DESIGN, CONSTRUCTION AND TESTING OF A LOCALLY ASSEMBLED DENSITOMETER

By

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DECLARATION

I declare that this project/thesis entitled "Design, Construction and Testing of a Locally Assembled Densitometer", is my own work and to the best of my knowledge it has not been submitted in any form for another degree or diploma to any other university or institution. Information derived from published or unpublished works of other workers have been acknowledged in the text.

.....

Oladipupo Muyideen Dawodu

23/10/2000

Date

DEDICATION

To my Parents, Brothers, Wife and Children

CERTIFICATION

This project thesis entitled "Design,Construction and Testing of a Locally Assembled Densitometer" by Mr Oladipupo Muyideen Dawodu meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

In this work a densitometer was designed and constructed locally, using available materials for quality assurance tests of X-ray machine. A Light Dependent Resistor (LDR) was used to convert light intensity to electrical current. The current, which is proportional to the intensity of light, was measured with a very sensitive digital multimeter. The electric current in LDR when light intensity changes was examined. X-ray films were exposed to various X-ray doses. The optical density of the films was measured with the constructed densitometer. The range of optical densities for low and high doses respectively in radiography was found to be between about 0.35 and 2.5. The base of X-ray films contributes an optical density of about 0.207 + 0.001. Different X-ray films exposed to the same X-ray energy and processed under different condition have different values of optical densities.. The output of X-ray unit was found to be dependent on Current-lime, Film Focus Distance, and Peak kilovollage. The densitometer is easy to operate, giving values of optical density as

$$\text{Optical Density} = 1.578 \log (i_u/i)$$

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CHAPTER ONE

INTRODUCTION

1.1 THE NEED FOR PROTECTION AGAINST IONISING RADIATION

Every process whereby man utilises nature for his benefits usually has some detrimental effects. This is why protection is very important in all utilisation of nature. One cannot overemphasise the importance of X-rays and other ionising radiation to mankind. These very penetrating radiations are mainly used in radiography where internal objects of a body such as bones can be seen on a film or a screen. This has been helpful in medical practice for treatment and diagnostic process. X-rays can be used for cancer treatment either internal or external on the body of patient without necessarily carrying out surgical operation. Some other sources of ionising radiation can be taken orally by patients for diagnosis purposes or implanted surgically for therapeutic purpose. Apart from medical use of ionising radiation they are also useful as radiotracers to study functions in plants and animals, and are used as research tool in laboratory of higher institutions of learning

Despite its usefulness, ionising radiation causes very severe biological damage to the body. Cancer, shortening of life span, damage of reproductive cells leading to infertility are some devastating effects of over- exposure to ionising radiation. Since X-ray examinations are common, they contribute significantly to public exposure to ionising radiation.

In order not to suffer the effect of radiation due to over-exposure, there must be adequate protection. This starts from constant monitoring of personnel, to constant inspection of radiation sources, ensuring that the dose does not lead to over exposure. The ALARA concept in radiation protection stipulates that all exposures must be kept

"as low as reasonably achievable, economic and social factors taken into account". The Effective Dose to individual from all practices should not exceed the applicable dose limits.

1.2 DENSITOMETER AS PROTECTION INSTRUMENT

All radiation protection methods require instruments for measuring and evaluating the dose to patients and workers to enhance adequate arrangement for their protection. Such instruments must have a property, which can be affected by ionising radiation and in such a way that the effect is proportional in a measurable way to the intensity of radiation energy. X-ray film is one of such materials. The darkening produced on it by X-radiation is proportional to the energy of the X-ray. The measurement of degree of darkness of such X-ray film is done with an instrument known as densitometer

Densitometer is one of the most essential instruments of radiation protection and health physics instrumentation. It is widely used in hospitals and research institutions. It is a light absorption meter calibrated to read values of photographic density. Different models of densitometer exist such as micro-photometer and microdensitometer which are specially designed to read values of photographic density of very small size films. There are two types of densitometers, one that measures transmission density and the other that measures reflection density and for both the measurement may be made either visually or photo-electrically. Of the various types of instrument that have been described for measuring density many are based on the simple photometric comparison of two light beams, using a calibrated wedge as a check against the unknown sample. One of the most widely adopted of the photoelectric densitometer is that made by Western Electric in America, which

gives density readings directly on a calibrated galvanometer scale. A modern type Model 07-423 manufactured by Victoreen Company for example, gives reading of density on a digital scale and is known as hand-held dual reference densitometer, (Rehani, 1995). Special densitometer designs are available that give continuous reading, measuring extremely small fields with great accuracy and to deal with both transmission and reflection density. The optical density of an X-ray film is the degree of darkening produced on it by ionising radiation. It is expressed in terms of logarithm of fraction of visible light passing through the darkened film. The optical density of a film is proportional to X-ray energy absorbed and when properly calibrated, can be used to determine doses in a radiation field.

1.3 STATEMENT OF PROBLEM

Despite the importance of densitometer in quality assurance study and film-badge dosimetry, which is essential for radiation protection, it is not very common in this country. It is well known that imported goods are usually very expensive. Imported densitometer are also susceptible to difficult in maintenance and service as it is usually difficult to get the exact faulty component from the Nigerian market for replacement. This has been the case for most electronic equipment imported into this country. There is limit to the researches requiring its use and this ultimately affect radiation protection in hospital and learning institutions.

1.4 OBJECTIVES OF THIS WORK

The main objectives of this work are:

(i) To construct a densitometer using materials available locally.

(ii) To calibrate the densitometer for intensity of light using principle of inverse square law.

(iii) To test the densitometer by measuring the optical densities of films exposed to varying X-ray intensities and energies

(iv) To examine the nature of the characteristic curves obtained including the range of values of optical density and the effect of film base on the value of the optical density.

