is used in the Radiology Department of ABUTH. All exposures were made using AEC which was tested for consistency before and at intervals during the study.

The films are double coated (green sensitive) films, fast film-seen intensifying screens (screen speed of 200) and x-ray cassettes of 40 x 30 sizes that were all made by MEDIPHOT X-O/RP Austria. The exposed films were processed using MP 902/903 automatic processor. Performance consistency of the processor was checked by sensitometric analysis. The secondary radiation grid used in this study (moving grid with bucky) was shown to be focused at 100cm and to be tolerant to increases in the FFD of up to 30%.

3.1.2 Hip Bones

The hip bones used in this work was obtained from the Anatomy Department, Faculty of Medicine, Ahmadu Bello University, Zaria. These types of bones are usually acquired for teaching Medical Students.

3.1.3 The Construction of A Pelvic Phantom

A total of 50 adult patients with an average of 46 years of both sex for pelvic examinations were radiographed and their pelvic height was measured (average of 15.3 cm). A pelvic phantom made up of a perspex material that simulates the pelvis of an adult patient was constructed which dimensions are 25cm x 20cm x 15cm of length, width and height respectively. Two human pelvic bones (left and right) were fixed in position in the phantom and made to be stable to avoid floating. The phantom was filled with water to cover the bones completely that stands for the tissue of the pelvic area and the phantom was closed with a cover. A picture of the phantom with bone is shown in Plate 3.1

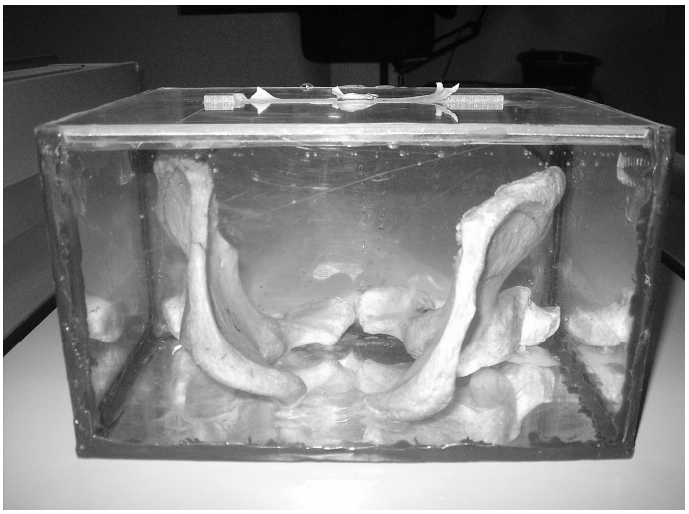


Plate 3.1: Picture of Phantom with Bone

3.1.4 Instruments for Measurement

Calibration Source

A Cs-137 Serial Number LB440F of activity 370MBq collimated with lead shield of thickness 67 mm was used for the dose determination during the dosimeter calibration.

TLD Chips

The dose measurements were made with LiF TLD chips of dimension: 4mm by 4 mm by 1mm supplied by RISØ Laboratories in Denmark. The chips were annealed and rechecked with the facilities from the Centre for Energy Research and Training, Ahmadu Bello University, Zaria.

TLD Reader

The thermoluminescent dosimeter (TLD) reader used is a VINTEN SOLARO READER MODEL 680 made by VINTEN ANALYTICAL SYSTEM LTD, UK. It is suitable for most TLD applications. It is used mainly for personnel and environmental monitoring in radiological application, research into materials and basic dosimetry, Vinten and GCA (1989).

Densitometer

A PEHAMED DENSONRM densitometer was used to obtain optical densities on the resulting radiographs.

Survey Meter

An ATOMTEX DKC-AT1121 was used as the survey meter. It is essentially an x-ray and gamma radiation dosimeter manufactured by SPE ATOMTEX Minsk, Belarus. It measures in the energy range of 15 keV to 10 MeV. Its detection mechanism is by use of plastic scintillator.

3.2 Methods

3.2.1 Determination of Statistical Contribution of Pelvic Examinations to Collective Dose

The number of patients examined using x-ray for diagnostic purpose in the Radiology Department of ABUTH, Zaria were studied for a period of six months. The different examinations that involve direct exposure of the pelvis were recorded. The percentage of the total number of examinations involving direct exposure of the pelvis during the period of study was calculated.

3.2.2 Calibration of TLD Chips

Two chips were put in a sample tray at a distance of 20 cm from the cesium source. The chips were irradiated for a given time. This was repeated 30 minutes and 1, 2, 4, 8, 12 and 16 hours. The survey meter was placed at the same distance and the dose rate 65μSv/h measured. The dose from the survey meter was compared with the counts recorded from the TLD after reading it to obtain the calibration curve.

