ASSESSMENT OF SAFETY MEASURES IN THE DESIGN AND UTILIZATION OF X-RAY DIAGNOSTIC RADIOGRAPHY

IN SOME HOSPITALS IN KADUNA STATE

BY

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DECLARATION

I declare that the work in this Project Thesis entitled ***Assessment of Safety Measures in the Design and Utilization of X-Ray Diagnostic Radiography in Some Hospitals in Kaduna State*** has been carried out by me in the Department of Physics. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project thesis was previously presented for another degree or diploma at this or any other institution.

Ida Akoji Patrick

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Name Signature Date

CERTIFICATION

This project thesis entitled *ASSESSMENT OF SAFETY MEASURES IN THE DESIGN AND UTILIZATION OF X-RAY DIAGNOSTIC RADIOGRAPHY IN SOME HOSPITALS IN KADUNA STATE* by PATRICK AKOJI IDA meets the regulations governing the award of the degree of Masters in Radiation Biophysics of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Health hazards are associated with exposure to ionizingradiations such as x-rays. The risks associated with x-rays in radiography are minimized through international best practices. In Kaduna state there are many hospitals and diagnostic centers using diagnostic x-ray machines. The major concern is the safety involved in the use of these machines. The aim of this research is to assess the safety precautions taken in these diagnostic radiography centers. One public hospital in Kaduna metropolis and four private centers in Zaria were assessed for x-ray room dimension, x-ray tube leakage and environmental safety, kilovoltagepeak(kV_p) accuracy, Half Value Layer(HVL), mA linearity, optical and x-ray beam congruence, beam alignment, and timer accuracy. X-ray room dimensions were determined by direct measurements with a measuring tape, x-ray tube leakage was determined with four TLDs each positioned at each interface of the tube while the highest possible exposure was made. Two survey meters were used to monitor the environment during exposures. kV_paccuracy was tested using RMI multifunction meter model 245 positioned at 100cm FFD. The HVL was determined with series of Al sheets of varying thickness placed on an exposure meter. mA and timer accuracies were tested using exposure meter (Rad Check). The optical radiation beam congruence was determined with four metallic markers placed at the edges of the light beam indicated on a loaded x-ray cassette while beam alignment was determined with collimator and beam alignment test tools. Only one out of the four centers complied with the $16m^2$ minimum room dimension required for an x-ray room. All the five centers passed the tube leakage test with none of the centers recording up to 1mSv/h at 100cm from the tube surface. Only one center passed area monitoring without a compromise. One out of the five centers wholly complied

with kV_perror limit of 5%. Only one center defaulted in mA linearity with coefficient of 0.49. Two centers failed optical radiation beam congruence. Two centers also failed beam alignment test with$>3.0^0$. Out of the three machines tested for timer accuracy two passed with coefficient of linearity of approximately 0.1.

In conclusion adequate safety precautions are not taken in these diagnostic centers. Therefore, staff and patient safety is compromised to an extent in most of the centers. Much efforts must be made towards improving radiation protection in most radiography centers in Kaduna state.

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CHAPTER ONE

INTRODUCTION

1.1 Brief History of X-ray

Radiations can be conveniently categorized into charged particulate radiations (fast electrons and heavy particles) and uncharged radiations (electromagnetic radiations and neutrons). Radiation can also be classified as ionizing or non-ionizing. Ionizing radiation is further classified into directly ionizing and indirectly ionizing (IAEA, 2005).

X-ray which is the radiation of interest in this research is an electromagnetic and uncharged radiation. It was discovered by a German professor of Physics known as Wilhelm Conrad Rontgen on 8 November, 1895 while he was working with a cathode ray generator (Gail, 2012). When electrons are accelerated to energies in excess of 5 keV and are directed on to a target surface, x-rays are emitted. The emitted radiationoriginates principally from rapid deceleration of the electrons when they interact with the nucleus of the target atoms. These x-trays are referred to as bremsstrahlung. The second sets of x-rays are characteristic in nature and areproduced when the fast beam of electrons from the cathode displaces the electrons in the K-orbits of the target atoms.

1.1.1 Properties of X-ray and Exposure

All X-rays exhibit the following properties (Andy, 2008):

- Fluorescence
- Photographic effects
- Penetration
- Ionization and Excitation
- Chemical changes

- Biological effects

Fluorescence

Visible light is produced by certain phosphors like calcium tungstate and caesiumiodide when they absorb x-ray photons. This property of x-ray is utilized in fluoroscopy for screening and intensifying screens used in x-ray cassettes.

Photographic effect

A photographic film can be fogged when exposed to x-rays. A latent image can also be formed on the photographic film if the x-ray passes through a material (tissue) to expose on the film.

Penetration

X-rays have the ability to penetrate opaque substances. The ability of a material to absorb x-ray beam depends on its atomic number, density and the energy of the x-ray beam. The ability of x-rays to penetrate substances is highly applicable in diagnostic and therapeutic radiography. It also forms the basis for careful selection of materials for shielding.

Ionization and Excitation

The ability of x-ray to raise an electron to a higher energy level in an atom or eject it completely from the atom forms the basis for most of its properties. X-ray quantity or exposure is measured based on ionization of air. The ionization increases with x-ray quantity.

Chemical Changes

X-rays can effect chemical changes when they pass through substances. A typical example is the oxidation of ferrous sulphate ($feSO_4$)to ferric sulphate [$fe_2(SO_4)_3$] when irradiated. This is the basis for chemical dosimeters.

Biological effects

Biological effects of x-rays on living tissues can be directly or indirectly. In direct effect the x-ray energy ionizes a biological macromolecule essential for survival and reproduction of the cell. In indirect effects, the x-ray energy ionizes water molecule to produce hydrogen(H^*)and hydroxyl (OH^*)free radicals respectivelywhich further produce hydrogen peroxide (H_2O_2) and hydroperoxyl radical (HO_2^*) which are poisonous to the cell (Gail, 2012). The cell may be killed or its reproduction may cease consequently.

However, any of these properties can lead to radiation exposure of an individual either directly or indirectly. The over exposure may result in health detriment depending on many factors such as degree of radiation absorption, area affected, exposure time,etc.

X-rays have been proved to be highly beneficial to man when properly managed based on international set standards otherwise have been observed to be hazardous to human health. To enforce the safe and proper utilization of the radiation in different scientific ventures, radiation protection programme must be implemented alongside its utilization to avert non-stochastic effect and minimize stochastic effect.

Take for instance its application in medicine which can be diagnostic or therapeutic in nature, its utilization must be focused on sound and acceptable radiological principles. In diagnostic radiology x-rays are highly utilized in conventional, fluoroscopic, mammographic, dental, tomographic units and so on. Similarly high energy x-ray therapy via linear accelerators,orthovoltage units are commonly put in place for various types of cancer treatments. Each of these has to be based on sound and acceptable radiation protection principles both in the design of the equipment,laboratory design and proper utilization to achieve safety.

1.1.2 Radiation ProtectionProgramme

The science of radiation protection or "health physics" grew out of the parallel discoveries of x-rays and radioactivity in the closing years of the 19thcentury for their safe utilization, safety of workers and the public. X-rays were used by military field hospitals as early as 1897 although the number of x-ray injuries escalated duringthe great war when primitive mobile x-ray equipment was used in the field. Early radiologists suffered skin cancers and amputation due to handling of x-ray sources(ICRP, 2009).The major aim of radiation protection programme is to ensure safe utilization of radiation and safety to man.

The International Commission on Radiological Protection (ICRP) set out three principles of radiation protection namely: justification of practice, optimization of protection and individual dose limits. The main focus of this research is to generally assess the level of compliance of radiological units to the principle of optimization of protection in the utilization of x-rays in diagnostic radiography. The principle states that the amount of exposure given and the number of people exposed should be "As Low As Reasonably Achievable (ALARA)".

1.2 Statement of Problem

The issue of safety in the utilization of radiation sources in medicine and industries has not been given adequate attention in most radiological centers found all over the world despite the efforts of national and international law enforcement agencies such as Nigerian Nuclear Regulatory Authority (NNRA) and International Atomic Energy Agency (IAEA), respectively (Adejumo*et al*,2012).

In 2005, a Florida hospital disclosed that 77 brain cancer patients had received 50% more radiation than prescribed because apowerful linear accelerator had been programmed incorrectly for nearly a year (Walt, 2010). This anomaly was detected after a long time due to lack of regular quality control checks on the machine.

Most x-ray machines tested in Tanzania were in a bad state as only 13% passed the quality control tests performed by Sungita*et al*,(2006). This prompted the Tanzanian government to introduce rehabilitation projects on their x-ray machines.

In Nigeria, Okeji*et al*, (2010) assessed radiographs taken in some teaching and specialist hospitals in South-East to evaluate the levels of x-ray beam collimation on the radiographs.It was reported that 52% and 59% of the radiographs taken in the teaching and specialist hospitals, respectively, were poorly collimated.This normally leads to greater exposure of staff and patients. Unfortunately, only about 60% of Nigerian employers and employees in x-ray diagnostic centers have good knowledge of hazards associated with radiation exposure (Aweda and Awosanya,2007).

The environmental monitoring and quality control tests carried out by Oluwafisoye*et al*,(2009) at an x-ray facility in a Nigerian hospital showed dose rates of 4μSv/h and 5μSv/h at the reception and outside the entrance door respectively.

In our society today many of such radiation facilities are installed for medical use. What is their standard of safety practice? Could it be that people are over exposed to radiation in such units due to poor states of the machines, their installations and bad laboratory designs? These are some of the questions that prompted this study.

1.3 Scope of Work

This work is limited to conventional x-ray diagnostic units in five centers namely:National Ear Care Center Kaduna, Alheri Diagnostic Center Zaria, Zazzau Radiological Center Zaria, First Scan Diagnostic Center Zaria and Salama Hospital Zaria.

1.4Aim and Objectives

The aim of this research is to assess the level of compliance to ALARA principle in the hospitals of interest. The objectives are:

1. To assess the layout and design of the x-ray laboratory
2. To perform radiation monitoring during exposures
3. To take inventory of the surveyed x-ray machines.
4. To perform some important quality control tests on the x-ray machines.
5. To assess the barriers within the x-ray laboratory.

1.5Justification

The risk of radiation induced fatal cancer is 5% per Sievert for exposure to low doses of ionizing radiation (Mettler,2012).Cancer is a leading cause of death worldwide,accounting for 7.6 million deaths(about 13% of all deaths) in 2008(WHO,2013). It is well known that the risk of developing cancer and the severity of other health effects increases with the dose of radiation absorbed. X-ray is not perceptible but by assessing the level of compliance to rules and principles guiding the design and utilization of its facilities it is possible toestimate how much safety is implemented.

Visual inspection of the location of the laboratory in respect to adjoining offices, corridors, patient waiting area,etc and also its dimension and shielding can indicate the level of exposure to staff and public. Likewise the age,design, location and performance of the x-ray machine can contribute to over exposure of staff and patients, and even the public. These parameters have to be properly assessed for safety purpose. The choice of conventional radiography is because it is the unit that is most commonly installed and abused in the society.Eze*et al*, (2011) reported that the x-ray facilities in Edo state of Nigeria are in bad states of safety. Conventional x-ray investigation accounts for 65%-70% of all radiological examinations performed in the hospital (Bruce et al,2005).

This research shall reveal the level of safety practisedin the target hospitals and may generally call for enforcement of quality control measures in medical diagnostic and therapeutic equipment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Production of X-ray

The main components of a conventional x-ray unit are the x-ray tube, the x-ray examination couch/chest stand, the image receptor(film) and the control console. The x-ray beam is generated from the x-ray tube in Fig.2.1.

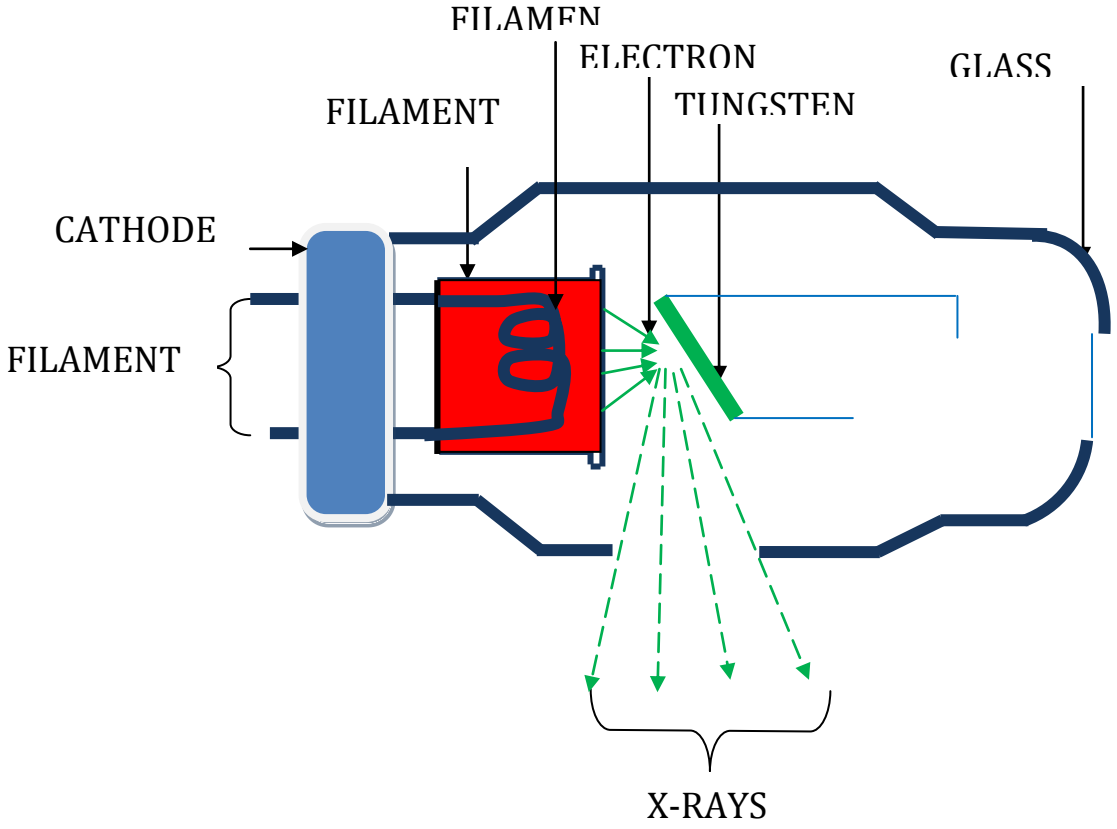


Fig. 2.1 Major components of a stationary x-ray tube

The production of x-rays makes use of three properties of the atoms in the target of the x-ray tube; the electric field of the nucleus, the binding energy of electrons and the propensity of atoms to exist in the lowest energy states possible (James,2006). When the tungsten filament in the cathode assembly is heated it provides stream ofelectrons by a process of thermionic emission. The electrons are focused toward the anode target with the aid of the focusing cup and are accelerated rapidly by a high voltage applied across the x-ray tube between the cathode and the anode. When

the fast moving electron strikes the target it transfers its energy to the atoms of the target through several interactions resulting in x-ray production and 99%heat. This is obtainable at the level of diagnostic radiography.

2.1.1 The X-ray Spectrum

The fast moving electron interacting with the atoms of the target can pass close to the nucleus of the atom which causes change of direction and reduction in velocity of the electron due to the electrostatic field of the nucleus. This loss of kinetic energy is converted to an x-ray photon called bremstrahlung which has a broad range of energies (Continuous spectrum) in Fig.2.2. The fast moving electron from the cathode can also interact with the orbital electrons of the target atoms with energy higher than the bindingenergy of the orbital electrons leading to an ejection of electron from the orbit. An electron from a higher orbit automatically fills the vacancy created. A characteristic x-ray with a single energy (characteristic or line spectrum) is emitted in the process (Andy, 2008). In diagnostic radiography only K-shell characteristic x-ray is applicable because its energy is high relative to the energies of other shells.

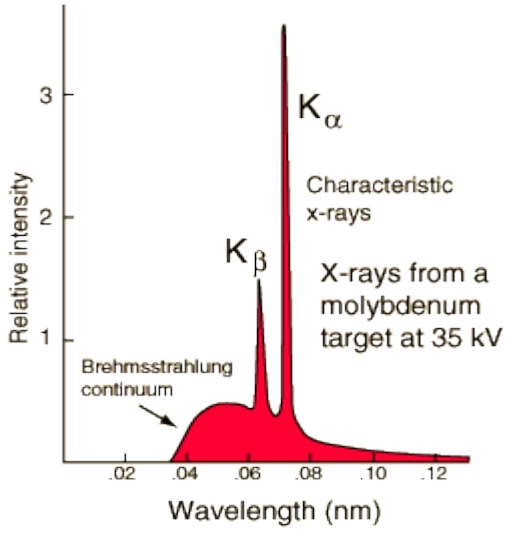


Fig 2.2 X-ray spectrum

The spectrum features provide the characteristic of the target material elements and are superimposed on the continuous spectrum of the x-ray beam.