(v) To examine the relationship between peak kilovoltage, current-time, film-focus distance and the output of the X-ray unit.

1.5 JUSTIFICATION OF THE WORK

The need to measure dose arises from the fact that X-rays and other ionising radiation cause biological damages. The personnel handling ionising radiation need adequate protection that can be accomplished by monitoring and evaluation of doses in the radiation field around. Optical density measurement can also be used to verify aspects of radiographic procedure in order to show compliance with accepted standards.

1.6 OUTLINE OF THESIS

The nature and measurement of X-rays for radiation protection is considered in chapter two. Photometry and photoconductivity that are the basis for operation of a densitometer were also considered. Chapter three has been devoted to the construction techniques and measurements. The results of experiments are given in chapter four. Chapter five consists of discussion, conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The blackening of X-ray film results from the interaction of X-ray with silver halide grains on the film. This blackening can be quantitatively measured as the optical density, measured by a form of light meter called a densitometer. This chapter discusses the nature, production and effect of X-ray on materials. It also discusses the fundamental physics of a densitometer.

2.2 X-RAYS

X-rays was discovered by Wilhelm Conrad Roentgen on November 8, 1895 at the University of Wurzburg in Germany (Eugene, 1978). They are electromagnetic energy in the form of waves of wavelength about 10^{-10}m. They are emitted on bombardment of matter by sufficiently energetic electrons. They travel in straight lines from the source and are not deflected in passing through electric or magnetic fields. They are thus not charged particles (Nelkon, 1987). They have refractive index that is very small and slightly less than one. (Henry, 1972)

2.3 INTERACTION OF X-RAYS WITH MATTER

When X-ray photons pass through matter they may undergo changes in energy and direction. X-rays can only be reduced in intensity by increasing absorber thickness; it can not be completely absorbed. The intensity of X-rays transmitted through an absorber is given as

$$I = I_o e^{-\mu t} \qquad (2.1)$$

Where I_o is intensity of the incident beam on the absorber, I is intensity of the transmitted beam, t is thickness of the absorber, μ is linear attenuation coefficient (cm^{-1}). The attenuation coefficient is the fraction of the X-ray beam attenuated per unit thickness of absorber.

The fraction of an incident X-ray beam that is attenuated by a single atom is also the attenuation coefficient μ_a. This is also the same as the probability that an absorber atom will interact with one of the photons in the beam. It can also be referred to as cross section of the absorber. The three most significant interaction processes of X-ray with matter at the photon energy used in diagnostic radiography (20kVp to 150kVp) are photoelectric absorption, elastic scattering and Compton scattering. Pair production which can occur only when the energy of the photons are greater than 1.02 MeV do not occur.

2.3.1 Elastic Scattering

In this type of scattering there is no energy loss by the incident photon but its direction is changed. In a material, the mass attenuation coefficient for elastic scattering varies in proportion to the square of the atomic number of the material and inversely with the radiation energy. The mass and linear attenuation coefficients are related by equation shown below.

$$\mu_l = \mu \qquad (2.2)$$

Where μ_l is total linear attenuation coefficient (cm^{-1}), μ_m is mass attenuation (absorption) coefficient (cm^2/g), ρ is density of the absorber (g/cm^3).

2.3.2 Photoelectric Absorption

The photoelectric effect, in which the photon disappears, is an interaction between a photon and a tightly bound electron whose binding energy is equal to or less than the energy of the photon. The primary ionising particle resulting from this interaction is the photoelectron, whose energy is given by

$$E = hf - \phi \qquad (2.3)$$

Where h is the plank constant, f is the frequency of the photon, ϕ is referred to as the work function. The photoelectron may ionise and excite other atoms before it loses its kinetic energy gained from the photon. In addition, after the electron escapes from the atom, characteristic radiation is emitted. In this process, the material absorbs energy. Low-energy photons and high atomic number absorbers favour the photoelectric effect.

2.3.3. Compton Scattering

This is a collision between a photon and a free electron. In such collision, it is impossible for all the photons energy to be transferred to the electron if momentum and energy are to be conserved. Therefore the photon must be scattered, and the scattered photon must have less energy or longer wavelength than the incident photon. The energy of the scattered photon is given as (Herman, 1983)

$$E' = \frac{E}{1+(E/m_oc^2)(1-\cos\theta)} \qquad (2.4)$$

The probability of a Compton interaction decreases with increasing quantum energy and with increasing atomic number of the absorber. Compton interaction is the main mechanism of interaction in light atomic number elements.

2.4 RADIATION DOSIMETRY

2.4.1 Absorbed Dose

Radiation damage depends on the absorption of energy from the radiation, and is approximately proportional to dose which is expressed in terms of energy per unit mass of tissue. This is called Gray (Gy) and is defined as an absorbed energy of one joule per kilogram ($1Gy = 1Jkg^{-1}$) (Kiefer, 1990)

2.4.2 Exposure

The exposure unit is a measure of the photon flux, and is related to the amount of energy transferred from X-ray field to a unit mass of air. One exposure unit is defined as that quantity of X-ray (or gamma ray) that produces in air, a charge (of either sign) per kilogram. (1 X unit = 1 C/kg air). (Herman, 1983)

2.5 BIOLOGICAL EFFECTS OF RADIATION

Radiation effects may be classified into stochastic and deterministic effects. The deterministic effect is characterised by three qualities:

(i) A certain minimum dose must be exceeded before the particular effect is observed.

(ii) The magnitude of the effect increases with the size of the dose

(iii) There is a clear casual relationship between exposure to radiation and the observed effect.