3.2.3 Dosimetry

The TLD chips were annealed before and after each use according to the manufacturers instructions and were kept in light-tight polythene seals. All TLD chips were read within 24 hours of exposure. Control TLDs were used to monitor background radiations at strategic points.

3.2.4 Determination of Image Quality

This was done using the optical densitometer. Optical density measurements were made on the image at positions corresponding to the left and right ovaries and at various FFDs. It is expected that the image is of good quality if the optical density at these spots do not vary significantly for the various FFD.

3.2.5 Assessment of Patients' Pelvic Doses

Dose administered to patients undergoing examinations that involve the pelvis in the Department under study was investigated by placing a sachet containing 2 TLD chips on the patient's apron at the level of the pelvis. The chips were placed at the beam entrance and at the beam exit points. The values obtained were used to estimate the dose absorbed after subtracting the backscatter dose. Informed consent was provided to the patients. Patients with prosthesis or hip fractures were excluded from the study.

3.2.6 Measurement of the Entrance Skin Dose

Two TLD chips were placed at the center point on the entrance surface corresponding with the central ray on the phantom and exposed to x-rays with a setting of 62 kVp. The FFD was set at 100, 110, 125, 135, 140 and 145 cm for subsequent measurements. The x-ray machine has an automatic mAs and radiation field adjustment, aimed at giving good image quality. For the patients, a chip was placed as above except that another one was placed at the exist point behind the patient. The sketch of the irradiation station for phantom is shown in Fig. 3.1 and the picture in Plate 3.2.

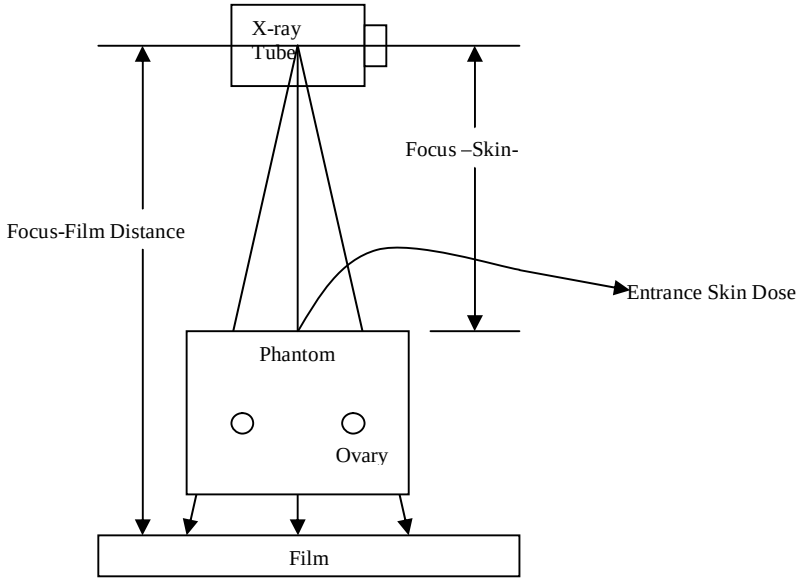


Fig. 3.1: Sketch of the Irradiation Station

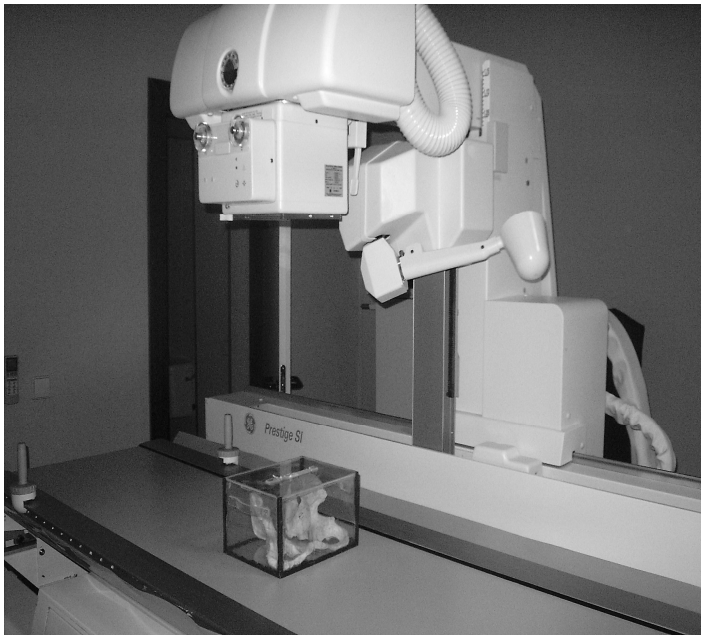


Plate 3.2: Picture of the Irradiation Station

3.2.7 Measurement of Backscatter Factor

The backscatter factor for the entrance dose was measured using the Perspex phantom. The TLDs were tapped at the entrance surface of the phantom to coincide with

the central ray. Two exposures were made using fixed 62 kVp and 64 mAs and a set of FFDs used previously while the total field size was allowed to vary proportionally with the sets of FFDs, one with water and the other without water in the phantom.