2.1.2 **Photon Energy**

As it was stated earlier, electrons are produced in the x-ray tube by thermionic emission at the cathode. They are accelerated to the anode target by a high voltage applied across the tube.

If the charge *q* coulombs flowing in time *t* seconds is measured then the current *I* amperes is given by

$$I = \frac{\mathrm{q}}{\mathrm{t}} \qquad (1)$$

This implies that if a current I, flows for a given time *t* the total charge generated is

$$q = It \qquad (2)$$

In diagnostic x-ray, current is always in milli-ampere (mA) which is equal to 10^{-3} ampere (A).

Therefore, charge generated q = It(mAs)

The energy of an electron E, arriving at the target after being accelerated is given by

$$E = qV_p \qquad (3)$$

Where V_p is the peak voltage

Substituting equation (2) in (3) above we have

$$E = V_p It \qquad (4)$$

But this electron energy is all converted into the energy of the photon with minimum wavelength,λ_{min}.

Therefore, $E_{max} = E$

$$E_{max} = \mathrm{V_p It} \qquad (5)$$

Where E_{max} is the maximum energy of the photon produced. Now applying the quantum theory,

$$E_{max} = h\upsilon_{max} = \frac{hc}{\lambda_{\min}} \qquad (6)$$

Substituting equation (5) in (6) above, we have

$$V_p It = \frac{hc}{\lambda_{\min}} \qquad (7)$$

Where h =plank's constant

C = velocity of electromagnetic radiation in vacuum

υ_{max} = maximum frequency of the photon

$$\lambda_{min} = \frac{hc}{qV_p} \qquad (8)$$

The maximum energy of the photon incident on the material (patient in diagnostic radiography) is therefore directly proportional to the peak voltage following the equation

$$E_{max} = qV_p \qquad (9)$$

Percentage kV_p error is calculated using

$$\% \text{ Error} = \frac{Measured\ \mathrm{kVp} - Real\ \mathrm{kVp}}{Real\ \mathrm{kVp}} \text{ x } 100 \qquad (10)$$

The tolerance limit is 5% of the real kV_p (Rehani, 1995).

2.2 X-ray interaction with Matter

The major interactions of x-ray with matter are photoelectric effect, Compton scatter and pair production. The interaction varies depending on the photon energy and the atomic number of the material medium. A fourth interaction known as photo-nuclear disintegration also takes place with a

very high photon energy far beyond application in diagnostic x-ray. X-ray photon energy applicable in diagnostic radiography is in the range of 50-125keV (Chen et al, 2012).

2.2.1Photoelectric Effect

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 kinetic energy of the secondary electron is equal to the energy of the incident photon minus the binding energy. The vacant site is then filled with an electron from an outer shell giving off a characteristic radiation. If the photon energy is kept constant, mass attenuation(μ_m) is proportional to Z/A where Z and A are the atomic number and mass number respectively of the medium.

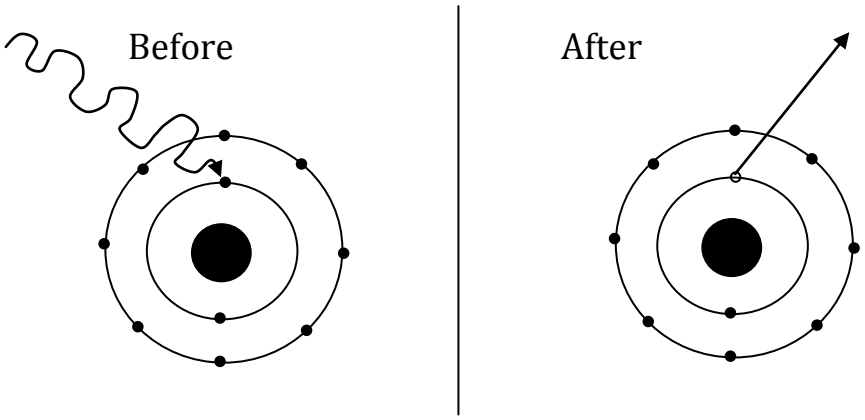


Fig.2.3Diagram showing Photoelectric Effect

$$E_k = h\nu - E_b \quad (11)$$

whereE_k, $h\nu$ and E_b are the kinetic energy of the electron, the energy of the incident radiation, and the binding energy of the electron respectively.

2.2.2 Compton Scattering

This occurs when an incident photon has much greater energy than the binding energy of an electron in an atom of the medium, so that the electron behaves as if it were free. On colliding with the electron, the photon causes it to recoil, thus part of the photon energy is transferred to the electron. The photon changes direction and with a reduced energy and modified wavelength.

Figure 2.4: Compton scattering of an incident photon from an electron.

$$h\nu' = \frac{h\nu}{1+\frac{h\nu}{m_o c^2(1-cos\theta)}} \qquad (12)$$

where $h\nu'$ = scattered photon energy

$h\nu$ = incident photon energy

m_o= rest mass of electron

c = speed of light in vacuum

$\theta = angle\ of\ scattered\ photon$

θ_e= recoil electron angle

T = kinetic energy of electron

$$h\nu' = \frac{h\nu}{1+\alpha(1-cos\theta)} \qquad (13)$$

where$\left(\alpha = \frac{h\nu}{mc^2}\right)$

Energy transferred to the electron that is kinetic energy of the electron T is given by

$$T = h\nu - h\nu' \qquad (14)$$

$$= \frac{h\nu\alpha(1-cos\theta)}{1+\alpha(1-cos\theta)} \qquad (15)$$

2.2.3 **Pair Production**

This can only occur if the photon energy is equal to or greater than 1.02Mev. At these energies, a photon can interact with the field around the nucleus of an atom of the medium; this result in the spontaneous creation of a pair of electrons, one negatively charged and the other positively charged (negatron and positron) respectively.

In this process mass and energy are seen to be interchangeable according to Eisten's equation:

$$E = mc^2 \qquad (16)$$

Where E is the energy needed to create the mass m.

The kinetic energy of the electron and positron emitted is given by

$$E_{e-} + E_{e+} = h\upsilon - 2m_o c^2 \qquad (17)$$

Where E_e-and E_e+ are the kinetic energy of the electron and positron respectively.

When the negatron slows down, it is indistinguishable from the ordinary electron and the positron loses its kinetic energy to recombine with the electron by a process of annihilation in the medium. A 1.02MeV photon is produced back in the process.

2.2.4**Photo-nuclear Disintegration**

This can only occur if the incident photon has a sufficiently high energy to cause the disintegration of the nucleus of the atom leading to an ejection of either a neutron or proton. This is only possible in radiotherapy where some linear accelerators depending on the model can treat cancer with electron energies ranging from 4-22 MeV(Charles and Dennis,2010). In diagnostic radiography only photoelectric absorption and Compton scattering are possible.

2.3**Health Effects of Radiation**

Radiation biology is defined as the study of the effects of ionizing radiation on biological systems (Gail, 2012). Understanding the effects is essential to the safe and effective use of radiation for diagnostic and therapeutic purposes. The body absorbed dose (D) during radiography investigation is given by

$$D = \frac{dE}{dm} \qquad (18)$$

Where dE and dmare energy absorbed by the exposed body and mass of the target exposed respectively.

Radiation effects can be broadly classified into stochastic (probabilistic) effects and non-stochastic (deterministic) effects (ICRP, 2005)

Deterministic effects are characterized by three qualities: First, a certain minimum dose must be exceeded before the effect is observed. This means that deterministic effect has a threshold dose. Additionally, the magnitude of the effect is proportional to dose. As the dose increases, the effect increases as well. Furthermore, there is a clear causal relationship between exposure and the effect observed.

Stochastic effects on the other hand, are probabilistic in nature. It has no threshold dose. This effect can occur in both exposed and non-exposed individuals but the chance of occurrence increases with exposure and its dose. In this light radiation protection principle is based on the non-threshold effect (stochastic effect). A very common example of stochastic effect is cancer.

2.4**Radiation Protection Quantities and Units.**

Special radiation protection quantities and units according to IAEA,(2006)are:

Organ dose

Equivalent dose

Effective dose

Committed dose

Collective dose

2.4.1 **Organ Dose (D_T)**

This is otherwise referred to as absorbed dose. This is defined as the mean dose in a specified tissue or organ T of the human body. It is given by

$$\mathrm{D_T} = \frac{E_T}{M_T}\,(\mathrm{J/kg}) \text{ or } \mathrm{Gray(Gy)} \qquad (19)$$

Where E_T is total energy imparted by radiation to the organ.

M_T is mass of target organ or tissue.

2.4.2 **Equivalent Dose(H_T)**

This is defined by the organ dose $D_{T,R}$ multiplied by a radiation weighting factor W_R. It is given by

$$H_T = W_R D_{T,R}(\ \mathrm{Sv}) \qquad (20)$$

Where: $D_{T,R}$ is the absorbed dose delivered by radiation type R averaged over the target tissue or organ T.

W_R is the radiation weighting factor for radiation type R.

2.4.3 **Radiation Weighting Factor W_R**

Radiation weighting factor W_R is a dimensionless number which depends on the way in which the energy of radiation is distributed along its paths through the tissue.

Table 2.1: Radiation Weighting FactorsSource: ICRP, (2005)

Type of energy range	**Radiation weighting factors (W_R)**
Photons of all energies	1
Electrons and muons of all energies	1
Neutrons, energy < 10keV	5
10keV to 100keV	10
>100keV to 2MeV	20
>2MeV to 20MeV	10
>20MeV	5
Protons, other than recoil protons, energy>2MeV	5
Alpha particles, fission fragments, heavy nuclei	20

2.4.4 **Effective Dose, E**

This is the summation of tissue equivalent doses multiplied by the appropriate tissue weighting factor W_T. Given by

$$E = \Sigma W_T H_T \quad (Sv) \qquad (21)$$

Table 2.2: Tissue Weighting Factors (ICRP 1991)Source:ICRP(2005)

Tissue organ	W_T	Tissue or organ	W_T
Gonads	0.20	Oesophagus	0.05
Bone marrow(Red)	0.12	Liver	0.05
Colon	0.12	Thyroid	0.05
Lung	0.12	Bone surface	0.01
Stomach	0.12	Skins	0.01
Bladder	0.05	Remainder	0.05
Breast	0.05	Total	1.00

2.4.5**Committed Dose**

For practical reasons committed dose quantities have been introduced into radiological protection.Radionuclide incorporated in the human body irradiate the tissues over time periods determined by their physical half-life and their biological retention within the body. The committed dose from an incorporated radionuclide is the total dose expected to be delivered within a specified time period. The committed radiation-weighted dose$H_T(\tau)$, in a tissue or organ, T, is defined by

$$H_T(\tau) = \int_{t_o}^{t_o+\tau} H_T\,(t)dt \qquad (22)$$

Where τ is the integrated time following the intake at time to. The quantity committed effective dose $\mathrm{E}(\tau)$ is then given by

$$\mathrm{E}(\tau) = \sum_T \mathrm{W_T}'\mathrm{H_T}(\tau) \qquad (23)$$

For compliance with dose limits it is recommended that the committed dose is assigned to the year in which the intake occurred.

A commitment period of 50years is considered for adults and 70years for infants and children (ICRP, 2005).

If the radionuclide is concentrated in the air, then parameters such as the Annual limit of intake (ALI) and the Derived Air Concentration (DAC) are considered. They are related as follows:

$$\mathrm{ALI} = \frac{Elimit.w}{\mathrm{e}(\tau)}(\mathrm{Bq}) \qquad (24)$$

$$DAC = \frac{ALI}{2400}\left(\frac{Bq}{m^3}\right) \qquad (25)$$

2.4.6**Collective Dose**

The previous quantities discussed are for individual radiation protection. ICRP introduced the collective dose quantities for exposure to a group of people (ICRP,2005). It is defined as the summation of the products of the mean doses in the various groups of exposed people and the number of individuals in each group. Its unit is man-sievert. (Man Sv).

The collective effective dose due to individual effective dose values between E_1 and E_2 is defined

$$S(E_{1,}E_{2,}\Delta T) = \int_{E_1}^{E_2} E\,\frac{dN}{dE}\,dE \qquad (26)$$

where$\frac{dN}{dE}$denotes the number of individuals who experience an effective dose between E and E + dE and ΔT specifics the time period within which the effective doses are summed.

2.5**Principles of Radiation Protection**

The basic principles of radiation protection are three. These include:

1. Justification of practice which states that any practice involving exposure should produce more benefits than harm to the individual or society exposed.
2. Optimization of protection which states that the magnitude of individual doses and the number of people exposed should be kept as low as reasonably achievable, economic and social factors being taken into account. This is popularly referred to as ALARA principle.
3. Individual dose limits: the exposure of individuals will be subjected to dose limits to ensure that no individual is exposed to radiation risks that are judged to be unacceptable.

The design of x-ray room and the operation of diagnostic radiography must be such that ALARA principle is obeyed. Under no condition shall safety be compromised in the design of an x-ray unit. X-ray is a highly penetrating radiation hence its safe utilization should be incorporated in the engineering design of the equipment, the design of the laboratory and safe handling/utilization of the equipment.

Three cardinal points are identified by National Council on Radiation Protection and Measurements (NCRP) for radiation protection in the safe utilization and handling of ionizing radiation sources and ionizing radiation producing devices. These include:

- Time
- Distance
- Shielding

Time

Going by the relationship below:

$$Dose\ rate(\dot{D}) = \frac{Dose(D)}{Time(T)} \quad (27)$$

$$\text{Therefore;} \dot{D} = D \times T \quad (28)$$

This means that if the dose rate is maintained constant, the radiation dose absorbed by the body is directly proportional to the time of exposure time. To minimize dose implies that the exposure time must be minimized.

Linearity of Timer: In diagnostic x-ray it is required that the ratio of the exposure (mR) to the product of time and tube current (mAs) remain constant through a range of timer station. Tolerance limit of linearity coefficient is 0.1(Rehani,1995). This is calculated using

$$\text{Coefficient of linearity} = \frac{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\max} - \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\min}}{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\max} + \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\min}} \qquad (29)$$

Distance

Electromagnetic radiation (x-ray in convectional radiography and gamma ray in radiotherapy) obey inverse square law which states that the intensity of a photon spreading out from a source (x-ray tube in radiography) is inversely proportional to the distance covered.

That is:

$$Intensity \propto \frac{1}{(Distance)^2} \qquad (30)$$

Therefore,

$$\frac{Intensity_1(I_1)}{Intensity_2(I_2)} = \frac{(Distance_2)^2(d_2^2)}{(Distance_1)^2(d_1^2)} \qquad (31)$$

$$I_1 d_1^2 = I_2 d_2^2 \qquad (32)$$

Reference to utilization of distance in the control of exposure, it is the most versatile of all the cardinal points. The closer the source of radiation to the target the higher the risk. The risk drastically decreases in proportion to the inverse square of thedistance away from the target. Maintenance of appropriate distance in the utilization of radiation serves a good control measure.