Stochastic effects are those effects that occur by chance. The probability of occurrence increases with increase in exposure to radiation. Stochastic effects of radiation are result of direct insult to a molecule by ionisation and excitation, and the consequent dissociation of the molecule. This can lead to point mutation in germinal or somatic cell. Most of the body is water, and most of the direct action of radiation is on water. The result of this energy absorption by water is the production of highly reactive free radicals that are chemically toxic and exert their toxicity on other molecules. The delayed effects of overexposure are cancer, genetic effects and shortening of life span. (Herman, 1983)

2.5.1 Radiation Weighting Factors, the Equivalent Dose

The higher the linear energy transfer (LET) of the radiation, the more effective is it in causing lethal damage. The radiation weighting factors are as shown below:

Table 2.1 Radiation Weighting Factors (Herman 1983)

Radiation	Weighing Factors (W_R)
X-rays and gamma rays	1
Beta rays and electrons	1
Thermal neutrons	2
Fast neutrons, protons	10
Alpha rays and heavy ions	20

The equivalent dose H_T, is the product of dose D, and the weighting factor W_R. Its unit is Sievert (Sv)

$$H_T = DW_R \qquad (2.5)$$

2.5.2 Effective Dose

For the purpose of setting radiation safety standards, it is assumed that the probability of a stochastic effect in any tissue is proportional to the equivalent dose to that tissue. However, because of the differences in sensitivity between the various tissues, the value for the proportionality factors differs among the tissues. The relative sensitivity to harmful stochastic effects, expressed as risk per sievert to several organs and tissues contribute to the overall risk. The values of weighting factors are shown in the table 2.2

Table 2-2 Tissue Weighting Factors, W_T (Herman, 1983)

Tissue	W_T	Risk Factor	Comments
Gonads	0.25	4.0×10^{-3}	Genetic risk two generation
Breast	0.15	2.5×10^{-3}	Average for all
Red Bone Marrow	0.12	2.0×10^{-3}	Leukaemia
Lung	0.12	2.0×10^{-3}	Cancer
Thyroid	0.03	5.0×10^{-4}	Fatal Cancer
Bone Surface	0.03	5.0×10^{-4}	Osteosacarcoma
Remainder	0.30	5.0×10^{-3}	Cancer

The effective dose H_E is given by:

$$H_E = \sum W_T H_T \qquad (2.6)$$

2.6 RADIATION PROTECTION

No practices resulting in exposure to ionising radiation should be authorised by the relevant competent authority unless its introduction produces a positive net benefit. For an operational system, the competent authority should keep practices under review to ensure that the positive net benefit is maintained in the light of technological advancement. All exposures must be kept as low as reasonably

achievable, economic and social factors being taken into account (ALARA). The equivalent dose to individual from all practices (excluding medical exposure as a patient) should not exceed the applicable dose limits.

2.6.1 Personal Monitoring and Assessment

This is the measurement of radiation doses received by individual workers. Workplace monitoring is used to determine the potential for exposure of personnel to ionising radiation, including the magnitude of any likely doses.

Dosimeters are designed to measure the dose in soft tissue at a defined depth below a specified point on the body. The quantity 'personal equivalent dose Hp (d) is normally determined at two depths, d = 0.07mm and d = 10mm, as measures of exposure to weakly and strongly penetrating radiation respectively. The former is representative of dose to skin and the later represent dose to the blood forming organ. If exposure to the eye is of particular concern, a depth of 3mm represents the eye lens. (IAEA, 1995) Measurement of individual exposure can be done with suitable instruments such as quartz fibre pocket meters, film badges, and TLD dosimeters.

Pocket Dosimeter: These are of two types, the condenser type and the direct reading type. The direct reading dosimeter operates on the principle of the gold leaf electroscope. A quartz fibre is displaced electrostatically by charging it to a potential of about 200V. An image of the fibre is focused on a scale and is viewed through a lens at one end of the instrument. Exposure of the dosimeter to radiation discharges the fibre, thereby allowing it to return to its original position. The amount of discharge and consequently the change in position of the fibre is proportional to the radiation exposure.

Film Badge Dosimeter: This dosimeter consists of a photographic film and a filter in a holder. The film usually has two emulsions of fast and slow sensitivities extending the dose response from one hundred microsievert to ten sievert. The emulsion may be on the same or separate bases and sealed in paper to prevent their exposure to light.

The holder creates a distinctive pattern on the film indicating the type and energy of radiation to which it was exposed. Cumulative doses from beta, X, gamma and thermal neutron radiation are calculated by measuring the optical densities of the film under the filters (IAEA, 1995) The film badge has a number of advantages. It provides a permanent exposure record and can measure dose over a very large range. The type and energy of the radiation may be inferred from film exposure. It is mechanically rugged. The disadvantages are the long delay time between exposure, development and interpretation of the film, and the relatively inaccurate exposures. (Herman, 1983)

2.7 X-RAY FILMS

A common type of X-ray film has two layers of emulsion which consist of gelatine in which is suspended a very large number of tiny flat triangular crystals, most of silver bromide and small amount of other silver halides. The crystal is uniformly distributed throughout the gelatine layer. In between the two layers of emulsion is a thick transparent layer known as film base, which is made of polyester. It supports the fragile emulsion layers. It is moderately flexible; comparatively non-flammable and neither contract nor expands during use. A sketch of X-ray film is shown in figure 2.1 below: -

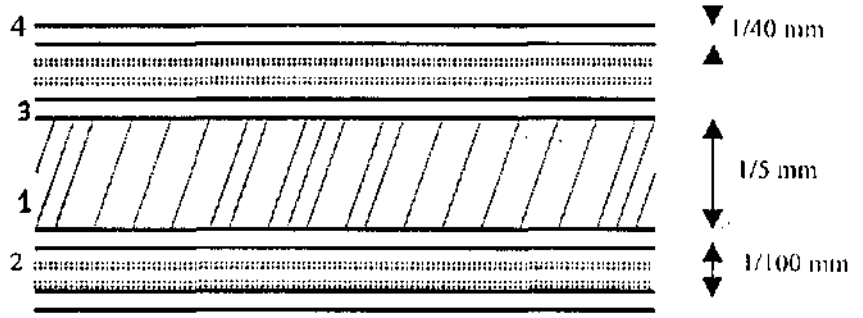


Fig 2.1 Sketch of X-ray Film

The very thin layer of gelatine plus a solvent for polyester (3) ensures that the emulsion layer is firmly attached to the base. The layer (4) is known as supper coating which consist of clear gelatine. It serves to protect the emulsion layer from mechanical damage such as pressure, scratching or friction.