3.2.8 Image Quality Assessment

An evaluative panel of five-experienced experts (two radiologist and three radiographers) were used to assess the resulting radiographs. All of these individuals underwent appropriate training prior to any evaluation of the radiographs.

CHAPTER FOUR

RESULTS

4.1 Contribution of Pelvic Exposure to Patient's Radiation Hazards

Figure 4.1 shows different examinations involving the pelvis of adult patients where gonads are directly irradiated and their frequencies. The figure represents the number of examinations made within the six months of study.

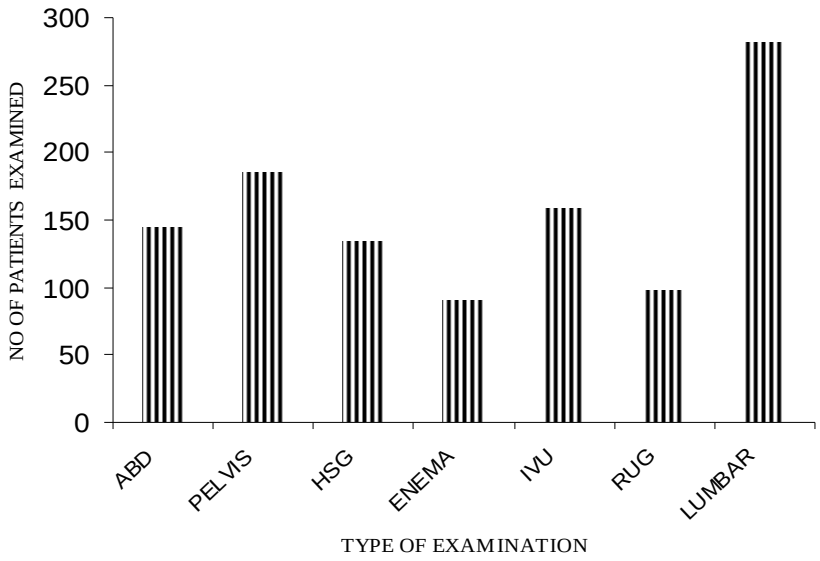


Fig. 4.1: Distribution of Exposures Involving Pelvis

Figure 4.1 indicates that at least two patients were examined for lumber daily and then one patient irradiated for abdomen, pelvis, HSG and IVU per day. This makes it important for the use of techniques that will deliver lower dose to these patients and invariably the staff and the public by way of scattered radiation.

Table 4.1 shows the statistical distribution of exposures involving direct irradiation of the pelvis when compared with the overall exposures in the Department for the six months period of study.

Table 4.1: Statistical Distribution of Pelvic Examinations

Types of examination	Number of patients examined	% Distribution
Abdomen (ABD)	144	3.12
Pelvis	185	4.01
Hysterosalpingography (HSG)	134	2.91
Enema	90	1.95
Intravenous Urography (IVU)	158	3.45
Retrograde Urethrogram (RUG)	97	2.10
Lumber spine	282	6.11
Others	3522	76.37
Total	**4612**	**100**

Table 4.2: Statistical Distribution of Patient Examinations in ABUTH

Types of examination	Number of patients examined	% Distribution
Pelvic Exposures	1090	23.63
Upper Extremities	229	4.97
Lower Extremities	239	5.07
Skull	334	7.24
chest	2379	51.58
Others	346	7.5
Total	**4612**	**100**

Table 4.2 shows that examinations involving pelvis would contribute about 24% of the total estimated dose and thus of detriment to the patients. This is significant considering that gonad is highly radiation sensitive with ICRP weighting factor of 0.20 used in estimation of equivalent dose. Thus a reduction in the contribution of pelvic exposure to collective detriment is required in this practice and this justifies the study.

4.2 Calibration of the Thermoluminescent Dosimeter Chips

Figure 4.2 shows the calibration curve obtained in this work

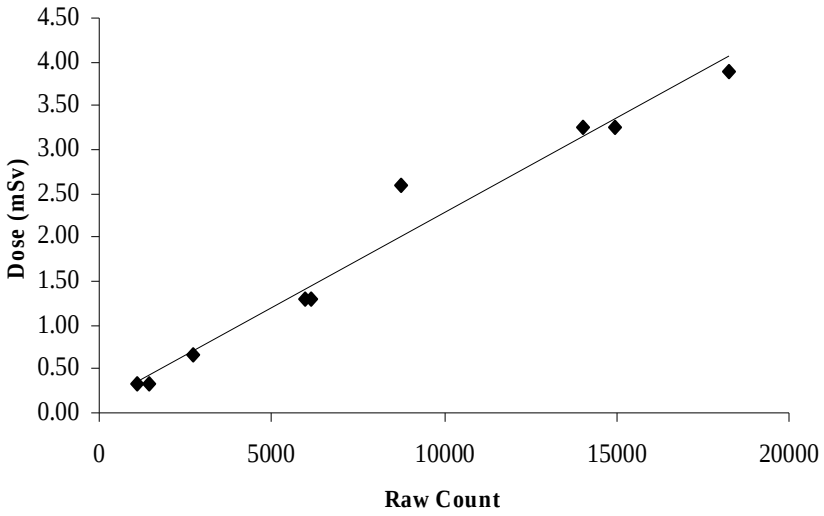


Fig. 4.2: TLD Calibration Curve

The fitting equation derived from the curve in figure 4.2 gives the following equation:

$$Dose\ (\text{mSv}) = 0.0002 \times \text{Raw Count} + 0.1088 \quad \text{with regression, } r^2 = 0.97.$$

This equation was then used to calculate all measured TLD raw counts for dose evaluation.

4.3 Comparison of Optical Density Measurements at Ovary Positions

Figure 4.3 shows the comparison of the optical density measurements made at positions of the left and right ovaries for different FFD. This is to determine if there is significant difference in image quality due to changes in FFD since the machine makes automatic adjustments to correct any possible changes in image quality.

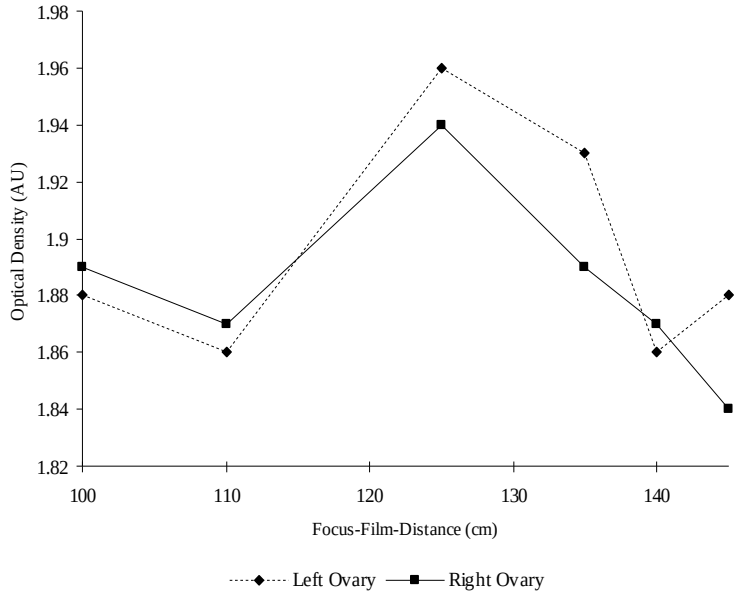


Fig 4.3: Optical Densities at Position of the Ovary

The exposure factors used at extended FFD gave constant optical densities indicating that the image quality was not compromised. Further analysis using one tail, independent, paired student "t" test shows the degree of freedom =10,confident error =95% ,the calculated t test =0.01 while the table =2.76 (Spiegel and Stephens,1999),t-statistics=1.15 and t-critical=2.02. Since t-critical is greater than t-statistical, it shows that there is no significant difference between the densities on the left and right ovaries.

4.4 Experts Assessment of Quality of Pelvic Radiograph

Two sets of viewers (3 -radiographers and 2-radiologist) assessed the films produced for their diagnostic quality. The results of the assessment is as shown in Table 4.3

Table 4.3: Image Quality Assessment of Pelvic Radiograph

Diagnostic Criteria	Inadequate	Adequate	Perfect	Total
Viisually Sharp Reproduction of:				
Sacrum and Inter-related Foramen	1	2	2	5
Pubic and Ischial Rami		2	3	5
Sacro-iliac joints		1	4	5
Femoral necks		2	3	5
Spongiosa and corticalis	1	2	2	5
Trochanters		1	4	5
Total	2	10	16	30
Percentage of Scores (%)	7	33	60	100

The overall average scores of the radiologists and radiographers for the set of FFD showed no significant statistical differences in their quality. Only 7% of the radiographs were adjudged to be inadequate and were not included in the study. Plates 4.1 and 4.2 shows the radiographs obtained at focus to film distances of 100 cm for phantom and patient respectively.