In the design of the x-ray laboratory, the distance is utilized in various parameters such as primary barrier, secondary barrier, source- to – image distance (SID), etc. The contribution of the inverse square law in the control of exposure cannot be under estimated. For instance if the dose rate from a source of radiation placed at Im from the target is approximately 10μR/h shifting the sourceto a new location of 2m will reduce the source intensity by ¼ of the initial intensity. Movement of the source to 3m will reduce the source intensity by 1/9 of the initial intensity and so on.See figure 4 below;

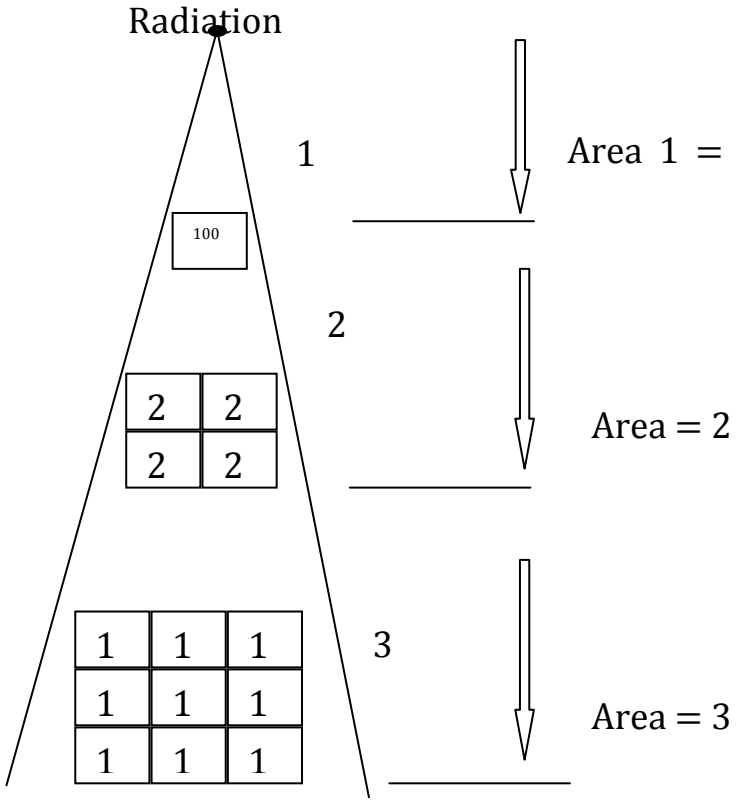


Fig 2.4: Diagram showing Inverse Square Law

Shielding

Shielding is a highly required method of radiation protection. It is specified by NCRP in designing an x-ray room. Commonly used shielding materials include lead, bricks, barium etc. It is required by IAEA that for any exposure by a radiographer, the exposure switch must be located behind a secondary barrier. Shielding does not completely stop radiation exposure but reduces it minimally to an acceptable level (NCRP,2006). A very important requirement to consider during x-ray room design is the calculation of the amount of scatter inside and outside the planned locations of the shielding barriers (Mcvey and Weatherburn,2004).

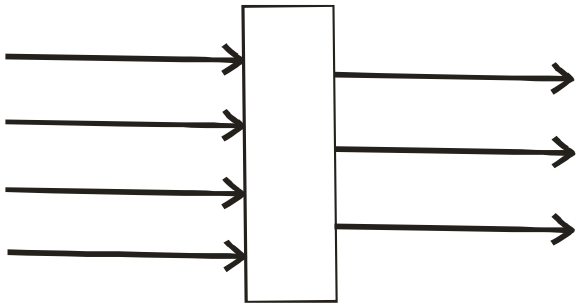


Figure2.5: Attenuation of a beam of X or gamma ray through an absorber of thickness x.

Where: I_o is the initial intensity

μ_l = linear attenuation coefficient of the absorber material.

x=thickness of absorber

The attenuation of the intensity of a beam of x or gamma rays in an absorber follows a true exponential variation with the distance of penetration. It follows that by increasingthe thickness of the absorber or using a material of high linear attenuation coefficient, the x-ray beam is greatly attenuated. The linear attenuation coefficient μ_l depends on incident photon energy hυ and the

attenuator atomic mass Z. For this reason, high Z element like lead is commonly used for photon beam shielding.

The thickness of material required to reduce the intensity of a photon beam to 50% of its original value isreferred to its half valuelayer (HVL). It means that after transversing HVLphoton beam intensity is reduced by a factor of ½.Therefore,

$$\frac{I_o}{2} = I_o e^{-\mu_l x_{1/2}} \qquad (33)$$

$x_{1/2}$ is referred as the half value layer (HVL).

Given μ_l and thickness of the material, the measured HVL enables the measurement of an effective energy reflecting the hardness or penetration power of the photon beam. In shielding calculation, the parameter HVL is much in use.

$$x_{1/2} = \frac{\ln 2}{\mu_l} = \frac{0.693}{\mu_l} \qquad (34)$$

The assessment of HVL of an x-ray machine is very necessary to avoid unnecessary patient dose due to low energy x-rays which are not filtered.

Similarly, the tenth-value layer (TVL) is defined as the thickness of the attenuator that attenuates the photon beam intensity to 10% of its original value.

$$\text{TVL}\left(x_{1/10}\right) = \frac{ln10}{\mu_l} \qquad (35)$$

$$\text{Therefore,} x_{1/10} = x_{1/2}\left(\frac{ln10}{ln2}\right) \qquad (36)$$

$=3.3x_{1/2}$

Individual Dose Limits

The exposure of individuals should be subject to dose limits. This ensures that no individual is exposed to radiation risks that are judged to be unacceptable from any practice in any normal circumstance. This is the reason why every radiation worker must be monitored regularly and the work environment monitored to avoid exposure of workers and public beyond acceptable dose limits.

Table 2.3: IAEA Dose Limits for Radiation Workers and Public. Source: (IAEA, 2007).

Tissue or organ	Radiation worker	Public
Whole body	20msv/yr	1msv/yr
Lens of eye	150msv/yr	15msv/yr
Skin	500msv/yr	50msv/yr
Hands and feet	500msv/yr	50msv/yr
Declared pregnancy	2msv to lower trunk	

2.6Specifications for X-ray Room Design

Thure, (2000) in collaboration with WHO specified the following for an x-ray examination room (conventional) with a single tube.

- The size of an x- ray room should be (18 – 24)m^2 including control console area. NNRA requires minimum dimension of 16m^2 (NNRA, 2013) and this is acceptable by most regulatory bodies at international level.
- The ceiling height should be at least 2.5m to permit full angulations of stand.
- The window if necessary should be at least 2m high above the floor outside.

- The main entrance door should be 110cm or (90 + 20)cm with two door hung on opposite side and there should be no step or threshold.
- The door must contain iron or lead for radiation protection and the door frame must be of iron or steel to carry the weight.
- The x- ray tube stand may weigh as much as 300kg concentrated on small support area (about 20x30cm). The best material is leveled concrete, covered by wood or PVC.
- A regular kitchen sink with a flat bottom is required.

Control Area

- The net area for control behind lead screen is 4-5m^2 with glass window of 30x30cm minimum dimension.
- If the control area is located outside the x-ray room in a brick or concrete wall, the lead glass windows should be 40x50cm minimum.
- The operator must have at least 0.697m^2 of unobstructed floor space in the control area (Regulatory Guide B6,2009).

Adjoining Offices

Adjoining offices must have separate entrances from x-ray room.

Toilet(s)

Toilet should be large enough for patient assistance (3 – 4)m^2 minimum.

Cubicle(s)

Changing Cubicle(s) should measure minimum of (1.5 – 3)m^2each.

Location of X-ray Room

- Ground floor close to out- patient department for accessibility(WHO,2004).
- Two separate entrances needed for patient to x-ray room and for staff/visitors to offices.
- The control room should have direct access to the x-ray room, the dark room and the office.

Distances

- The distance between control panel and chest stand should not be less than 3m.
- The distance between x-ray tube and operator should be at least 1.8m (AAPM, 2002).
- The distance between the operator and edge of the control cubicle during exposure viewing patient should be at least 0.457m (Regulatory Guide B6, 2009).
- The distance between fixed console and open edge of the control cubicle nearest to x-ray couch should be at least 1.02m (Regulatory Guide B6, 2009).
- The minimum distance from occupied area to shielded wall is 0.3m (NCRP, 2006)

Shielding

Lead apron; 0.25-0.35mm lead apron should be worn if the operator is not behind the protective screen or control area.

Protective screen

- 15kgm^{-2} (1.3mm) lead sheet or its shielding equivalence is specified. It is higher if the screen is less than 2m from patient or x-ray tube.
- The height of the screen from the floor should not be less than 2m.
- The width of the screen should be greater than 90cm to protect from tube leakage and patient scatter.

- The screen protective window is either lead glass (normal thickness 6mm, 1.5mm lead equivalence) or H-22 lead acrylic (1.0mm lead equivalence at 100kVp).
- The gap permitted between floor and screen for castor should be less than 5cm.All shielding overlap should be 5mm minimum.

Doors

- The steel door frames are to overlap the wall structure to take care of scattered radiation.
- Door shielding of $10kgm^{-2}$ lead sheet is satisfactory except if the entrance has a continuous occupancy.
- Warning light at entrance is required to be connected to the x-ray generator circuit to light at "prep" and for the duration of the exposure (RHB 2004).
- The door should be lockable from inside to avoid accidental exposure during operation.

Walls

- The minimum wall thickness required is 23cm and not less than 35cm of solid brick at primary barrier wall.
- Primary barriers in walls should extend to a minimum height of 2.13m above the floor (IAEA, 2004).
- Primary barrier section of the wall should extend at least 30cm beyond each boundary of the area normally exposed to primary x-ray beam. The primary barrier takes care of direct beam from the x-ray tube.
- Primary barriers should have minimum lead equivalence of 2mm.
- Secondary barriers must have 1mm lead equivalence minimum or 7.5cm thick concrete (WHO, 2004). This takes care of scattered radiation from the patient and other objects within the exposure room and also the leakage radiation from the x-ray tube.

Acceptable Dose Rates

According to USFDA,(2008),

*Leakage radiation should not be more than 1mGy/h from 1m from the x-ray head.

*Dose rate at console cubicle should not be more than 1µSv/h.

*Maximum permissible dose rate outside walls after shielding depends on how sensitive the path is, it is normally 2.5 and 7.5µSv/h for sensitively used and non- sensitively used paths,respectively.

*Doors must have equivalent shielding to the walls.

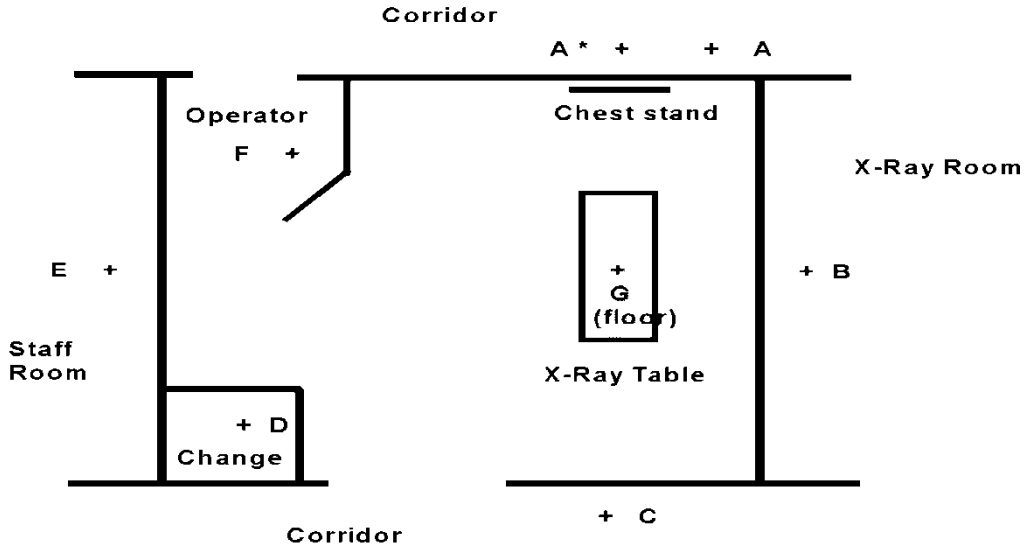


Fig.2.6 Typical X-ray Room Layout: Source IAEA, (2011)

2.7 REVIEW OF PREVIOUS WORK

Arun,(2010) carried out a quality assurance survey on 190 x-ray machines in India and discovered that out of the 190 machines examined only 43.6% had kVp accuracy within tolerance limit, 22.9% had mA accuracy within tolerance limit and 51% of the machines tested were more than 10years old.

In Erbil hospital Iraq, Saeed *et al*, (2014) evaluated the radiation protection level in the x-ray unit usingthe palm RAD 907 Nuclear Radiation Meter and Contamination Monitor CoMo 170 to measure radiation leakage. It was found out that dose rate in the technician office was 20 µSv/h, dose rate in front of the window at the console was 113 µSv/h while that at the reception was 20 µSv/h indicating high health hazard to the staff and the public.

Sungita, *et al* (2006) carried out some QC performance tests on 196 x-ray machines in Tanzania where 59% failed kVp accuracy test, 57% failed timer accuracy test, 60% failed beam alignment test and 20% failed leakage test.

Sonawane, et al (2010) conducted radiation safety and QA in 118 medical x-ray installations in 45 major hospitals in India for an audit report and found out that (23%) of the machines has inaccurate kVp, lack of optical radiation beam congruence was found in (19.6%), and (4%) faulty in beam alignment.

Taha, (2010) carried out a study on the quality assurance of conventional x-ray machines in Cairo, Egypt using noninvasive kV meter. Out of the six machines tested only one machine was found having kVp error of 20% that is above tolerance error of $\pm$ 5%. The machine was immediately corrected. The HVL of the six x-ray machines ranged from 2.31-2.70mmAL at 70kVp.

Oluwafisoye, et al (2009) performed QC and environmental monitoring of a private radiological center (Moroko x-ray center Lagos). Dose rates of 3.0 to 3.6 µSv/h were rcorded at the entrance door when the door was closed and when it was opened respectively. The dose rates at adjacent

room and waiting area were a factor of 60 higher than background. Around the control console a dose rate of 2.0 µSv/h was measured. In this center radiation warning light and signs were not provided and the workers were not monitored.

2.8. STATISTICS

It is necessary most times to interpret data obtained from an experimental research using some statistical parameters. A few of such parameters which shall be used in this research are discussed below:

Percentage Error: This is calculated as follows:

Error = Experimental (Measured) Value – Known (Real) Value

Relative Error = Error/Real Value

%Error = Relative Error x 100(Anne, 2015) (37)

Standard Deviation (σ): This is very important to correctly interpret the data. For example in physical science, a lower standard deviation for the same measurement implies higher precision for the experiment (Araoye, 2004).

Standard deviation is given by:

$$\sigma = \sqrt{[\sum(x-\mu)^2/N]} \quad (38)$$

Where σ = Standard deviation

x = Each item or score

N = Number of items

μ = Mean

Variance (V): This is the measure of dispersion relative to the scatter of the values about their mean. Variance is the square of standard deviation(Araoye,2015).

Coefficient of Variation (CV): This is a way to describe the variation of a test. The CV expresses the variation as a percentage of the mean and is calculated as follows:

$CV = \left(\frac{\sigma}{\mu}\right) 100$ (Madelon, 2009) (39)

A CV provides a general feeling about the performance of a method. CV of 5% or less generally indicates good performance of a method (Madelon, 2014).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

- Survey meters with GM detectors
- kV meter(RMI) model 245
- Exposure meter(Rad check)
- Collimator and Beam Alignment test tool model 161B and 162A
- X-ray cassette size 24 x 30 cm with films
- Metallic markers
- Aluminum sheets
- Thermoluminiscent dosimeters (TLD)

3.2 Methods

3.2.1 Layout and Design of the X-ray Room

The layout of each x-ray room was sketched to show its dimension, adjoining structures and offices near the x-ray facility,the source (x-ray tube), chest stand, operator's stand and their distances apart. The sketch also shows the windows, doors and lead linings within the x-ray room. The x-ray centers are indicated by A,B,C,D and E (fig.3.1-3.5).