2.7.1 Image Formation on X-ray Film

Exposure of a film by the X-ray depends upon the number of photons incident upon a given area, hence the pattern contained in the X-ray beam will be impressed on the film. The change that has occurred in the film is called an image. During development the irradiated silver bromide crystal are converted into tiny opaque black silver specks, while those, which have not been sufficiently affected, remain in their prevision yellowish translucent state. During fixation, the unaffected silver bromide crystals are dissolved away. The film is then washed thoroughly and dried. (Meredith, and Massey 1977).

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2.7.2 Film Calibration

The film sensitivity varies for different types of film, and for different batch of the same type. The sensitivity under tin filter is constant over a wide range of energy, so, it is possible to calibrate the film at only one energy using hard gamma rays from

Radium whose exposure rate of 1mg at 1cm (gamma factor) is fairly accurately known.The usual procedure is to expose a number of films with their badges to known exposures of the hard gamma ray. The films are left for different lengths of time at a constant distance from the central source. These specially exposed film and the monitoring films are developed together and a calibration curve for the batch of films in use can be made. The doses corresponding to the blackening of the monitoring films are easily read off on this curve, (Meredith, 1977).

2.7.3 Properties of X-ray Film

If the amount of blackening of a film is plotted against the amount of X-ray that produce it, a characteristic curve of the film is obtained. The blackening is measured by means of a quantity known as the optical density or Absorbance.

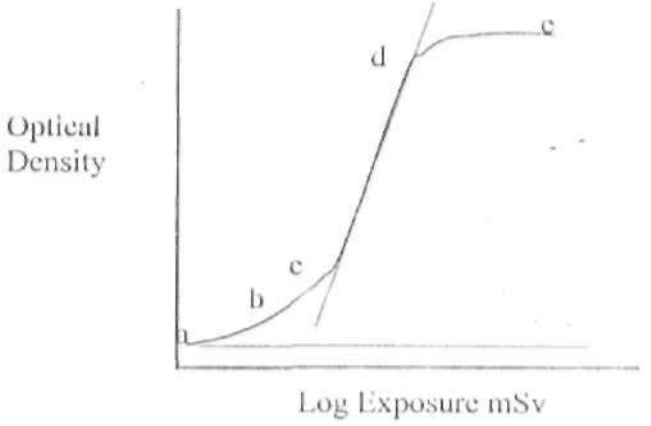


Fig. 2.2 Sketch of Characteristics Curve for X-ray Film

The optical density is defined as

$$D = \log \frac{I_o}{I} \qquad (2.7)$$

Where I_0 is the intensity of visible light incident on the film and I is the intensity of light transmitted through the film. The optical density is independent of the intensity of the light used for the measurement. The range of optical densities that is encountered in radiography runs from about 0.25 up to 2.5. (Meredith, 1977). The density of the transparent film is superimposed on the actual blackening of the film, It is therefore necessary to subtract the density of the film from measured value to obtain the true density of the film. The difference in density between various regions of the film can be named the contrast, which is expressed as

$$\text{Contrast } C = D_2 - D_1 \qquad (2.8)$$

Film manufacturing, storage and process control the shape of characteristic curve. It is therefore not to be expected that all films will have the same characteristic curve, but all curves do have the same general shape. The curve consists of four different regions which are; the fog level (ab), the straight portion (cd), the toe (bc) and shoulder (de) of the curve. See figure 2.2

The straight-line portion between points c and d is the most important region of the film. The slope of the curve is called the 'film gamma'. This is defined as the maximum slope of the characteristic curve and is measured by

$$\text{Gamma, } \gamma = \frac{D_2 - D_1}{\text{Log } E_2 - \log E_1} \qquad (2.9)$$

$$\text{Therefore, Contrast} = \gamma \log (E_2/E_1) \qquad (2.10)$$

The film gamma depends on film type, and conditions during its manufacture. It is a measure of the speed of the film. A fast film has a large gamma.

The effect of development on film characteristic is very important. This depends on the chemical composition of solution and its temperature, developing time and the degree of agitation of the film in the solution during development. Increase in any of these factors lead to increase in film density for a given exposure.

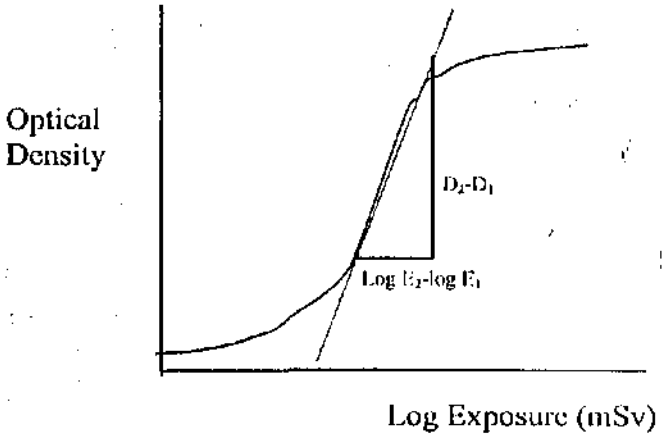


Fig 2.3 Determination of Film contrast

2.8 QUALITY CONTROL IN X-RAY DEPARTMENTS

Quality control comprises the qualitative and quantitative measurements or tests of performance of an instrument or program and the determination of adequacy and acceptability of performance. It includes the set of operations (programming, co-ordinating) intended to maintain or to improve quality. In other words, as applied to diagnostic procedures, covers monitoring, evaluation, and maintenance at optimum levels of all characteristics of performance that can be defined, measured and controlled. (Rehani, 1995)