Plate 4.1: Radiograph of Pelvic Phantom at FFD of 100cm

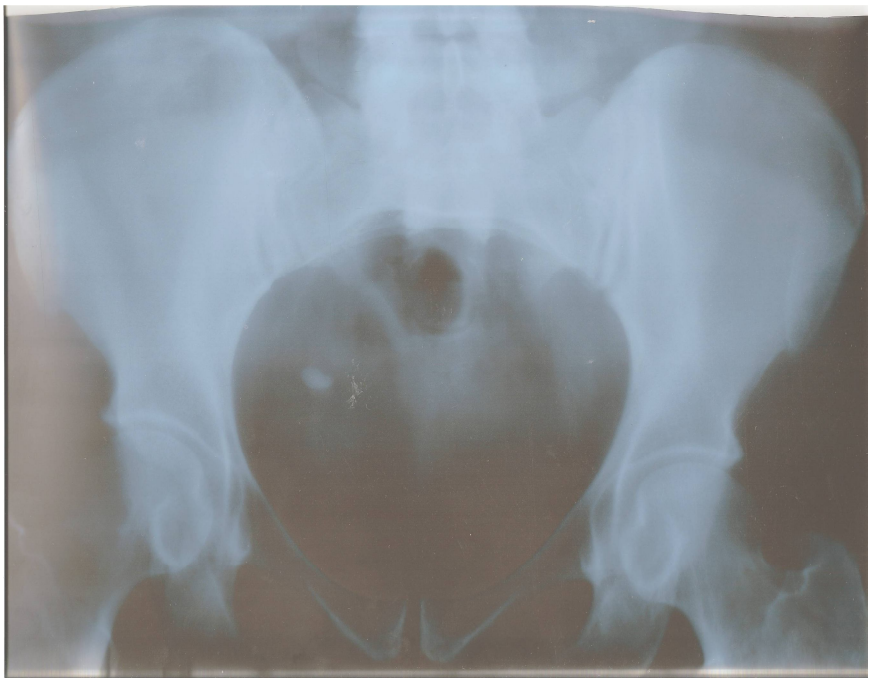


Plate 4.2: Radiograph of Pelvis of a HSG Patient at FFD of 100cm

Plates 4.1 and 4.2 shows that all the major bones in the pelvis are present in the phantom. With the water simulating the tissue, the scattering from both structures will be of the same pattern. The slight difference noted on the slide is due to orientation of the bones in the phantom.

4.5 Comparison of Measured and Calculated Doses

Figure 4.4 shows the comparison between doses measured on the phantom as ESD and that calculated using Kumar equation and the machine adjusted mAs.

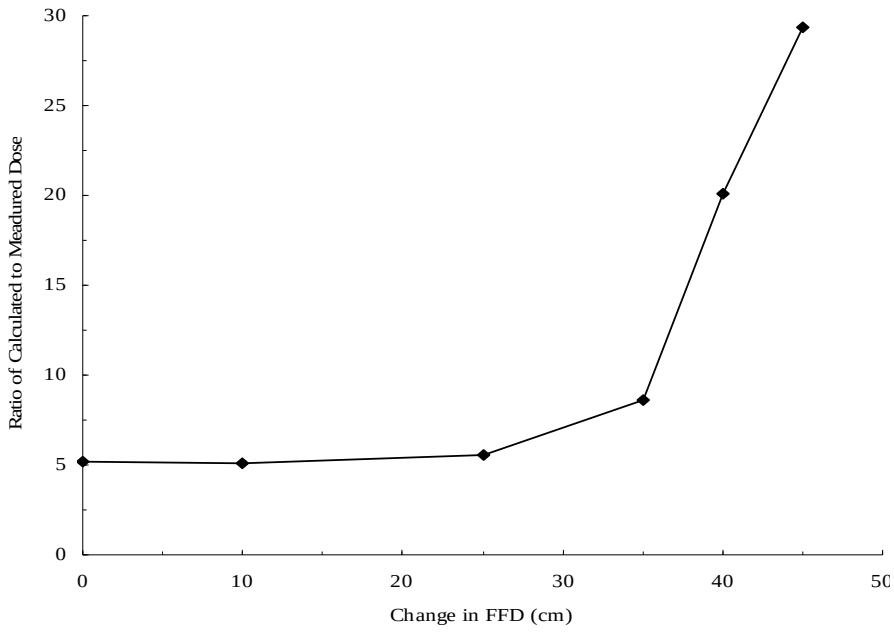


Fig.4.4: Comparison of Calculated and Measured Doses

This shows the dependence of ESD on exposure factors: the x-ray tube energy, mAS and focus to film distance. For the calculated dose to be higher than the measured dose indicates the effectiveness of the machine and the good sense of judgment by the operator in the choice of exposure parameters, Muhogora *et al.* (1998). The ratio of calculated to measured values showed visible drop in dose as the FFD is increased. The

close agreement of the values shows that equation 2.8 is good for calculating entrance surface dose.

4.6 Irradiation Parameters

Table 4.4 shows the mAs adjustment as a function of FFD. The adjustment is automatically built into the machine.