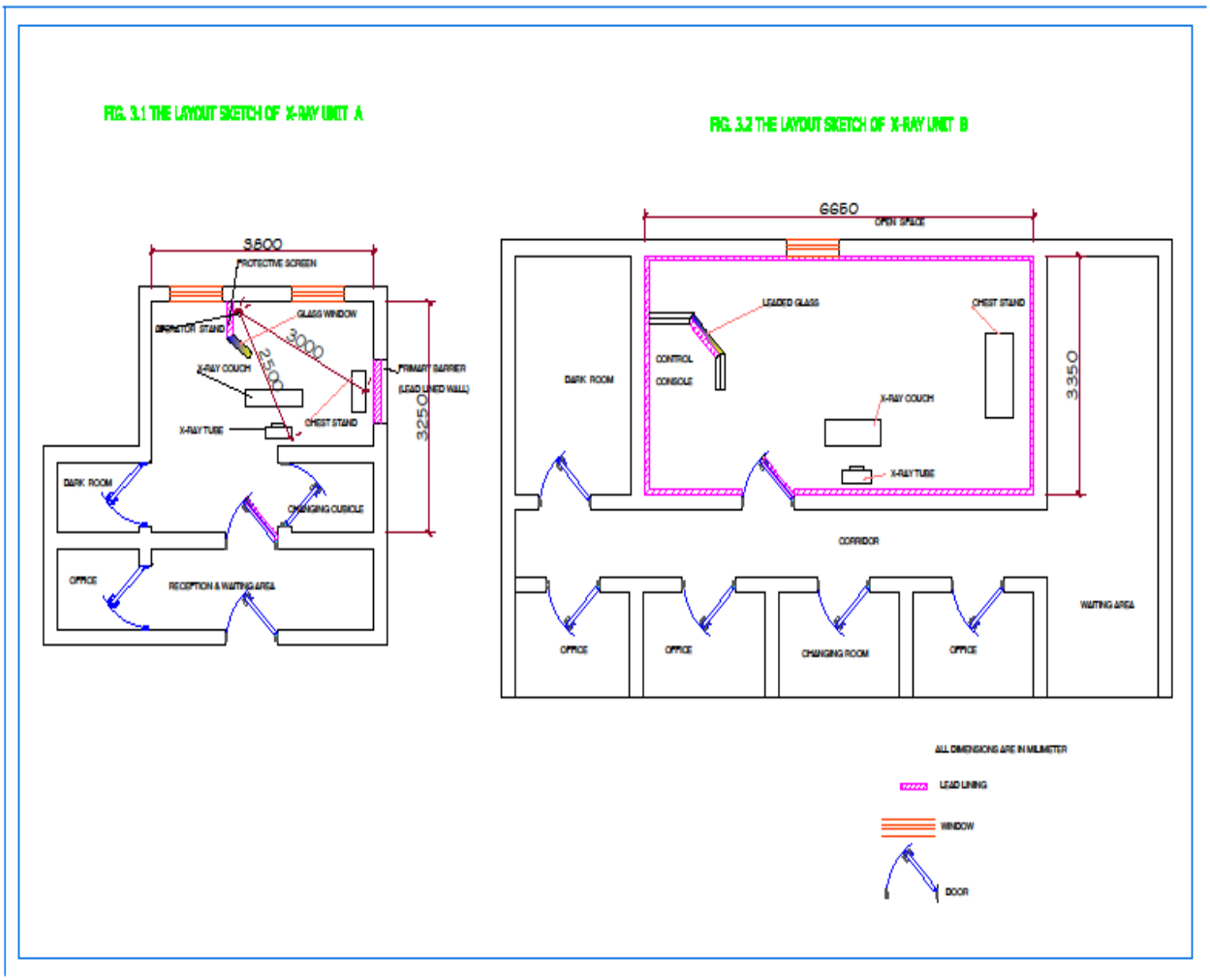


Fig.3.1 and 3.2 Layout Sketch of Units A and B respectively

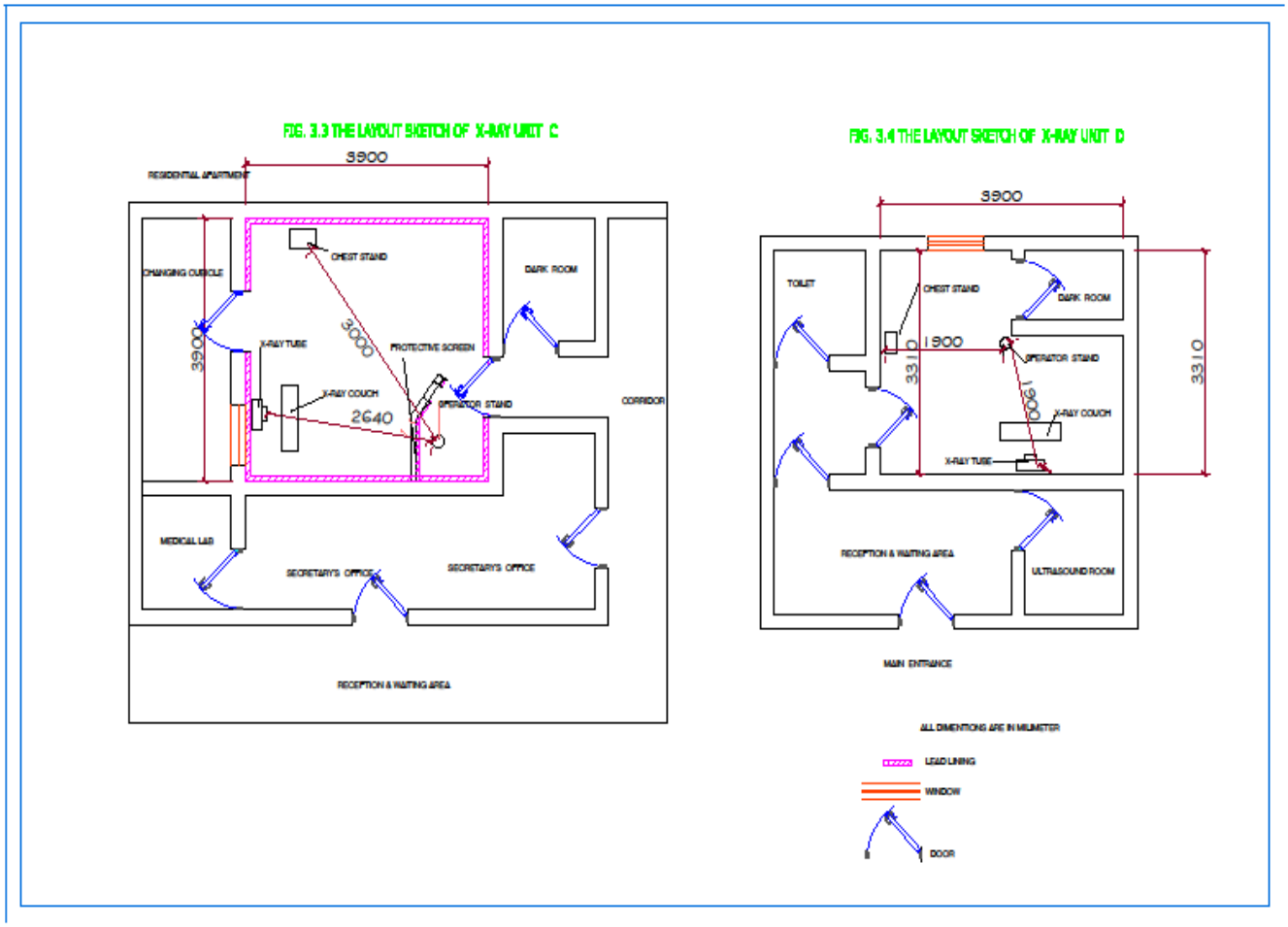


Fig.3.3 and 3.4 Layout Sketch of Units C and D respectively

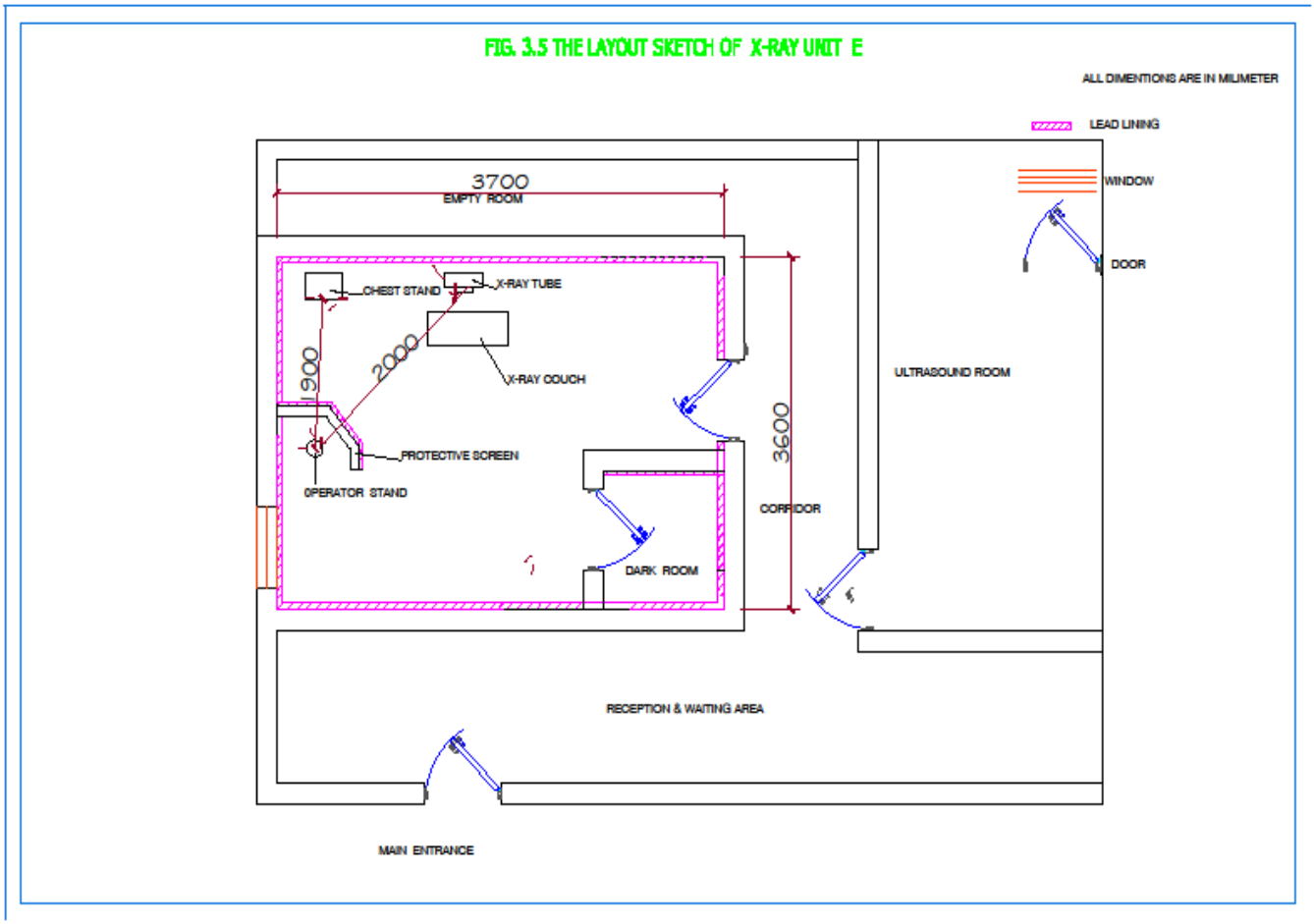


Fig.3.5 Layout Sketch of Units E

Table3.1 Layout parameters of the x-ray Centers(deviations are boldly italicized)

LAYOUT PARAMETER	**X-RAY CENTER**				
	A	B	C	D	E
ROOM					
Location	Bungalow	Bungalow	Bungalow	Bungalow	Bungalow
Dimension	***12.35m²***	22.28m²	15.21m²	***12.91m²***	***13.32m²***
WALL					
Type	Cement block	Cement block	Brick block	Cement block	Cement block
Thickness	0.27m²	0.27m²	0.27m²	0.27m²	0.27m²
Lead thickness(mm)		1.30			
Lead lining height(m)	-	2.30	1.30***1.84***	-	1.30 2.20
DOOR					
Number	1	1	1	1	1
Type	Wooden(double-leaved)	Wooden(double-leaved)	Wooden(single-leaved)	Wooden(single-leaved)	Wooden(single-leaved)
Dimension (m)	1.10 x 2.00	1.23 x 2.00	0.84 x 1.94	0.74 x 1.55	0.80 x 2.00
Thickness(cm)	5.00	5.00	4.00	4.00	4.00
Lead lining	Present	Present	Absent	Absent	Absent
Lead thickness (mm)	1.30	1.30	-	-	-
CEILING					
Height from floor(m)	2.50	2.50	3.65	2.20	3.00
Type	Wooden board	Wooden board	Wooden board	Wooden board	Wooden board
WINDOW					
Number	2	1	1	1	1
Height from floor(m)	***1.70***	***1.00***	2.10	***1.35***	
DISTANCES					
Operator –tube(m)	2.50	3.00	2.64	1.90	2.00
Operator -chest stand(m)	3.00	4.28	3.00	***1.90***	***1.90***
CONTROL CUBICLE					
Type	Leaded screen	Concrete	Leaded screen	-	Leaded screen

3.2.2 X-ray Machine Specifications

Table 3.2 X-ray Machine Specifications for Centers A-E

PARAMETER	**CENTER**				
	A	B	C	D	E
Machine type	Mobile	Fixed	Mobile	Mobile	Mobile
Manufacturer	Picker Intl	LIN Ltd	Watson ltd	Shimadzu	G&C Ltd
Year of manufacture	1986	2005	-	2001	-
Country	Japan	-	-	Japan	-
Tube Rating					
Inherent filter	0.7mm AL	1.5mm AL	-	2mm AL	-
Maximum kVp	125	150	160	100	200
Maximum mA	-	400	150	30	200
Common kVp	70-80	90-100	70-80	70-80	100
Common mAs	10-30	40-80	20-40	20-60	9

Table 3.2 shows the specifications of the x-ray machines assessed in this study. Certain information about some of the machines was not available on the machine labels and the manuals were not available.

3.2.2 Exposure Load on the Machines

Table 3.3. Exposure load distribution of the Diagnostic Centers

Center	Av.No. of Pts/day	Av.No.of Exp./pt	Total Exp./day
A	04	02	08
B	12	03	36
C	10	02	20
D	10	02	20
E	01	02	02

The data for Table 3.3 were collected from patients register and from interview with some operators where patient register was not sighted.

3.2.4 Area Monitoring

Two survey meters with calibration numbers 990097 and 990100 calibrated in year 2013 were labeled A and B respectively and were used simultaneously to assess the radiation exposures to strategic areas within the x-ray room and the surroundings. The areas assessed include the operator's stand, dark room(behind door),x-ray roomdoor(outside),reception/waiting area, adjoining offices, corridors, windows and walls (behind), changing cubicles and toilets. These exposures were taken at the upper borders of the range of exposure factors commonly used in these diagnostic centers. For each location three exposures were taken and the average recorded. The difference in the readings of the two survey meters was negligible. Therefore, the average of the two was taken to give the radiation dose for each location. Background radiation was measured before exposures were taken in each center and the values recorded.

3.2.5Quality Control Tests

The following quality control tests were performed on the x-ray machines.

- Tube leakage at an authorized distance of 100cm from x-ray tube.
- Peak kilovoltage (kV_p) test accuracy
- Evaluation of Half value layer (HVL)
- mA linearity and reproducibility
- Optical and x-ray beam congruence
- Beam alignment
- Timer Linearity

Assessment 1: Tube leakage at authorized distance from x-ray tube.

Materials: Four TLDs and meter rule

Aim: To assess the level of leakage radiation from the x-ray tube. High level of leakage contributes towards increase in dose to patient and the operator.

Objectives:

- To measure the dose recorded by the TLDs placed at different interfaces of the x-ray after exposure.
- To compare the readings with the tolerance limit of 1mGy/h from 1m from the x-ray head.

Procedure:

- The x-ray tube collimator was completely closed.
- Exposure factors ranging from 90-110kVp and 30-200mAs depending on the machine were set on the control console. These indicate maximum exposure factors that could be used for the x-ray machine.

- An exposure was made with a TLD positioned in each of the four interfaces of the x-ray tube at a distance of 100cm from the source.

Data interpretation: The TLDs were processed after the exposure in a TLD reader and the values recorded.

Assessment 2: Peak Kilovoltage (kV_p) Accuracy and Reproducibility

Materials: RMI multifunction meter model 245.

Aim: To assess the accuracy and reproducibility of the kV_p set on the machine console.

Objectives:

- To measure the kV_p across the x-ray tube. As applied kV_p affects the energy of the x-ray beam as well as the contrast of the image as indicated thus: $E = qV_p$. Where E is the energy of the x-ray beam and V_p and q are peak voltage and quantity of charge respectively.
- To assess variations between the kV_p set on the machine and the value measured by the kV_p multifunction meter.
- To assess the constancy of the variation by repeating the exposure three times on the same kV_p station.
- To compare the percentage error with the acceptable limit of 5% of set kV_p.

Procedure:

- The multifunction meter was located on the couch at 100cm FFD.
- kV_p was varied under constant mA and mAs in this experiment.
- Initially 60kV_ppeakvoltage was set on the control console.
- An exposure was made after which the kV_p value indicated by the meter was recorded.
- The exposure was made three times with the same exposure factors and the average recorded.

- The test was repeated subsequently with 60kV$_p$, 70kV$_p$, 80kV$_p$,90kV$_p$, and 100kV$_p$ respectively set on the console under same conditions of mA and mAs.