The application of a service of quality control includes multiple stages of a procedure to verify that all aspect of the procedure are acceptable quality. This is

termed quality assurance. This can also be defined as all those planned and systematic actions necessary to provide adequate confidence that a structure, system or component will perform satisfactorily in service. (Rehani, 1995)

2.9 PHOTOMETRY

The part of radiated energy, which can be perceived by the eye, is the luminous flux and is measured in lumen. This is defined as the amount of visible light energy emitted into a solid angle of one steradian in one second by a uniform point source of light having a luminous intensity of one candela. One candela is the light emitted by a black body of an area of $1/6 \times 10^5 m^2$ at the melting temperature of platinum (1772°C). The amount of light reaching an observer is inversely proportional to the square of the distance from the source. This is referred to as light flux per unit area, and is measured in lux, while luminance is light flux per unit area per unit solid angle and is measured in candela per cm^2.

2.10 PHOTOCONDUCTIVITY

The photoconductive effect is due to increase in the conductivity of certain crystals when they are exposed to light. All materials, which exhibit photoconductivity, are semiconductors. Those most generally employed in photoconductive devices include the element selenium, germanium and silicon, and compounds such as cadmium sulphide and lead sulphide. In these devices, metallic electrode are fitted to the crystal so that when they are connected to source of electric supply, electrons can enter the crystal at the negative electrode (cathode) and leave the crystal at the positive electrode (anode). (Harley, et al, 1963).

In semiconductors, the energy levels in the valence band are all occupied and only a narrow gap or forbidden band exists between the valence and conduction band. This corresponds to the stable bonding between the atoms in the crystal lattice in which a pair of electrons constitutes each bond, one from each of the two adjacent atoms. (Harley, et al, 1963). However, due to thermal agitation, there are always at room temperature a few electrons with energies in the conduction band. The material therefore has a certain low conductivity, even in the absence of light.

When light falls upon the material, further electrons are excited from the valence band to the conduction band, leaving behind a vacant or hole in a process known as hole-electron pair production. This results in large flow of electric current. With time, electrons in the conduction band falls back from its excited state into the valence band where it combines with a hole. At any given temperature of the crystal there is a condition of equilibrium between the rate of production of hole-electron pairs and the rate at which electron and holes recombine. Both processes are influenced by such factors as irregularities in the crystal lattice and the presence of impurities. The concentration of charge cariers is determined by the lifetime of the hole-electron pairs. It is possible to increase this lifetime and thus the conductivity by introducing into the crystal lattice impurities in the form of small numbers of atoms of some other suitable elements.

2.10.1 Cadmium Sulphide Cells

This cell, known as Light Dependent Resistor (LDR) consists of a thin plate of specially prepared cadmium sulphide, with metallic electrode deposited on the surface, enclosed in a glass envelop for mechanical protection. The plates are prepared from very pure cadmium sulphide to which is added an accurately controlled

proportion of activating material such as a mixture of gallium and copper. Heat treatment improves the granular structure and ensures distribution of the activators. The powder is compressed into tablets and given a second heat treatment to improve both the mechanical strength and lattice structure. To satisfy the two prime conditions for light photo-sensitivity namely a large sensitive area and a small inter-electrode distance, the electrodes are deposited as a metallic film in the form of inter-locking combs, the material e.g copper, silver, aluminium or gold, evaporated in vacuum.

The dark resistance of this cell is in the order of 10^6 to 10^8 ohms, depending on the type of cell. When light falls upon it, its resistance decreases rapidly to values in the order of 1000 ohms. The cell presents a pure resistance and the value of photocurrent is independent of the polarity of the applied voltage. When illuminated, generation of electrons and holes takes place, resulting in increasing conductivity. The resistance is expressed by the equation, (Collins, 1987)

$$R = BL^{-k} \qquad (2.11)$$

Where B and K are constants and L is the illumination level in lux.

The resistors are slightly temperature dependence. They have their maximum sensitivity at wavelengths of about 650nm, (orange-red colour) which correspond to maximum sensitivity of human eye. (Kaye, and Laby, 1978). They also exhibit a recovery time when a certain illumination level is suddenly reduced to darkness due to a time delay in the recombination process. The recovery rate is typically $200k\Omega s^{-1}$, (Collins, 1987)

2.11 SUMMARY

Interaction of X-ray was discussed in this chapter. Radiation dosimetry was also discussed including film badge and TLD dosimeters. Properties of X-ray film was discussed followed by Quality control in X-ray department. The physics of Photoconductivity was also discussed. The next chapter discusses the experimental procedures.

CHAPTER THREE

EXPERIMENTAL METHOD

3.1 INTRODUCTION

The main components of a densitometer are a source of light, a Light-Dependent-Resistor that converts light into electrical signal and an ammeter to read the electric current. In this chapter the materials used for construction and testing are considered first, followed by an experiment to examine the characteristics of the light dependent resistor. The construction and testing are later discussed.

3.2 MATERIALS USED FOR CONSTRUCTION

(i) A light bulb with-in built convex lens capable of producing parallel beam of light

(ii) A concave reflector

(iii) Light Dependent Resistor Model RPY 63 manufactured by SIEMES of West Germany. The Light Dependent Resistor is a disc shape 2mm thick with a diameter of 5mm. It has two connecting pins and a light sensitive front which surface is covered with glass.