Table 4.4: Parameters used in Irradiation during this Study

Set Focal Film Distance (cm)	Measured Focal Skin Distance (cm)	mAs Adjustment (AEC)	$mAs/(FFD)^2$
100	82.0	48.6	4.86
110	94.6	62.3	5.15
125	99.8	67.5	4.32
135	105.0	73.8	4.05
140	115.0	85.9	4.38
145	124.3	99.8	4.75
Average ± SD			**4.59±0.41**

The mAs adjustment by the machine follows the inverse square law. The mAs is automatically calculated to suite the patient or phantom thickness regardless of the selected kVp or mAs. The AEC can be said to perform optimally even at extended FFD. It therefore works in agreement with the European communion who recommended the use of AEC and FFD of 100-150 cm for pelvic diagnosis.

4.7 Doses and Typical Parameters used in Pelvic Examinations in the Study Hospital

Table 4.5 shows the typical settings and measured dose for five specialized examinations involving the pelvis of adult patients at a focus-to-film distance of 100cm.This is to ascertain the level of optimization in the study department.

Table 4.5: Typical Parameters and Doses Measured from Practice

Examination	kVp	FSD (cm)	mAs	Entrance skin dose (mGy)	Exist dose (mGy)	Absorbed dose (mGy)
Hysterosalpingography	64	74	101.2	2.99±0.11	0.19±0.13	2.8
Barium Enema	70	78	125	5.80±0.41	0.38±0.36	5.42
Intravenous Urography	68	74	115.2	5.40±0.15	0.46±0.24	4.94
Retrograde Urethrogram	63	76	100	7.80±0.56	0.24±0.18	7.56
Micturating Cystourethrogram	65	78	109.8	5.40±0.24	0.22±0.23	5.18

The ESD obtained in this work are all bellow the diagnostic reference level of 10mGy as recommended by the European commission for pelvic examinations (Berni *et al*., 2002). This shows that there is good and normal practice (optimization) in the study department with regards to diagnostic pelvic exposures. In all the irradiations, RUG appears to give higher dose to the patients. This calls for justification of the examination by the referring physicians.

4.8 Dose Reduction Obtained

Figure 4.5 compares the dose reduction obtained for phantom exposed with bone when the radiation field size (collimation) is fixed and when it is varied

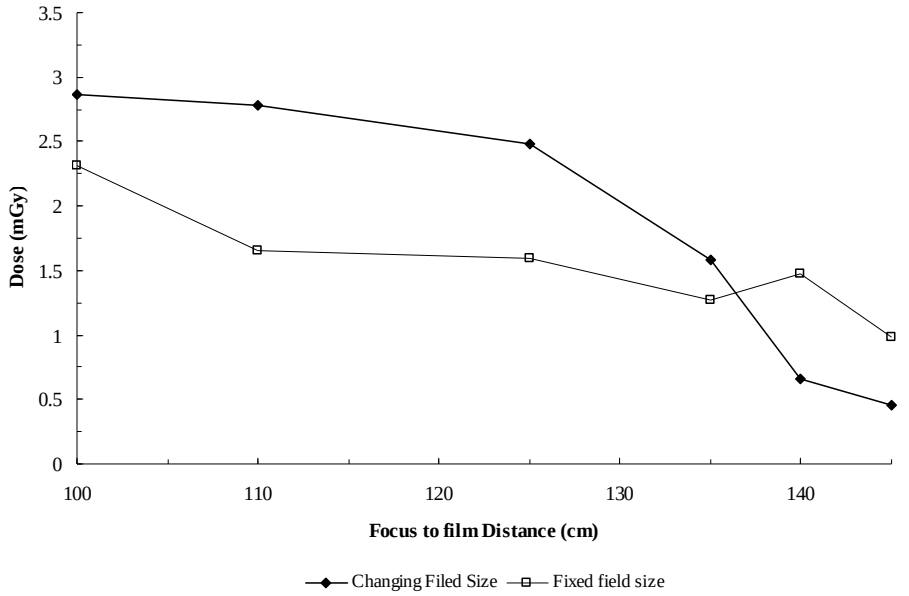


Fig 4.5: Dose Reduction

This shows the effect of collimation on the dose. When compared with the changing field size, lower doses are obtained with collimation as the FFD is increased. This indicates the importance of collimation to the area of interest in radiography. Collimation therefore becomes an important tool in radiation protection of patients. It reduces the effect of scattered radiation reaching the film and enhances contrast thereby improving the image quality. The calculated percentage dose reduction due to increase in FFD with pelvic phantom for fixed and varying field size is shown below, Table 4.6.

Table 4.6: Reduction in Dose due to Increase in FFD

Focal film Distance (cm)	% Reduction in ESD	
	Fixed Field Size	Varying Field Size
100	0.00	0.00
110	0.4	02.52
125	1.44	3.29
135	4.69	3.83
140	8.09	4.41
145	8.95	6.3

4.9 Effect of FFD on Backscatter Factor

Table 4.7 shows the doses obtained for the irradiation of phantom with and without water to determine the backscatter factor at varying focus to film distance.