Data interpretation: Deviation of set kV$_p$ to the measured is evaluated as the Percentage kV$_p$ error and is indicated thus:

$$\% \text{ Error} = \frac{Measured\ value - Real\ value}{Real\ value} \text{ x } 100$$

Assessment 3: Evaluation of Half -Value Layer (HVL).

Materials: Series of aluminum sheets of thickness 0.1, 0.5, 1 and 2mm, and exposure meter.

Aim: To assess the HVL of the x-ray beam. HVL values of the x-ray beam are used to judge the adequacy of filtration and reflect the penetration power of the beam. Too low filtration allows low energy x-rays to fall on the patient which increases patient dose. Too hard x-rays reduce the contrast leading to loss of details.

Objectives:

- To assess the gradual reduction in exposure by the increasing additional filters of varying thickness added on the path of the x-ray beam.
- To determine the thickness of filter that yielded the exposure that is equal to half of the original exposure without any external filter.
- To compare the HVL with the acceptable limit of 2.3 minimum for 80kV$_p$

Procedure:

- The exposure meter was located on the couch at 100cm FFD.
- The field was collimated to the size of the sensitive chamber of the meter.

- The first exposure was made at 80 kV_p and 20-100mAs without any filter interposed. The meter reading was recorded.
- 0.5mm aluminum filter was then placed on the meter and an exposure was made.
- The thickness of the filter was increased in steps of 0.5mm.
- Three exposures were made in each case under the same conditions of 80 kV_p and mAs and the average taken.
- The reduced reading of the exposure meter was recorded in each case.

Data Interpretation: The acquired result was interpreted and values were compared with acceptable standard.

Assessment 4: mA Linearity and Reproducibility

Materials: Exposure meter (Rad check).

Aim: To assess the linearity and reproducibility of the mA stations of the machine.

Objectives:

- To measure the exposure produced in mR at each mA station set on the control console.
- To repeat the exposure three times to verify if the exposure is constant for each mA station selected.This test is important because irregularities in mAs can lead to increase in patient dose.
- To evaluate the compliance of the coefficient of linearity of the mA stations to tolerance limit of 0.1 using the formula:

$$\text{Coefficient of linearity} = \frac{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{max}} - \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{min}}}{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{max}} + \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{min}}}$$

Procedure:

- The mA exposure meter was located on the couch at 100cm from the x-ray tube.
- The required mAs was set by adjusting the mA under constant time on the control console.
- Initially, 100mA was set on the control console, three exposures were made. The average of the readings gave the mR at that mAs station by the exposure meter.
- This exposure was then subsequently made with 75mA, 50mA, and 25mA respectively. Note that these mA stations were varied in some centers due to some peculiarities with their machines.
- The coefficient of linearity was calculated using the formula below:

$$\text{Coefficient of linearity} = \frac{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{max}} - \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{min}}}{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{max}} + \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{min}}}$$

Data interpretation: Acquired data were interpreted and deductions made. Obtained result was compared with the acceptable coefficient of linearity.

Assessment 5: Optical and X-ray Beam Congruence.

Materials: A cassette loaded with film and four metallic markers.

Aim: To find out the mismatch if any, between light and x-ray beam. Mismatch may be caused due to shifts in the relative positions of light bulb, reflecting mirror and anode focal spot. As a result there may be cut-off on the radiograph and exposure to unwanted areas of the body. This can lead to several repeats leading to overexposure of patient resulting in accrued patient dose.

Objectives:

- To assess the deviation of the light beam from the x-ray beam.
- To find out if the deviation is within the acceptable limit of 2cm for 100cm FFD (2% of FFD).

Procedure:

- The cassette loaded with film was located on the couch under the light beam of the x-ray unit.
- The x-ray tube was adjusted to focus-film-distance(FFD) of 100cm.
- The beam was collimated to about 20x25cm area on the cassette at the center.
- Four metallic markers were fixed at the four corners of the light field on the cassette.
- An exposure was made at about 70kVp and 30mAs.
- The field was then widened to cover the entire cassette.
- Another exposure was made after widening the beam with about 70kVp and 20mAs.
- The film was processed to check the matching of light and radiation field.

Data interpretation: The acquired data were interpreted and deductions were made. The derivation and percentage error was compared with the acceptable limit.

Assessment 6: Beam Alignment Test.

Materials: Collimator test tool, beam alignment test tool, cassette loaded with film.

Aim: To assess the perpendicularity of the x-ray beam to the image receptor and the patient. If the x-ray beam is not perpendicular to the film, the images may be distorted and diffused leading to repeat of exposures.

Objectives:

- To check the level of coincidence of the center point on the collimator test tool on the center point on the beam alignment tool after exposure.
- To compare the degree of deviation with acceptable limit of 1.5^0.

Procedure:

- The loaded cassette was located on the couch

- The collimator test tool was placed on the cassette and the beam alignment tool was placed at the center of the collimator test tool.
- The tube was adjusted to 100cm FFD.
- The beam alignment tool was adjusted until its center coincided with the center of the collimator test tool.
- The film was exposed at about 70kVp and 20mAs and then developed.

Interpretation of Data: the perpendicularity of the beam was interpreted by the position of the two steel balls. The result was compared with the standard value to find out if it was within the acceptable range.

Assessment 7:Timer Accuracy and Linearity

Materials: Exposure meter (Rad check)

Aim: To assess the accuracy and linearity of the machine timer since the dose administered is directly proportional to the time of exposure with other parameters constant. This is indicated thus: q = It where q is the charge and I and t indicate tube current and exposure time respectively.

Objectives:

- To measure the exposure produced in mR at each exposure time set on the control console under constant mA and kV_p.
- To repeat the exposure three times to verify if the exposure is constant for each exposure time selected. This test is important because irregularities in exposure time can lead to increase in patient dose.
- To evaluate the compliance of the coefficient of linearity of the timer to tolerance limit of 0.1 using the formula:

$$\text{Coefficient of linearity} = \frac{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{max}} - \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{min}}}{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{max}} + \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\text{min}}}$$

Procedure:

- The mA exposure meter was located on the couch at 100cm FFD.
- The required exposure time was set on the console under constant mA and kV_p.
- Initially, 100ms was set on the control console, three exposures were made. The average of the readings gave the mR at that exposure time by the exposure meter.
- This exposure was then subsequently made with 200ms, 300ms, 400ms and 500ms respectively.
- The coefficient of linearity was calculated using the equation above.

3.2.6 Other Assessments: Other assessments made include staff competence, personnel monitoring, repair log book, radiation protection unit/committee, acceptance tests certificate and QC documentation.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Area Monitoring

The result of the area survey conducted in the five x-ray centers A-E are shown in *Table4.1*.

Table 4.1 Area Monitoring of the X-ray Centers(deviations are boldly italicized).

AREA	DOSE RATE (µSv/h)				
	A	B	C	D	E
Background	0.12± 00	0.10±00	0.12±00	0.13±00	0.13±00
Operator's stand	***1.60±00****	0.13±00	***6.13±0.04****	Not accessible	0.45±00
X-ray room door	0.10±00	0.20±00	0.84±00	***7.60±0.04****	***31.00±0.09****
Dark room door	***32.50±00****	0.10±00	0.13±00	***7.20±0.04****	1.55±0.01
Adjoining offices	0.10±00	0.10±00	0.10±00	0.12±00	0.10±00
Reception/waiting area	0.10±00	0.10±00	0.10±00	0.13±00	0.10±00
Corridor	Not sighted	0.14±00	0.10±00	Not sighted	0.13±00
Changing cubicle	***5.30±0.03****	0.10±00	***5.30±0.03****	Not sighted	Not sighted
Behind x-ray room	0.13±0.01	0.12±00	0.10±00	No access	No access
X-ray room window	0.13±00	0.65±0.01	***5.30±0.03****	No access	No access
Toilet	0.13±00	0.10±00	0.10±00	0.64±0.01	Not sighted

From the above results exposure to operator's stand in A and C are very high (1.60 and 6.13 µSv/h respectively). Acceptable limit is 1 µSv/h (USFDA,2008).

4.2 Leakage Test

The results of the leakage test conducted in the five radio-diagnostic centers are shown in Table 4.2.

Table 4.2 Result of Leakage Test performed in the X-ray Centers

INTERFACE	DOSE RATE(mSv/h)					
	A	B	C	D	E	TOLERANCE
RIGHT	0.44	0.08	0.10	0.10	0.05	1.0
LEFT	0.06	0.04	0.15	0.05	0.05	1.0
BACK	0.16	0.07	0.07	0.07	0.05	1.0
DOWN	0.10	0.05	0.20	0.08	0.10	1.0

From Table 4.2, A has the highest level of leakage while B has the least. The leakage radiation from all the machines are however, within acceptable limit of 1.0 mSv/h.

4.3 Kilovoltage Peak (kV_p) Accuracy Test

The results of kV_p accuracy test performed are shown in the following tables and figures.

Table 4.3 kVp Accuracy of X-ray Machine in Center A

kV_p Station	MEASURED kV_p							
	1ST	2ND	3RD	MEAN	S.DEV.(σ)	CV	ERROR(%)	TOLERANCE(%)
60	59.00	58.60	59.40	59.00	0.330	0.56	1.70	5
70	68.70	68.40	68.00	68.40	0.290	0.42	2.30	5
80	82.40	81.80	81.70	82.00	0.310	0.39	2.50	5
90	91.60	91.30	92.00	91.60	0.290	0.32	1.80	5
100	105.50	105.40	105.50	105.50	0.060	0.06	5.50	5

The most common range of kV_p applied in this center is 70-80. The parts of the body commonly examined with x-ray here are the chest and the limbs.

Table 4.4 kV_p Accuracy of X-ray Machine in Center B.

kV_p Station	MEASURED kV_p							
	1ST	2ND	3RD	MEAN	S.DEV.(σ)	CV	ERROR(%)	TOLERANCE(%)
60	83.10	83.30	82.90	83.10	0.16	0.19	38.50	5
70	93.30	93.70	93.00	93.30	0.29	0.31	33.30	5
80	101.80	102.40	102.40	102.20	0.28	0.27	27.80	5
90	115.00	115.20	115.40	115.20	0.16	0.14	16.90	5
100	127.50	127.30	127.00	127.30	0.21	0.17	27.30	5

The most common range of kV_p applied in this center is 90-100. The part of the body commonly examined with x-ray here is the skull. High kV is required for penetration.

Table 4.5 kVp Accuracy of X-ray Machine in Center C.

kV_p Station	MEASURED kV_p							
	1ST	2ND	3RD	MEAN	S.DEV.(σ)	CV	ERROR(%)	TOLERANCE(%)
60	63.10	63.00	63.00	63.00	0.06	0.10	5.0	5
70	70.70	71.10	71.20	71.00	0.22	0.31	1.4	5
80	79.00	78.90	78.80	78.90	0.08	0.10	1.4	5
90	85.20	84.80	85.00	85.00	0.16	0.19	5.6	5
100	94.00	93.90	93.90	93.90	0.06	0.06	6.1	5

The most common range of kV_p applied in this center is 70-80.The parts of the body commonly examined with x-ray here are the chest and the limbs. The abdomen and pelvis are sometimes examined in this center under special examinations.)

Table 4.6 kV_p Accuracy of X-ray Machine in Center D.

kV_p Station	MEASURED kV_p							
	1ST	2ND	3RD	MEAN	S.DEV.(σ)	CV	ERROR(%)	TOLERANCE(%)
60	-	-	-	-	-	-	-	5
70	76.20	75.50	75.90	75.70	0.33	0.44	8.10	5
80	78.50	78.40	77.80	78.20	0.31	0.40	2.80	5
90	98.60	99.00	98.80	98.80	0.16	0.16	9.80	5
100	-	-	-	-	-	-	-	5

The most common range of kV_p applied in this center is 70-80. The parts of the body commonly examined with x-ray here are the chest and the limbs. The abdomen and pelvis are sometimes examined in this center under special examinations. The kV_p knob on the control panel of this machine is only adjustable within the range of 70-90. Therefore, 60 and 100kV_p are not applicable.

Table 4.7 kV_p Accuracy of X-ray Machine in Center E.

kV_p Station	MEASURED kV_p							
	1ST	2ND	3RD	MEAN	S.DEV.(σ)	CV	ERROR(%)	TOLERANCE(%)
60	-	-	-	-	-	-	-	5
70	-	-	-	-	-	-	-	5
80	-	-	-	-	-	-	-	5
90	-	-	-	-	-	-	-	5
100	65.1	65.4	65.4	65.3	0.14	0.21	34.7	5

The exposure factors for this machine are kept permanently at 100kV_p and 9mAs due to a faulty condition. Other kV stations are not applicable in this center. The table above even shows that the actual kV_p measured is 65.3 against the 100kV selected on the machine.. This led to double exposure being made for each x-ray projection constituting double dose to the patient in each case.

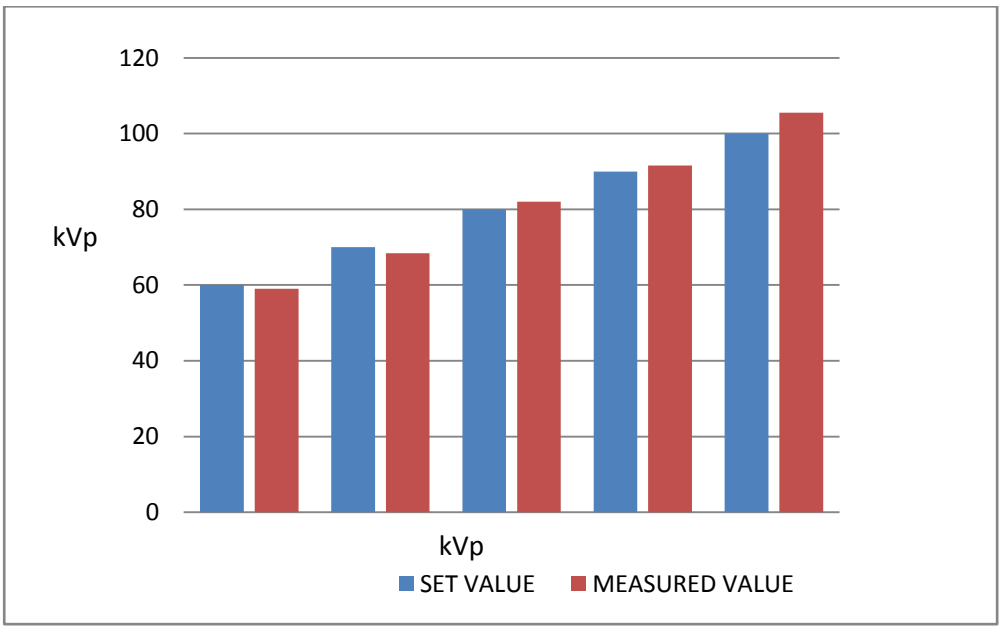


Fig. 4.1 .Distribution of set and measured kVpin Center A.

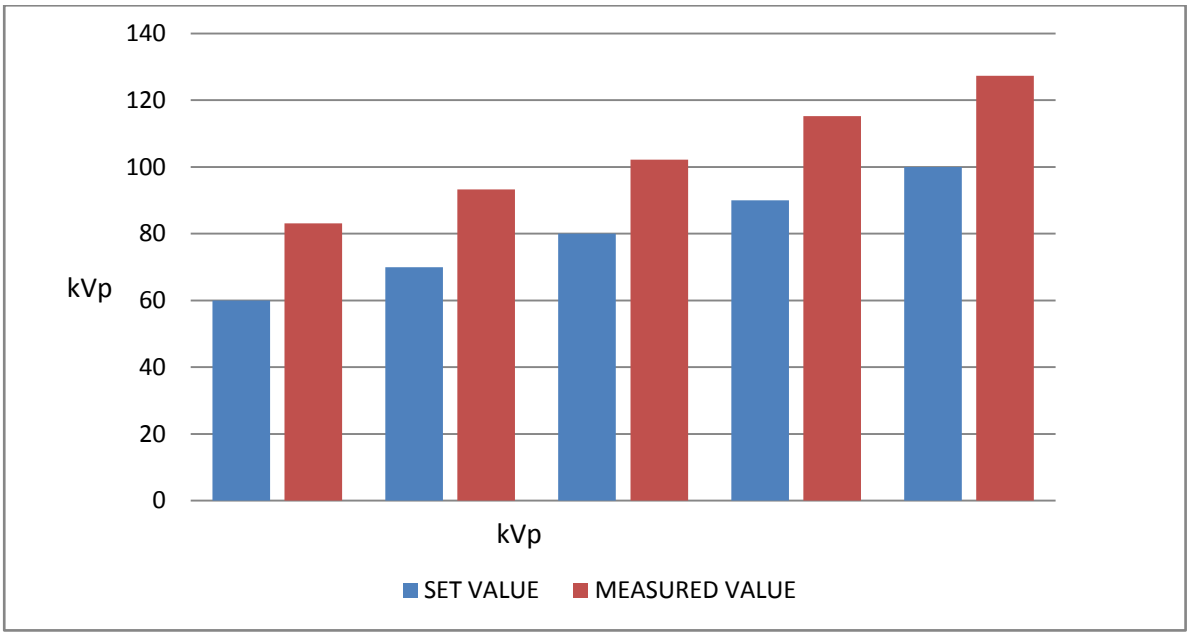


Fig. 4.2 .Distribution of set and measured kV_p in Center B.