(iv) A Digital Multimeter, Model DT 830B by ALDA CORPORATION INC., JAPAN.

(v) A metal (iron sheet) box with dimensions 17x11x2$^1/_2$ cm constructed with spaces to contain various component of the equipment.

(vi) A sheet of rubber

(vii) A 3V Direct Current Source (Dry cell)

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3.3 MATERIALS USED FOR TESTING, AFTER CONSTRUCTION.

(i) X – ray films; a fast film manufactured by AGFA

(ii) Mercury in glass Thermometer.

(iii) Lead shield, about two-centimetre thick, twenty centimetre square surface area.

(iv) Self-reading quartz fibre Radiation Dosimeter, Model 1962, made by Dosimeter Corporation. Ohio U.S.A

(v) X – ray machine with three phase full wave rectification, tungsten target, and tube filter of 0.7mm, illuminator filter of 1.5mm, total filter of 2.2mm. It was manufactured in London in 1983 with the tube serial number SE 241 and panel serial number CW 234.

3.4 INVESTIGATING THE CHARACTERISTIC OF LIGHT DEPENDENT RESISTOR (LDR)

Since the densitometer was to convert light intensity to electric current, the behaviour of LDR was examined. This was to know whether the change in current is linearly proportional to change in light intensity. Electric currents in the LDR were measured at various illumination levels. Keeping a constant source of light at various distances from the LDR varied the intensity of light. This was done inside a light proof pipe to avoid interference from the environment. The intensity at a distance x from the light source, according to inverse square law, is proportional to x^{-2}. Ten values of currents were measured with a digital multimeter, for ten corresponding distances x between light source and the LDR.

3.5 CONSTRUCTION OF THE DENSITOMETER.

A Light Dependent Resistor was mounted into small cylindrical opaque tube. This was then inserted into an opening on a sheet of rubber. The rubber was screwed to one side of a metal box inside which is the light bulb and digital multimeter. The beam of light from the bulb falls directly on the LDR through an opening. The LDR, Light bulb and a digital ammeter were connected in a circuit and contained in the metal box. A slit was provided between the LDR and the bulb where X – ray film can be inserted for measurement of optical density. The rubber was made to press firmly on the metal box, and their contact surfaces were very smooth to ensure that light rays from the outside the box do not reach the surface of the LDR. Two switches were provided on the equipment. One to control the main circuit, and the other to control the light bulb.

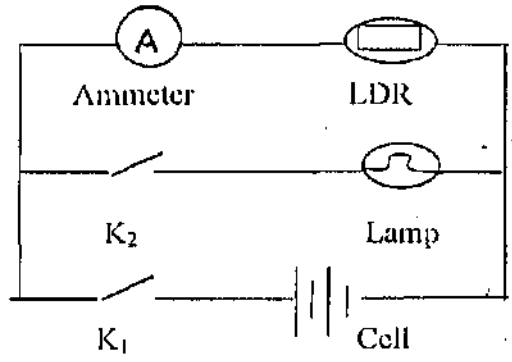


Fig. 3.1 Circuit diagram of a densitometer

3.6 TESTING OF THE DENSITOMETER.

3.6.1 Exposing X – ray Films for Various Optical Densities.

The temperature of the X-ray room and that of the chemicals for developing the films were measured, and fixed throughout the experiment. X-ray film was placed under collimated beam of light on the X-ray bench. A lead shield was placed on the

film such that only the portion to be exposed was not covered. Two dosimeters were placed on the film under collimated beam of light to determine the dose to the film during exposure. A label was placed on the film for identification.

Films exposed with varying peak voltage (kVp): The X–ray machine was set at Film Focus Distance (FFD) of fifty centimetre, and current-time of five milliampere – second (mAs). The peak voltage of the machine was set at forty kVp and the film was exposed. This was repeated for four other values of voltage between 40kVp and 120 kVp. The films were developed for five minutes.

Another set of films were exposed at film-focus-distance of one hundred centimetre, current-time of thirty mAs, and eight values of voltage from forty to one hundred and ten kVp. They were developed for three minutes.

Films exposed with varying current – times (mAs): In order to vary optical density with respect to current – time of the X-ray machine, the peak voltage and film –focus distance were kept constant at fifty kVp and fifty mAs respectively. The current – time was varied between five and twenty-five mAs for five sets of exposures. The films were developed for five minutes.

The same procedure was repeated at film-focus-distance of one hundred centimetres, voltage of eighty kVp, and five values of current – time from two to one thousand mAs. These films were developed for three minutes.

Films exposed with varying Film Focus Distance (FFD): The peak voltage of the X-ray machine was set at a constant value of fifty kilovoltage, the current –time was constant at five mAs. The distance between film and X-ray tube was varied between forty centimetres and one hundred and twenty centimetres, for five sets of

exposure. The films were developed for five minutes. Throughout the experiment, the average readings of the two dosimeters were recorded.

3.6.2 Measuring Optical Density of Films with the Densitometer

Each of the exposed film was inserted into the densitometer to measure the fraction of light transmitted through it. This was done as follows: The digital multimeter was set to read electric current up to a maximum of twenty milliampere, with a sensitivity up to a hundredth of milliampere. The bulb on the densitometer box was switched on and it illuminated the LDR. The electric current in the LDR due to the illumination was measured as i_o. An X-ray film was inserted to intercept the rays of light reaching the LDR from the bulb. The light transmitted through the film illuminated the LDR and the corresponding electric current was recorded as i. This was repeated several times to obtain an average value for each film. The ratio of the currents (i_o/i) was found.

3.6.3 Variation of Optical Density of Film Base.

The same procedure for measuring optical density of exposed film was repeated for the optical density of unexposed transparent film base. The different values of LDR currents, indicating some reduction in the light passing through the film – base, was recorded for several parts of X-ray film and an average value was obtained.