Table 4.7: Reduction in Dose Due to Increase in FFD with Phantom

Focal film distance (cm)	Dose With Water (mGy)	Dose Without Water (mGy)	Backscatter Factor
100	2.32±0.27	0.21±0.02	0.09
110	1.97±0.14	0.2±0.02	0.1
125	1.88±0.07	0.2±0.02	0.11
135	1.64±0.06	0.18±0.02	0.11
140	1.39±0.09	0.18±0.02	0.13
145	1.06±0.03	0.15±0.02	0.14

The backscatter factor is constant for the varying focus to film distance. This experiment indicates that large portion of the x-ray beam is attenuated by tissues or interposed objects. Again only an integral amount of x-rays reaches the image receptor to form an image. Backscattered radiation contributes to the overall entrance dose recorded at skin level. Figure 4.6 shows the percentage reduction due to air attenuation. This indicates that a small theoretical dose reduction (3.4%) occurs due to air attenuation with increased FFD.

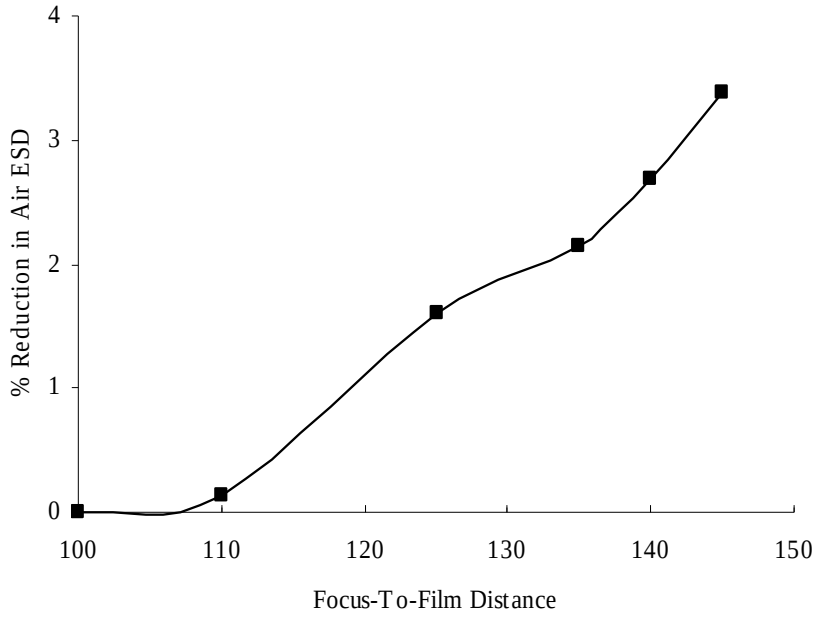


Fig.4.6: Percentage Reduction in Dose Due To Air Attenuation

4.10 Measurement of Dose Area Product

The results of dose area product measured at varied and fixed collimation settings at different focus to film distances are shown in Table 4.8. A small change in beam field size on the patient can lead to large area of organ irradiation and the consequent dose increase.

Table 4.8: Dose Area Product for Varied and Fixed collimation

Focal film Distance (cm)	Measured Field Area (cm^2)	DAP for Varied Collimation (mGy-cm^2)	DAP for Fixed Collimation (mGy-cm^2)
100	1546	4.28	3.43
110	1561	4.15	2.44
125	1509	3.81	2.40
135	1635	2.40	2,24
140	1658	0.88	2.06
145	1673	0.49	1.37

The measured DAP is compared with IAEA standards. The references DAP and field area is 5mGy-cm^2 and 1505cm for pelvic examinations respectively (IPSM, 1992). The measured DAP is therefore below the reference value, however, it decreases further as FFD is increased. This shows the effectiveness of the collimators in limiting the beam area and correct alignment of the beam with the image receptor.

Collective Dose

This is the product of the number of patients examined and their average doses in man-sievert. It is a population-based parameter used to assess the impact of radiation on the populace. The estimated collective dose due to some of the examinations that involve direct irradiation of the gonads in ABUTH, Zaria is 5.9 man-sievert from mean dose of 5.45mGy. This means that approximately one person will receive 1 sievert of radiation as a result of pelvic examination in six months.

CHAPTER FIVE

5.1 Discussion

This work using a Perspex pelvic water phantom and adult patients has investigated the effect on the entrance surface dose when the focal film distance is incrementally varied between 100 and 145cm, studied in the Radiology Department of Ahmadu Bello University Teaching Hospital, Zaria. The following findings were made:

5.1.1 Pelvic Exposure and Patient's Radiation Hazard

Different examinations involving direct exposure of the gonads were studied for a period of six months. These examinations were found to contribute about 24% of the total collective dose (5.9 man-sievert) and thus of detriment to the patients. This justifies this study by finding further techniques for reducing pelvic exposures at the lowest cost.