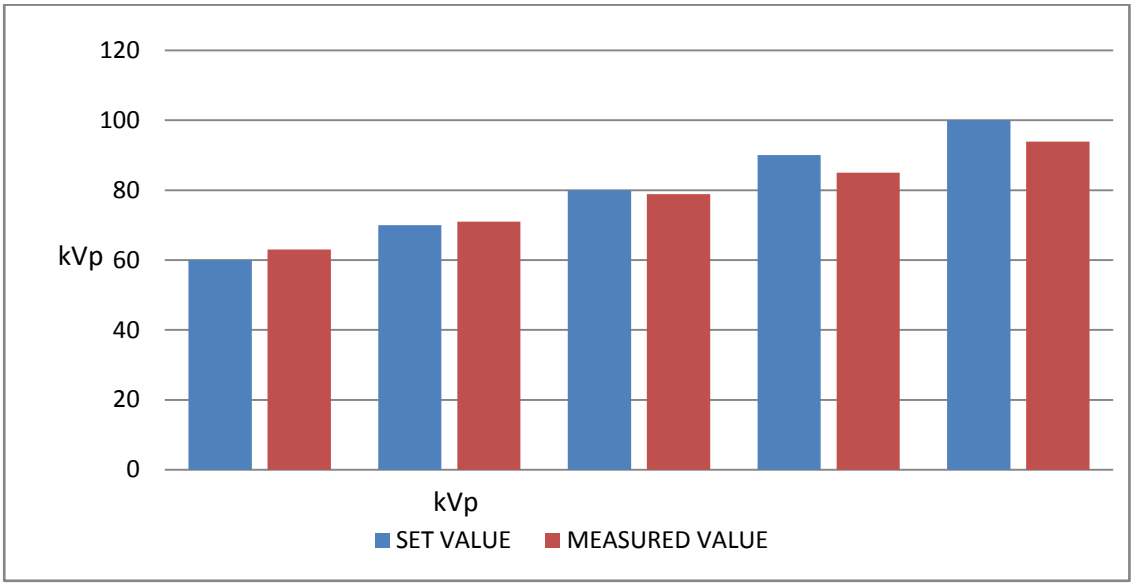


Fig.4.3.Distribution of Set and Measured kV_p in Center C.

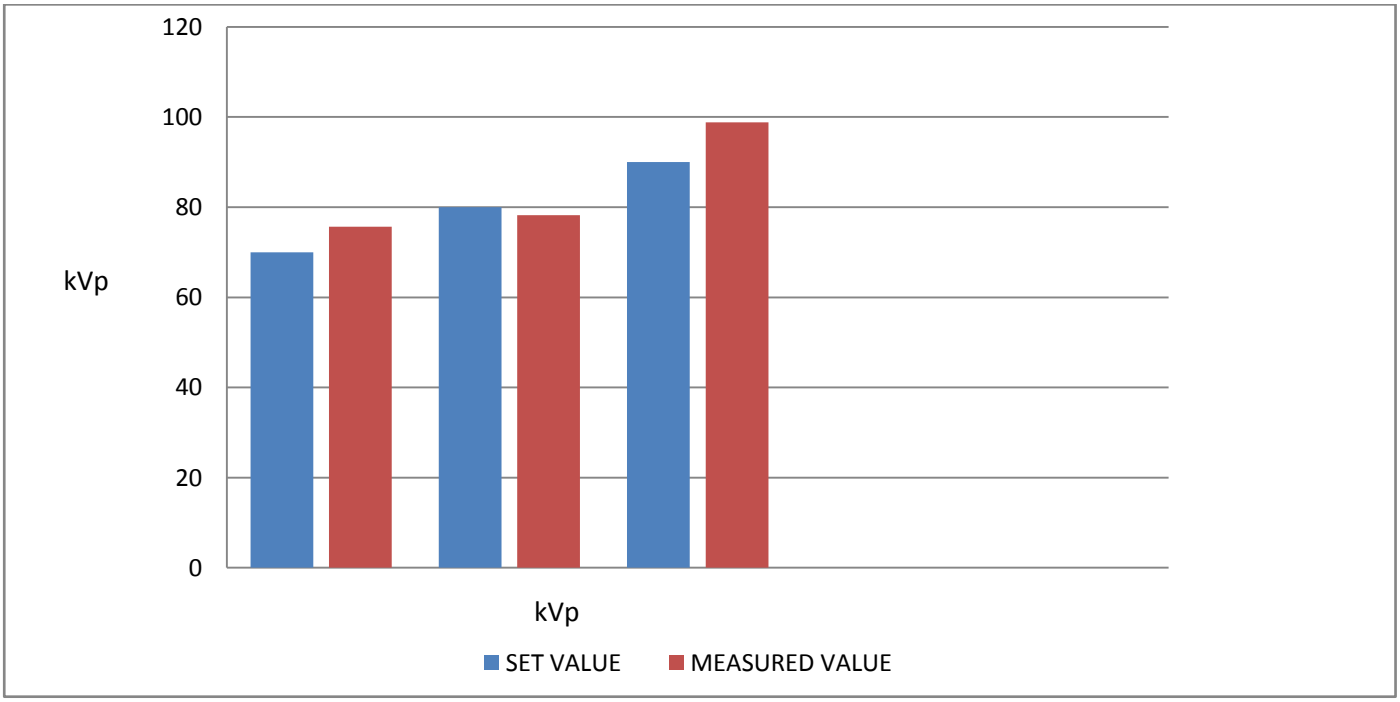


Fig. 4.4 .Distribution of set and measured kV_p in Center D

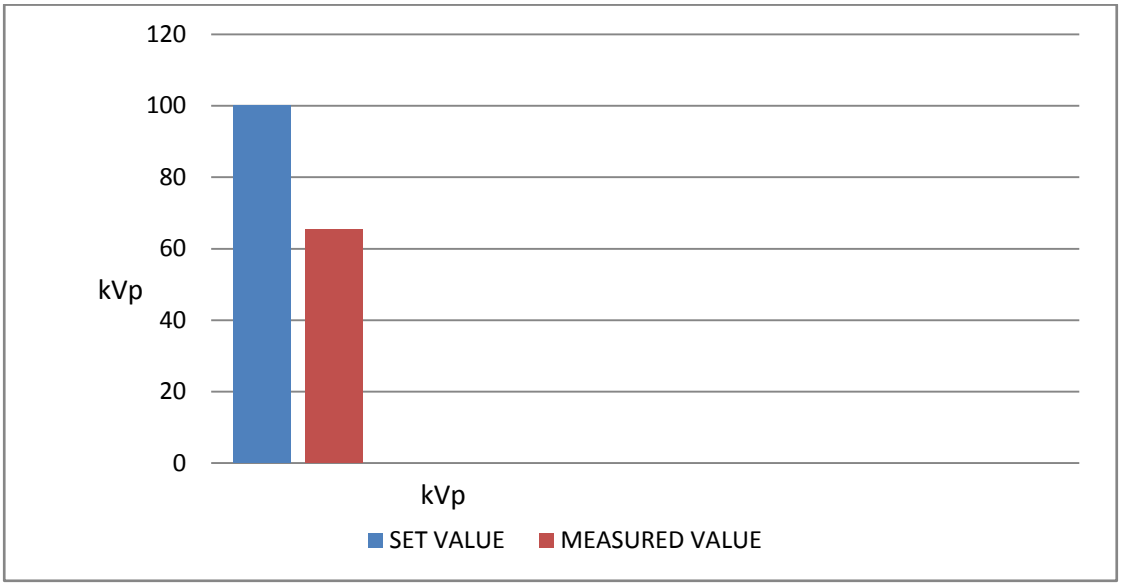


Fig. 4.5 .Distribution of set and measured kVp in Center E

Table 4.8 kV_p Variations among the Centers

kV_p Station	MEASURED kV_p				
	A	B	C	D	E
60	59.0	83.1	63.0	-	-
70	68.7	93.3	71.0	75.7	-
80	82.4	102.2	78.9	78.2	
90	91.6	115.2	85.0	98.8	
100	105.5	127.3	93.9	-	65.3

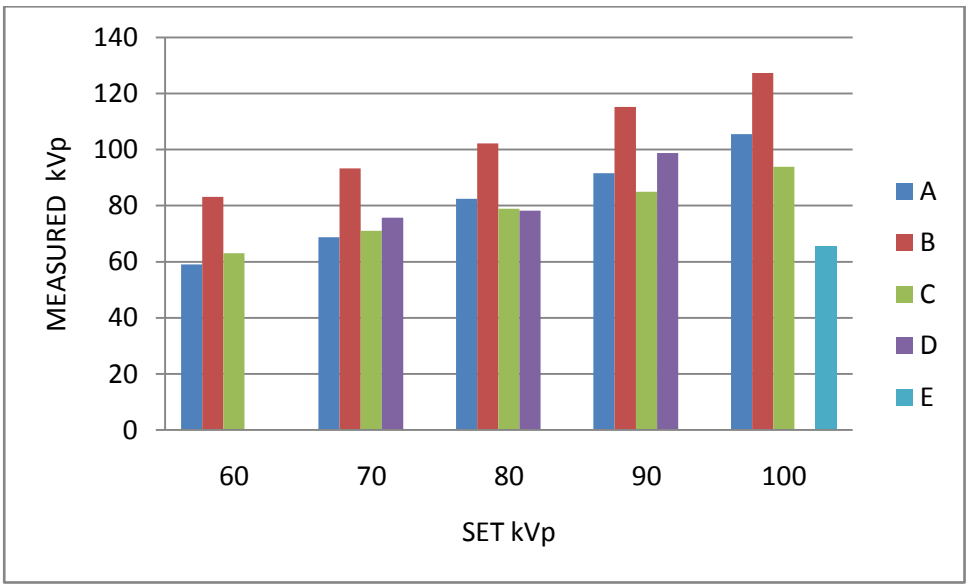


Fig.4.6 kV_p Variations compared among the Centers

Table 4.9 Comparing kV_p errors among the Centers

SET kV_p		60	70	80	90	100
error(%)	A	1.70	2.30	2.50	1.80	5.50
	B	38.50	33.30	27.80	16.90	27.30
	C	5.00	1.40	1.40	5.60	6.10
	D	-	8.10	2.80	9.80	-
	E	-	-	-	-	34.70

kV_p error in B is extremely high. Acceptable error limit is 5%(Rehani, 1995). The drastic increase in error noted at $100kV_p$ may be due to contribution from scatter to the meter (Marco et al,2007). kV_p accuracy in A and C are moderately fair. kVp in E is not selectable on the console. It is constantly at $100kV_p$ and the error is very high(Table 4.9).

4.4 Determination of HVL

Table 4.10 HVL of X-ray Machine in Center A

Al THICKNESS (mm)	EXPOSURE (R)			
	1ST	2ND	3RD	MEAN
0.0	0.040	0.039	0.040	0.040
1.5	0.034	0.034	0.033	0.034
2.0	0.028	0.027	0.028	0.028
2.5	0.026	0.026	0.026	0.026
3.0	0.023	0.024	0.024	0.024
3.5	0.023	0.023	0.022	0.023
4.0	0.021	0.021	0.021	0.021
4.5	0.020	0.021	0.020	0.020
5.0	0.019	0.019	0.019	0.019
5.5	0.019	0.018	0.018	0.018

The half value layer of this machine is 4.50mm Al. This is acceptable because it reduces patient dose by producing hard x-ray beam that cannot settle on the patient. X-ray machines are expected to have minimum HVL 2.5mm Al at 80kV_p(Rehani, 1995).

Table 4.11 HVL of X-ray Machine in Center B

Al THICKNESS (mm)	EXPOSURE (R)			
	1ST	2ND	3RD	MEAN
0.0	0.026	0.026	0.025	0.026
0.5	0.024	0.024	0.024	0.024
1.0	0.023	0.022	0.023	0.023
1.5	0.021	0.021	0.021	0.021
2.0	0.020	0.020	0.019	0.020
2.5	0.019	0.019	0.019	0.019
3.0	0.017	0.018	0.017	0.017
3.5	0.016	0.016	0.016	0.016
4.0	0.014	0.015	0.015	0.015
4.5	0.013	0.013	0.013	0.013
5.0	0.012	0.012	0.011	0.012
5.5	0.011	0.011	0.011	0.011

This machine has the same HVL as the machine described in A above.

Table 4.12 HVL of X-ray Machine in Center C

Al THICKNESS (mm)	EXPOSURE (R)			
	1ST	2ND	3RD	MEAN
0.0	0.016	0.015	0.016	0.016
0.5	0.014	0.014	0.013	0.014
1.0	0.012	0.013	0.012	0.012
1.1	0.009	0.009	0.009	0.009
1.2	0.008	0.007	0.008	0.008
1.5	0.007	0.006	0.006	0.006
2.0	0.003	0.002	0.003	0.003

The half value layer of this machine is 1.2mm Al at 80kV$_p$. This value is too low compared to the acceptable minimum. Soft x-rays are produced which do not contribute towards forming the desired image but rather constitute unnecessary patient dose. The machine is therefore not safe for the patient. This machine however contributes to reduced dose to the operator and the public through reduced x-ray scatter.

Table 4.13 HVL of X-ray Machine in Center D

Al THICKNESS (mm)	EXPOSURE (R)			
	1ST	2ND	3RD	MEAN
0.0	0.042	0.042	0.041	0.042
0.5	0.037	0.038	0.037	0.037
1.5	0.033	0.032	0.033	0.033
2.5	0.028	0.028	0.028	0.028
3.5	0.024	0.024	0.024	0.024
4.5	0.023	0.023	0.022	0.023
5.0	0.021	0.020	0.021	0.021
5.5	0.019	0.019	0.018	0.019

This machine has HVL of 5.0mm Al. The x-ray beam produced is hard, there is therefore less patient dose due to soft x-rays. On the other hand, the x-ray beam produced by this machine is too hard causing reduction of contrast which leads to repeat exposure and additional patient dose. Dose to the operator and public also increases due to increase in x-ray scatter.

Table 4.14 HVL of X-ray Machine in Center E

Al THICKNESS (mm)	EXPOSURE (R)			
	1ST	2ND	3RD	MEAN
0.0	0.101	0.102	0.102	0.102
1.0	0.090	0.091	0.090	0.090
1.5	0.073	0.073	0.074	0.073
2.0	0.060	0.059	0.060	0.060
2.5	0.052	0.051	0.051	0.051
3.0	0.048	0.047	0.048	0.048
3.5	0.042	0.041	0.042	0.042

This machine has HVL of 2.5mm Al which is the minimum required.

Table 4.15 HVL of X-ray Machines in the five Centers

X-RAY UNIT	HVL(mm) Al	Limit(mm Al)
A	4.5	>2.5
B	4.5	>2.5
C	1.2	>2.5
D	5.0	>2.5
E	2.5	>2.5

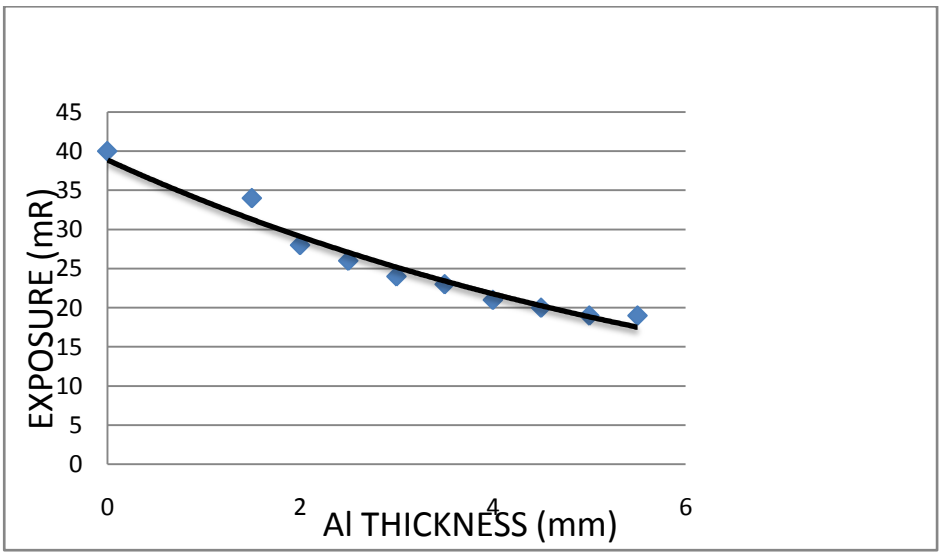


Fig. 4.7HVL Curve of X-ray Machine in Center A

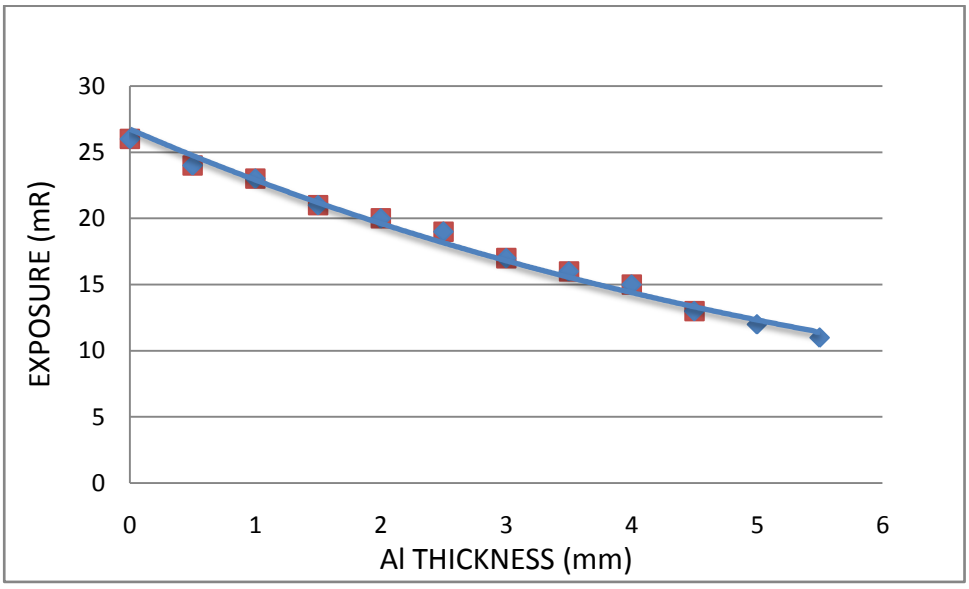


Fig. 4.8 HVL Curve of X-ray machinein Center B

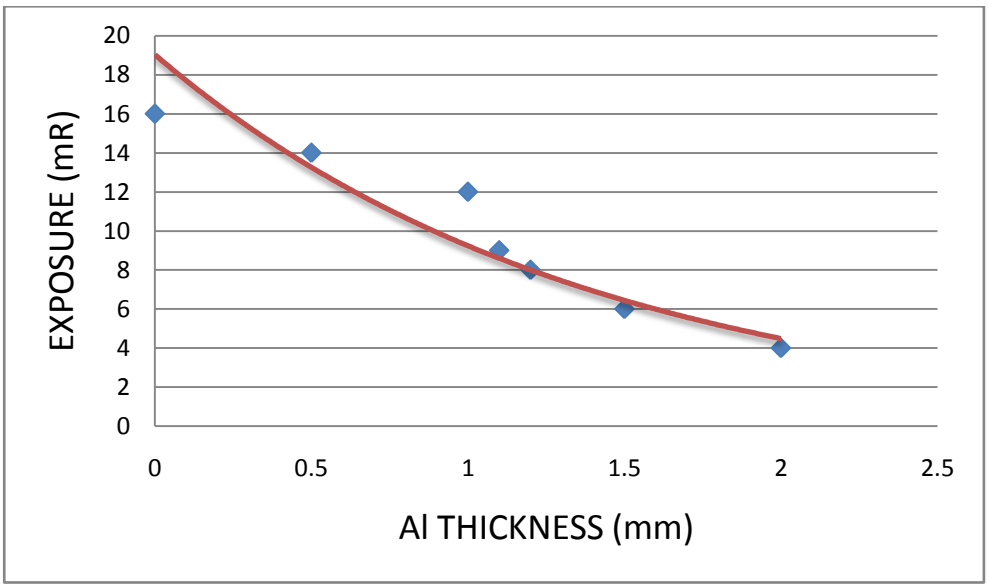


Fig.4.9 HVL Curve of X-ray Machine in Center C

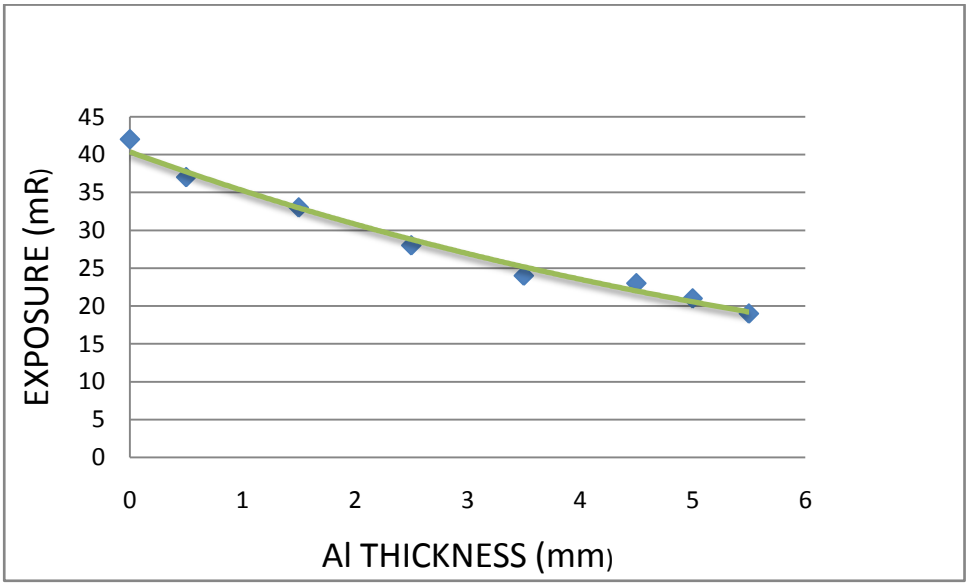


Fig.4.10 HVL Curve of X-ray Machine in Center D

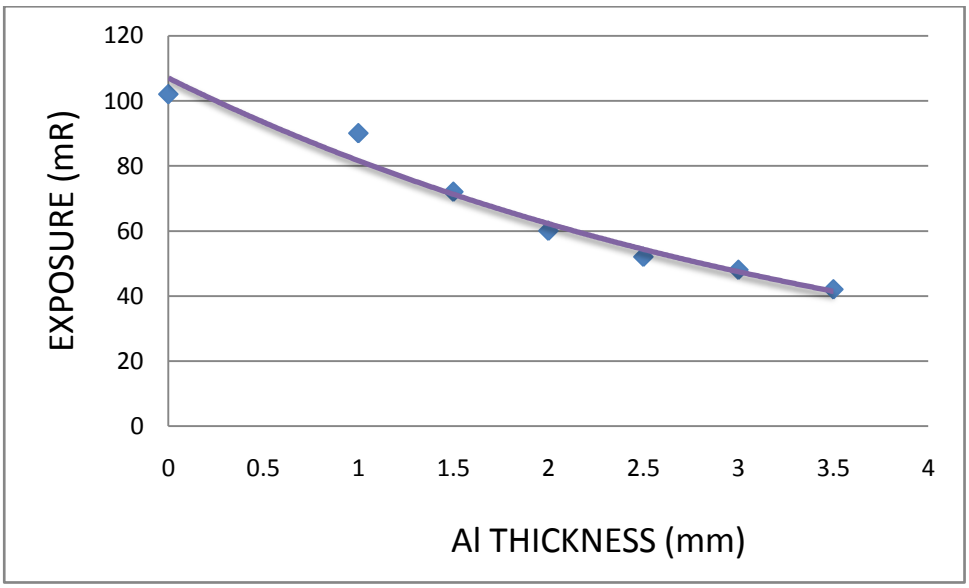


Fig.4.11 HVL Curve of X-ray Machinein Center E

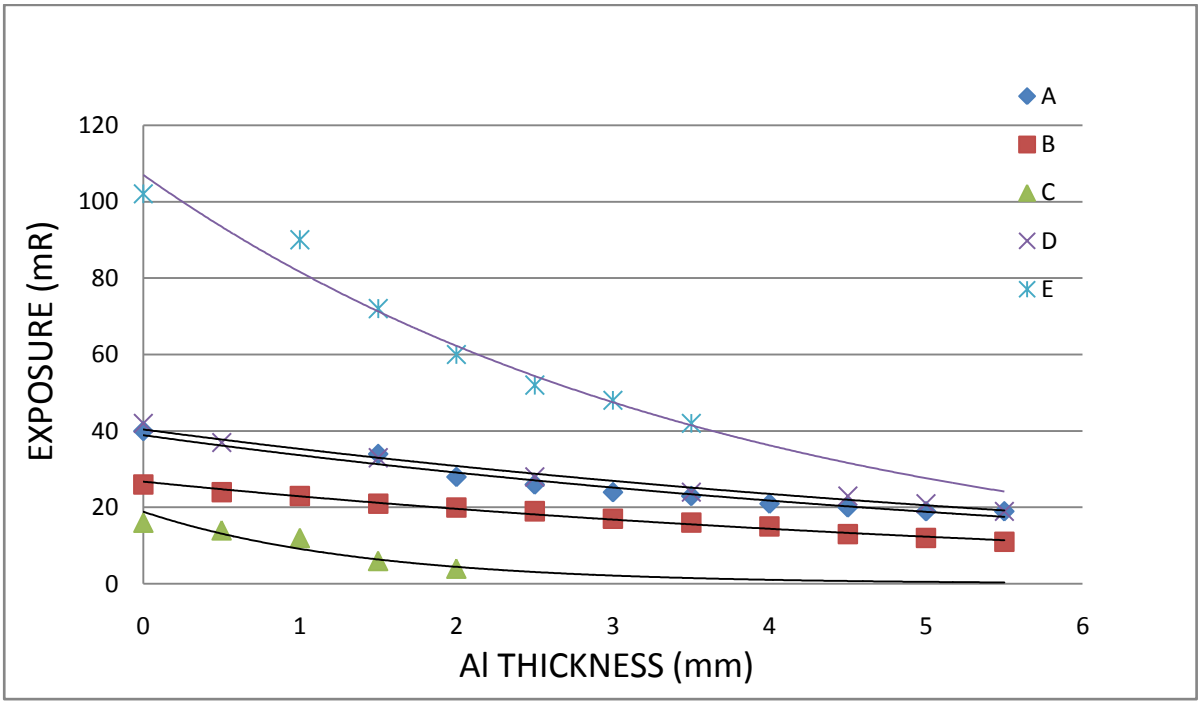


Fig. 4.12 HVL Curves of the five X-ray machines compared

4.5 mA Linearity Check

Table 4.16 mA Linearity of the X-ray Machine in Center A (70kV set on the console.)

EXPOSURE FACTORS	EXPOSURE (mR)				
	1ST	2ND	3RD	AVERAGE	mR/mAs
30mAs	73.00	72.00	73.00	72.67	2.42
20mAs	48.00	48.00	47.00	47.67	2.38
10mAs	26.00	26.00	26.00	26.00	2.60

Table 4.17 mA Linearity of the X-ray Machine in Center B (70kV set on the console.)

EXPOSURE FACTORS	EXPOSURE (mR)				
	1ST	2ND	3RD	AVERAGE	mR/mAs
100mA, 40mAs	95.00	96.00	96.00	95.67	2.39
75mA, 30mAs	75.00	75.00	76.00	75.33	2.51
50mA, 20mAs	60.00	59.00	60.00	59.67	2.98
25mA, 10mAs	30.00	30.00	30.00	30.00	3.00

Table 4.18 mA Linearity of the X-ray Machine in Center C (70kV set on the console.)

EXPOSURE FACTORS	EXPOSURE (mR)				
	1ST	2ND	3RD	AVERAGE	mR/mAs
100mA, 40mAs	94.00	94.00	94.00	94.00	2.35
75mA, 30mAs	91.00	90.00	91.00	90.67	3.02
50mA, 20mAs	88.00	87.00	87.00	87.33	4.37
25mA, 10mAs	69.00	69.00	69.00	69.00	6.90

Table 4.19 mA Linearity of the X-ray Machine in Center D (70kV set on the console.)

EXPOSURE FACTORS	EXPOSURE (mR)				
	1ST	2ND	3RD	AVERAGE	mR/mAs
30mA, 45mAs	80.00	79.00	79.00	79.33	1.76
20mA, 30mAs	45.00	45.00	44.00	44.67	1.49
10mA, 15mAs	28.00	27.00	28.0	27.67	1.84

$$\text{Coefficient of linearity} = \frac{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\max} - \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\min}}{\left({}^{\text{mR}}/_{\text{mAs}}\right)_{\max} + \left({}^{\text{mR}}/_{\text{mAs}}\right)_{\min}}$$

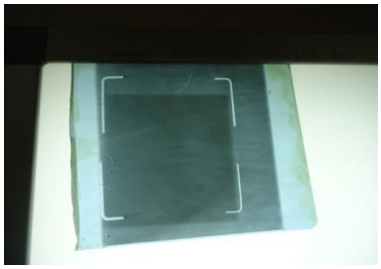
Using equation 34 above,the coefficients of linearity of the various machines are shown in Table 4.17.

Table 4.20 Coefficient of mA Linearity of the five X-ray Machines

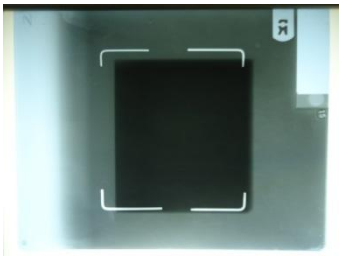
X-RAY UNIT	COEFFICIENT OF LINEARITY	TOLERANCE
A	0.04	<0.10
B	0.11	<0.10
C	0.49	<0.10
D	0.11	<0.10
E	-	<0.10

All of the machines are barely within the coefficient of mA linearity that is acceptable except C. The acceptable maximum limit is 0.1(Rehani, 1995) while E was not accessible.