5.1.2 Optical Density Measurement and Image Assessment.

Optical density measurements were made at the position of the ovary and no significant differences were noted. This indicates that the quality of the radiographs were maintained even at increased FFD up to 145cm, hence there will be no loss of diagnostic information if this extended FFD technique is put into practice. The useful range of the optical densities throughout a radiographic image is between 0.25-2.5.0.D while the mean density in this work is 1.89.

The radiographs produced in this study were subjected to experts' assessment by 2 radiologist and 3 radiographers to ascertain their qualities. No marked differences were found in the radiographs at increased FFD based on visibility of detailed anatomical features. A low dose does not mean, good radiographic technique, so dose measurements have to be accompanied by an evaluation of the clinical quality of the images (Berni, 2002). The general findings in the survey indicated that with the use of higher FFD,

images of acceptable subjective value could be obtained with substantial decrease in dose. However, it would be useful to study whether the good visualization of anatomical structures correlates with the clinical efficiency and whether it improves the confidence of radiologist and clinicians to reach a confirmative diagnosis.

The x-ray machine used in this work has an automatic exposure control in line with CEC recommendations, Brateman (1999). The AEC system ideally provides constant optical density regardless of patient or phantom thickness or exposure parameters selected by the operator (Shepard and Lin, 2002). AEC is an effective method of reducing patient exposure because it delivers the minimum exposure to produce consistent radiographic images. This machine was found to be performing optimally.

5.1.3 Reduction in Dose

Increasing the focus to film distance reduces the dose accordingly. The percentage dose reduction at FFD of 145cm for fixed collimation was found to be 8.95% and 6.30% for varying collimation settings respectively as shown in table 4.6. It is a good practice to reduce the field size whenever possible as this reduces the area of irradiated tissue and minimize the scattered radiation reaching the image receptor thereby improving the quality of the radiograph. This implies that extended FFD and collimation are good techniques of dose reduction for pelvic x-ray examinations.

Patients ESD were measured for five different examinations involving the pelvis (table 4.5). The values obtained showed that the doses are below the diagnostic reference level for the pelvis (10mGy). Diagnostic dose reference level is to promote good practice for a more specific imaging task. Whereas retrograde urethrogram records the highest dose of 7.56 mGy; care should be taken by the referring physicians to justify their request

for this examination, because of the inherent radiation hazard to the patients, staff and the public.

The backscatter factor was calculated for the pelvic phantom as shown in table 4.7 and found to be constant as the FFD varied incrementally. It also shows that large portion of x-ray beam is attenuated by tissues or interposed materials and only an integral amount of x-ray beam reaches the receptor to form an image. Figure 4.6 indicates that a small theoretical dose reduction (3.4%) occurs due to air attention at increased FFD of low energy x-rays. The radiation involved may have been absorbed in air due to its soft nature following increase in FFD. The dose area product measured is within the IAEA standard. This indicates the effectiveness of the collimators in limiting the beam area and correct alignment of the source with the image receptor.

5.2 Summary of Results

With the steady increase in public and professional concern regarding the biological effects of ionizing radiation, there is need for radiography profession to improve imaging techniques using gonads as the critical target organ. Collimation can effectively reduce dose to the patients producing a percentage reduction of 9%.

The results are consistent with the principles of inverse square law and also demonstrate the beam hardening effect on patient doses in radiology. That is, while increasing radiation exposures for FFDs, the additional air gap will reduce patient dose significantly by removing lower energy radiations. The radiation doses delivered to patients from the measured examinations are generally lower compared with the guidance reference dose level for pelvic examinations. There is optimization in the department for both patient and equipment.

The study suggests that increasing the FFD can substantially reduce patient doses while maintaining image quality with no additional cost implication. The findings of this study will be highlighted to those involved in medical imaging so as to formulate and ensure effective implementation of regulations defining acceptable standards of good radiographic practice during pelvic radiography.

5.3 Conclusion

The data provided in this study demonstrates that increasing the FFD is an effective dose reducing tool with no deleterious effects on the total image quality or additional cost implication for AP pelvic radiography and that collimation can effectively reduce doses to the patients.

5.4 Recommendation

1. The work should be put in practice to reduce doses to the patients, staff and public since it is easy to apply and of no cost implication to the imaging departments.
2. Further research should be carried out to find the dose delivered to the gonads during chest radiography since this investigation from statistics available occupies about 52% of the total diagnosis in the department during the period under review.
3. Comparative studies of dose received by patients and the estimated dose could be made for various examinations normally carried out in the radiology department.
4. Assessment of radiographic image can be evaluated through comparison with the recommended image criteria providing a means of continuous monitoring of image quality in the radiology department.

5. This study should be carried out for other radiology departments with manual x-ray machine and a more improved method of ESD measurement such as low dose ionization chamber.
6. A health physicist should be employed in the radiology department for proper monitoring of the equipment performance, personnel and quality assurance.

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