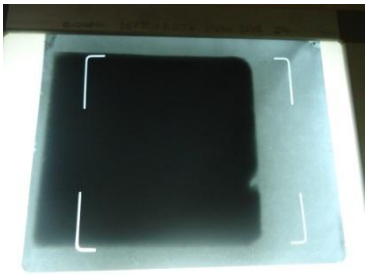
4.6 Optical and Radiation Field Congruence



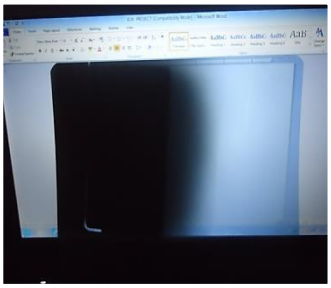
A



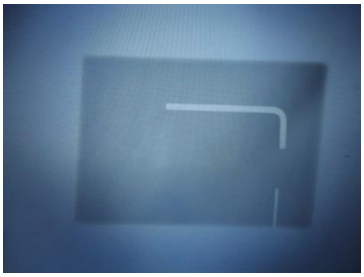
B



C



D



E

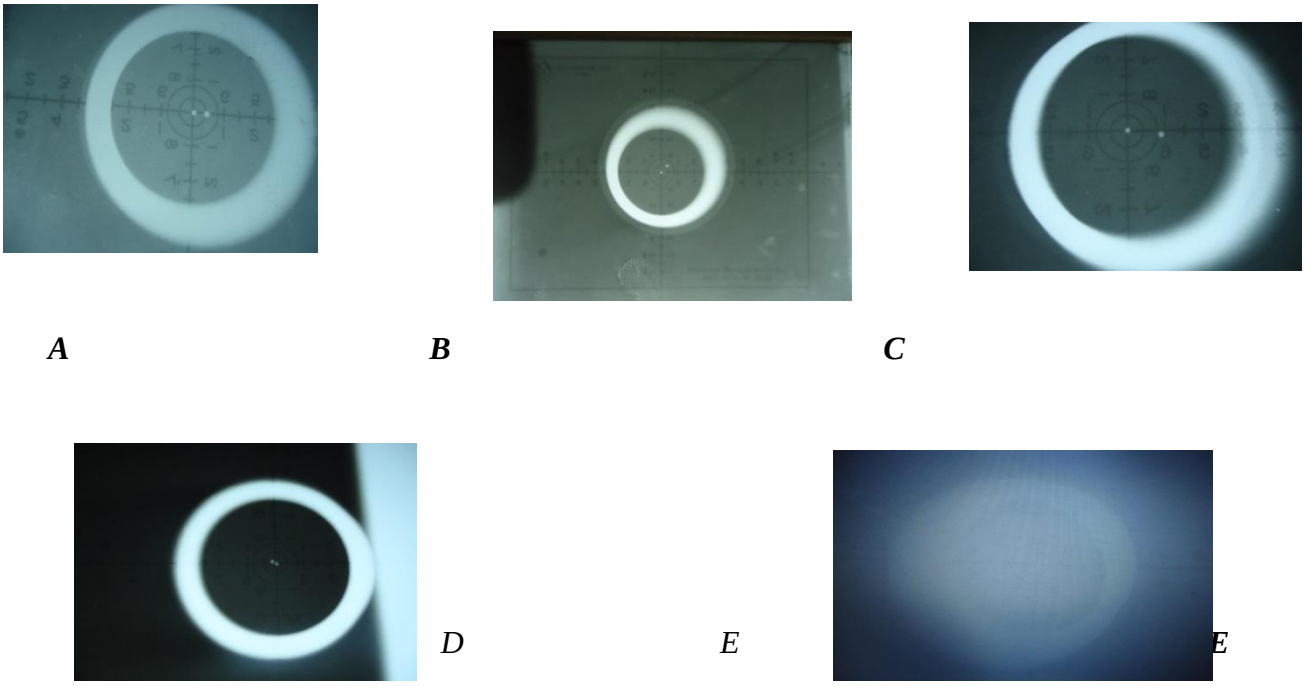
Fig. 4.13 Optical and Radiation Field Congruence

Table 4.21 Optical Radiation Beam Congruence

Center	Optical radiation congruence(cm)	Tolerance limit
A	1.8 and 0.2	2.0cm
B	1.1 and 0.7	2.0cm
C	3.8 and 2.0	2.0cm
D	7.1 and 0.1	2.0cm
E	2.0 and 1.6	2.0cm

Centers C and D are out of the tolerance limit of 2.0cm (Rehani, 1995). This implies cut off on the radiographs which leads to repeat exposures and hence increase in patient dose.

4.7 Beam Alignment



A ***B*** ***C***

D *E* ***E***

Fig.4.14 Beam Alignment

Table 4.22 Beam Alignment Results.

Center	**Beam alignment(degree)**	**Tolerance limit(degree)**
A	1.5	1.5
B	1.5	1.5
C	>3.0	1.5
D	0.5	1.5
E	>3.0	1.5

The acceptable limit of beam alignment 1.5^0. Beyond this value, distortion could be seen on the image produced. This can lead to wrong diagnoses and perhaps increased patient dose due to repeat exposures.

4.8.Timer Linearity Check

Table 4.23.Timer linearity in Unit B. 200mA was set and the coefficient of linearity calculated is 0.12).

EXPOSURE FACTORS	EXPOSURE (mR)				
	1ST	2ND	3RD	AVERAGE	mR/mAs
100ms, 20mAs	59.00	60.00	60.00	59.67	2.98
200ms, 40mAs	118.00	116.00	117.00	117.00	2.93
300ms, 60mAs	181.00	180.00	180.00	180.33	3.01
400ms, 80mAs	275.00	276.00	275.00	275.33	3.44
500ms ,100mAs	370.00	372.00	371.00	371.00	3.71

Table 4.24.Timer linearity in Unit C. *(100mA was set and the coefficient of linearity calculated is 0.25).*

EXPOSURE FACTORS	EXPOSURE (mR)				
	1ST	2ND	3RD	AVERAGE	mR/mAs
100ms, 10mAs	18.00	19.00	18.00	18.33	1.83
200ms, 20mAs	46.00	46.00	47.00	46.33	2.32
300ms, 30mAs	90.00	92.00	91.00	91.00	3.03
400ms, 40mAs	100.00	102.00	101.00	101.00	2.53
500ms ,50mAs	125.00	124.00	124.00	124.33	2.49

Table 4.25.Timer linearity in Unit D. *(30mA was set and the coefficient of linearity calculated is 0.12).*

EXPOSURE FACTORS	EXPOSURE (mR)				
	1ST	2ND	3RD	AVERAGE	mR/mAs
100ms, 3mAs	80.00	80.00	80.00	80.00	26.67
200ms, 6mAs	170.00	170.00	171.00	170.33	28.39
300ms, 9mAs	250.00	260.00	250.00	253.33	28.15
500ms, 15mAs	500.00	510.00	510.00	506.67	33.78

It is generally seen that none of the three machines tested for timer accuracy complied to the maximum limit of coefficient of linearity of 1.0.

4.9 Other Assessments

Other assessments made include staff competence, personnel monitoring, repair log book, radiation protection unit, acceptance tests certificate and QC documentation. These revealed the followings:

- Only one radiographer (B.Sc) was found in all the centers under this study and he was employed in the only public center under the study. The other four centers are operated by x-ray technicians from state schools of health technology.
- No health surveillance with full blood count test or radiation monitoring with TLD, film badge, etc, was carried out on personnel in any of the centers monitored.
- Repair log book or QC log book was not sighted in any of the centers under this study.
- A designated radiation safety officer (RSO) was found only in the public center but no center has a constituted radiation protection unit or committee.
- No pre-installation check or acceptance test certificate was found in any of the centers under this study.

4.10. DISCUSSION

Five x-ray machines in five radiological centers were assessed in this study. Both the quality control and environmental assessment of the facilities were carried out.

4.10.1Layout of the X-ray Centers

The layout of the five centers were assessed. The important parameters in radiation protection studied from the layouts are as shown.

Room Dimension: Large space is required in an x-ray room for easy movement of patients on trolley and beds, for easy manipulation of equipment and for radiation safety of staff and the public (IAEA, 2000). The smaller the size of an x-ray room the more important extra shielding for radiation protection is required (Palmer,et al,2011). The minimum room dimension required for diagnostic x-ray by NNRA is $16m^2$ (NNRA, 2013). From this study only center B complied with the minimum room dimension required.

Wall Thickness and lead Lining: The minimum wall thickness required by IAEA,(2004) is 23cm. This study shows 100% compliance by the x-ray centers. However, only centers B, C and E complied with the required wall lead lining with center E falling short of the 2.13m

minimum height required of the lead lining above the floor (IAEA,2004). Primary barrier is not given any special attention by any of the centers. This can lead to increased exposure to the public.

Doors and Windows: An x-ray room requires a lead lined double-leaved door hanging from opposite directions. Only A and Bcomplied with this requirement. If a window is necessary in the room it must not be less than 2m high. This is to allow minimal radiation scatter to people within the surrounding. Only center C complied with this requirement.

Operator's Distance from X-ray Tube and Chest Stand: AAPM, (2002) requires that operator's distance from the x-ray tube and chest stand should not be less than 1.8m and 3m respectively. 100% compliance is recorded by the five centers in operator's distance from the tube while only centers A, B and C complied with the required distance between the operator and the chest stand (table 3.1).

Hazard Light and Signs: Warning light was only seen in center B and radiation warning signs were pasted on the exposure doors of only A and C. Absence of hazard light and signs may lead to accidental exposure of staff and the public.

4.10.2 Area Monitoring: Exposure to operator's stand in A and C are very high (1.60 and 6.13 µSv/h respectively). Acceptable limit is 1 µSv/h (USFDA,2008). The protective screen in C has an open window which is not covered with a lead-ligned glass. This is responsible for the high exposure at the operator's stand. In D the dose at the operators stand could not be assessed because there is no protective cover. The operator stands facing the x-ray tube directly only partially covered with a lead apron (fig.3.4). This practice is completely condemned. The locations of the changing cubicles in A and C in relation to the x-ray tube is faulty. The acceptable location by IAEA, (2011) is shown in figure 2.6. The cubicle in center C has an open window into the x-ray room. Therefore, high exposure of 5.30 µSv/h is recorded in the cubicles of A and C . Centers A and D have high exposures of 32.5 and 7.2 µSv/h respectively in their dark rooms because of their locations in

respect to the x-ray room. The dark rooms open directly into the exposure room and their doors are not lead lined. However, the radiation exposure to the adjoining offices and reception/waiting areas in all the centers are within background level. This is of great importance since these areas are more constantly occupied.

4.10.3 Tube Leakage : This test shows the amount of radiation that leaks from the x-ray tube outside the area of interest during exposure. Excess leakage indicates higher patient dose and more contribution to staff dose. Leakage radiation should not exceed 1mSv/h at 1m from the source (USFDA,2008 and NNRA, 2013). Sungita et al, (2006) performed leakage test on some x-ray machines in India and discovered that most of the machines emitted less than 0.5mSv/h. This agrees with the result of this study. The highest amount of leakage obtained in this study is 0.44mSv/h and that is found at the right interface of A. This agrees with the work of Sungita et al, (2006) in which he reported that only 20% of the 196 x-ray machines tested in Tanzania failed leakage test.

4.10.4 kVp Accuracy: Optimization of x-ray beam tube potential (kVp) in radiological examinations can minimize patient dose (Fung et al, 2001). This test should be performed annually and the result should be within 5% of the value set on the machine (Rehani,1995). Center A shows good level of compliance in kV_p accuracy. The highest kVp error measured in this center is 5.5% which corresponds to 100kVp. Center B shows gross lack of compliance in kVp accuracy. In this center the kVp error drops from 38% at 60kVp to 16% at 90kVp and then rises to 27% at 100kVp. The gradual drop in the measured kV_p may be due to falling load on the capacitor while the sudden rise may be due to contributions from scattered radiation into the meter noting that scatter increases with kV_p rise (Marco et al, 2007). Center C shows moderate accuracy in kVp. The maximum error recorded in this unit is 6%. The x-ray machine in center D does not allow setting of 60kVp and 100 kV_p. A wide range of percentage error is recorded in this unit. The machine in center E is constantly set on 100kVp and 9mAs. Factor selection is not made on this machine. An error of 34.7% is

measured on this machine. The resulting effect is underexposure in all examination performed. Double exposure is made in every examination performed leading to unwarranted patient dose.
Out of the five center studied only A and C show moderate compliance in kVp accuracy.

4.10.5. Half Value Layer(HVL) Determination: The HVL of an x-ray beam is a very important parameter. Too low HVL shows that the x-rays generated are soft and therefore, very weak in penetration ability leading to more patient dose. A minimum HVL of 2.5mm Al at 80kVp is required for a diagnostic facility (Rehani, 1995). This study shows compliance in A ,B, D and E. The HVL of 1.2mm Al recorded in C is too low for radio-diagnostic. In this center patient dose is expected to be very high. Fig.4.12 shows very close values of HVL in A,B and D. From this work and the work of Taha, (2010) in which none of the six x-ray machines tested failed HVL test, we can deduce that HVL of most machines are within acceptable limit. The HVL of an x-ray machine is age dependent. Older machines are expected to have lower HVL

4.10.6. mA Linearity: The tolerance limit of coefficient of mA linearity is maximum of 0.1 (Rehani,1995) . Three of the centers studied complied with the mA linearity acceptable. Large coefficient of mA linearity means higher dose to the patient even with little mAs selected. A, B, and D show coefficient of linearity close to the acceptable limit while C shows wide deviation from the acceptable limit. mA linearity test could not be carried out in E because the mAs is not selectable.

4.10.7. Optical and Radiation Field Congruence: This test shows the correlation between the field delineated by the light beam and the actual exposure field by the x-ray beam. It is required that the shift should not be greater than 2% of the FFD which corresponds to 2cm. A, B and E show moderate compliance while C and D show complete lack of compliance. D shows a shift of upto 7.1cm with a high level of penumbra. The radiographs produced in these centers are expected to have a high level of ‘cut off’ leading to repeated exposure and more patient dose.

4.10.8 Beam Alignment : This shows the perpendicularity between the x-ray beam and the image receptor. Acceptable error limit is 1.5^0 (Rehani, 1995). The error detected in C and E are far beyond the acceptable limit. Image distortion is likely to be common in these centers. Repeat leading to more patient dose may be common due to misinterpretation of radiographs.

CHAPTER FIVE

CONCLUSION, SUMMARY AND RECOMMENDATION

5.1. Summary of Findings: The level of compliance by individual center is summarized in Table 5.2. Some important parameters assessedare tabulated. Each parameter is assigned an arbitrary maximum score as a weighting factor based on its relative importance in radiation protection as indicated in Table 5.1.

Table 5.1 Arbitrary Weighting Factors for Assessed Radiation Protection Parameters

Parameter	Arbitrary Maximum Score (%)
Room Size	15
Lead Lining	10
Operator's Protection	15
Area Monitoring	10
Leakage Test	10
kVp Accuracy	10
mA Accuracy	10
Optical Radiation Beam Congruence	05
Beam Alignment	05
HVL	10

Table 5.1 Summary of Findings

PARAMETERS	SCORES (%) A	B	C	D	E
Room size	11	15	14	11	12
Lead lining	03	10	08	00	09
Operator's protection	10	15	05	02	12
Area Monitoring	05	10	08	06	05
Leakage test	10	10	10	10	10
kVp accuracy	10	00	08	04	00
mAs linearity	10	09	00	09	00
Optical-radiation beam congruence	05	05	02	02	04
Beam alignment	04	04	00	05	00
HVL	10	10	00	10	08
Percentage compliance	78%	88%	55%	59%	60%

The results of the assessments made in the five x-ray centers A-E are summarized in Table 5.2.

From thetable it is clear that center B has the highest percentage of compliance to radiation protection under the parameters considered. This center is the only government owned (public) center in this study. The major non-compliance noticed with B is in the area of kVp accuracy. Regular QC checks and corrections are required on this machine which is the newest machine of all assessed in this study (Table 3.2). The x-ray machine in A has good performance though it is an old machine (Table 3.2). The major fault with center A is environmental. The x-ray machine in C shows the least level of compliance. Patient safety is grossly compromised by the machine. E shows moderate level of compliance relatively from the parameters considered but actually patient safety is compromised since exposure factors are not selectable and double exposure has to be made in every case.

5.2. CONCLUSION

From the findings of this study the following conclusions are derived.

1. The level of compliance to general requirements for installation of diagnostic x-ray and quality control is low in most radio-diagnostic centers assessed.
2. Government owned radio-diagnostic centers comply better than private centers.
3. Radiation safety to staff and patients is greatly compromised in most private radio-diagnostic centers assessed.
4. Most x-ray centers assessed are not designed purposely for x-ray installation. Ordinary rooms are converted to exposure rooms. This has led to poor layouts observed in most centers.
5. Radiation protection is not taken seriously by owners of most diagnostic centers as no center under this study has engaged service providers for regular quality control and assurance.
6. There is very low level of competence among x-ray operators employed in private diagnostic centers. The only radiographer found in the centers assessed is employed in the only public center. All the private centers only engaged the services of x-ray technicians.

RECOMMENDATIONS

1. Regular quality control tests like those assessed in this study should be performed annually in every x-ray diagnostic center by certified experts. However, in very busy centers there is need to assess these parameters every six months. This is necessary to evaluate deviations from acceptance tests performed initially on all x-ray machines at installation and to correct such deviations.
2. Every QC and repair performed on the x-ray machine should be properly documented in separate log books.
3. A qualified engineer should be attached to every x-ray machine to carry out repairs and corrective measures after QC.
4. A radiation safety officer should be designated and a radiation protection committee should be constituted in every x-ray center.
5. Every radiation worker in all x-ray centers should be monitored adequately with monitoring devices such as TLD, film badges, etc. Health surveillancewith full blood count should be performed annually for all radiation workers.
6. Every x-ray center must be licensed and monitored by regulatory bodies such as NNRA.
7. Pre-installation checks should be properly carried out and documented to ensure compliance.
8. At least a qualified and licensed radiographer should be attached to every x-ray center to monitor all the operations of the x-ray technicians.
9. All centers where safety is compromised should be stopped from operating till compliance is ensured.
10. Further studies are required involving more private and public centers for more comparison.
11. Further studies are required to compare busy centers with centers with low work load.

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