CHAPTER FOUR

RESULT

4.1 INTRODUCTION

This chapter consists of the result of all experiments. In section 4.2, the result of experiment to investigate the characteristics of Light Dependent Resistor (LDR) was presented, as can be seen in figure 4.1 and figure 4.2. The results of experiment to measure the Optical Density of X-ray films were presented in section 4.3, which include figure 4.3 to 4. 11. The variation of dose with kilovoltage and current – time of X –ray machine is presented in section 4.4 as figures 4.12 and 4.13.

4.2 CHARACTERISTICS OF LIGHT DEPENDENT RESISTOR (LDR)

To examine the behaviour of LDR when illuminated, the distance between light source and the LDR was successively varied to obtain different electric currents in the LDR for different intensities of light. In figure 4.1, the electric current in ampere is plotted on vertical axis against distance x, in meters. A curve was obtained that showed decreasing current as x increases. The curved was fitted with an equation as,

$$Y = 0.1394\ x^{-1.2675} \qquad (4.1)$$

Also, in figure 4.2, the logarithm of electric current is plotted on vertical axis against logarithm of x^{-2}. A straight line curve was obtained and was fitted with equation as

$$Y = 0.6339\ x - 4.8561 \qquad (4.2)$$

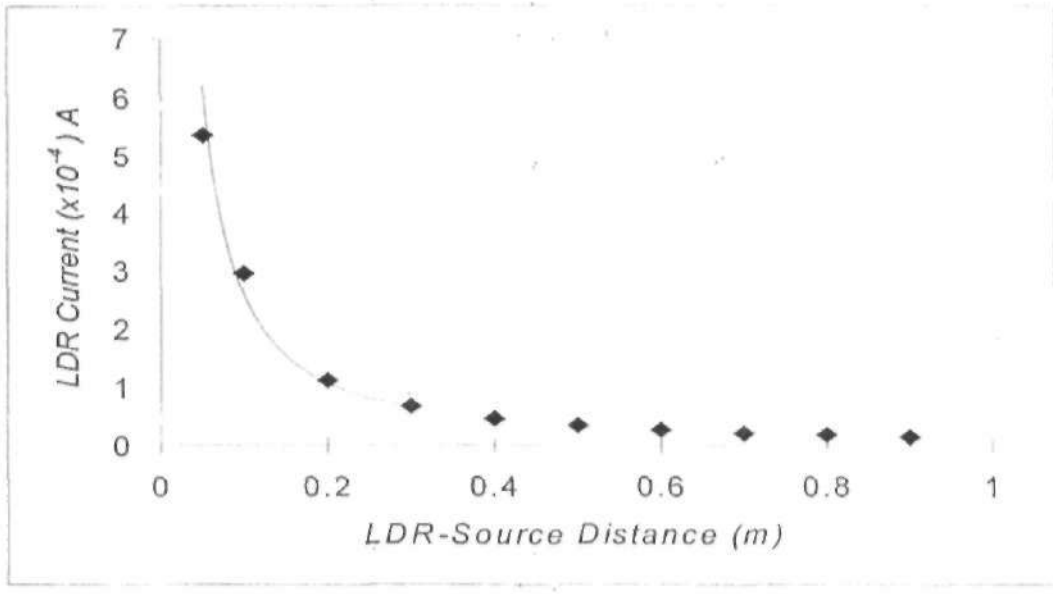


Fig. 4.1 Characteristics of Light Dependent Resistor (LDR)

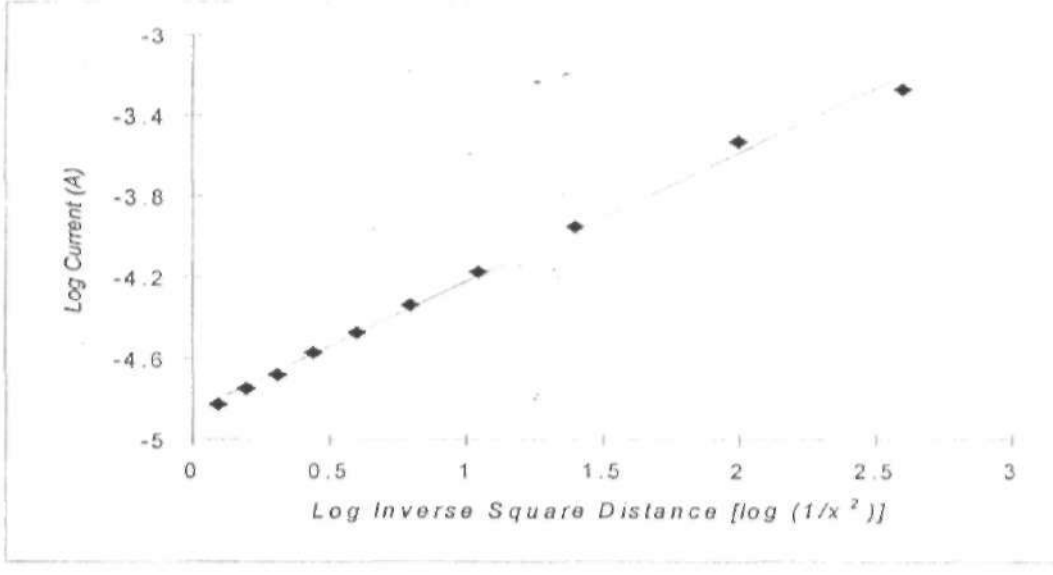


Fig 4.2 Characteristics of LDR on Log-Log Scale

4.3 OPTICAL DENSITY OF X –RAY FILMS

All the films were exposed at the following temperatures:

Room temperature: 29°C

Developer temperature: 26 °C

Fixer temperature; 25 °C

4.3.1 Variation of Optical Density with Peak Voltage.

Figure 4.3 is the graph of optical density against dose, for films exposed at constant FFD of 50cm, current-time of 5 mAs and developed for five minutes. The optical density is on the vertical axis against dose on the horizontal axis. The optical density increases as dose increases. The curve was fitted with equation

$$Y = 0.355 \text{ Ln } (x) + 2.9814 \qquad (4.3)$$

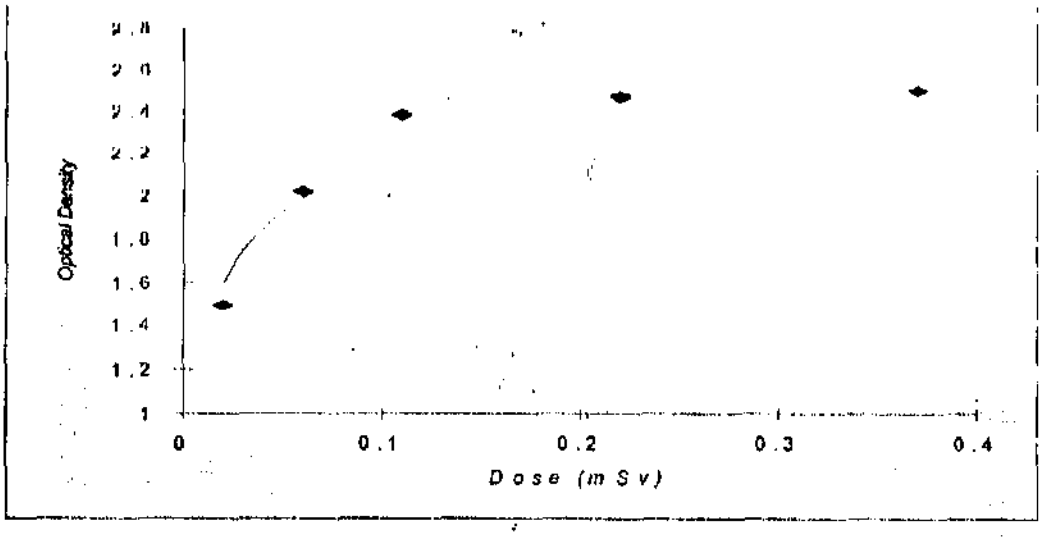


Fig 4.3 Variation of Optical Density with Dose at Varying Peak Voltage for films developed for five minutes

In figure 4.4, the optical density against dose for films exposed at FFD of 100cm, current –time of 30 mAs and developed for three minutes, was presented. The curve was fitted with equation.

$$Y = 0.1305 \text{ Ln } (x) + 2.3263 \qquad (4.4)$$

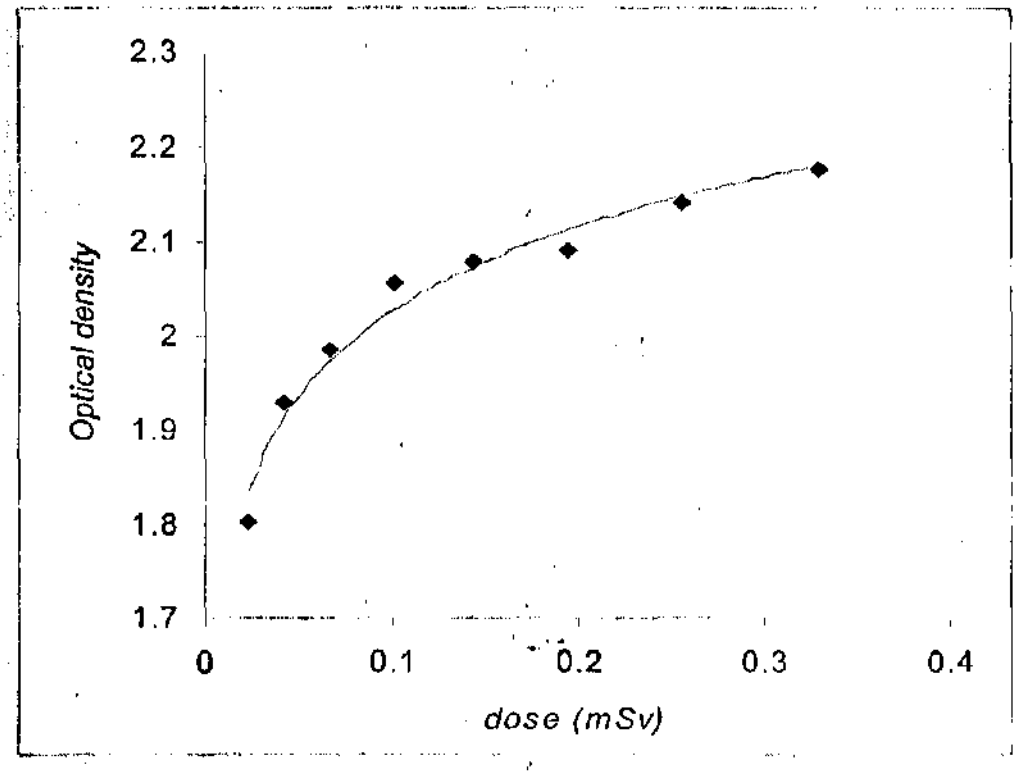


Fig 4.4 Variation of Optical Density with dose at varying kVp for films developed for three minutes

4.3.2 Variation of Optical Density with Current – time

Figure 4.5 presents the optical density of films exposed at 50kVp, 50cm and developed for five minutes. The curve was fitted with equation

$$Y = 0.3789 \text{ Ln } (x) + 3.2748 \qquad (4.5)$$

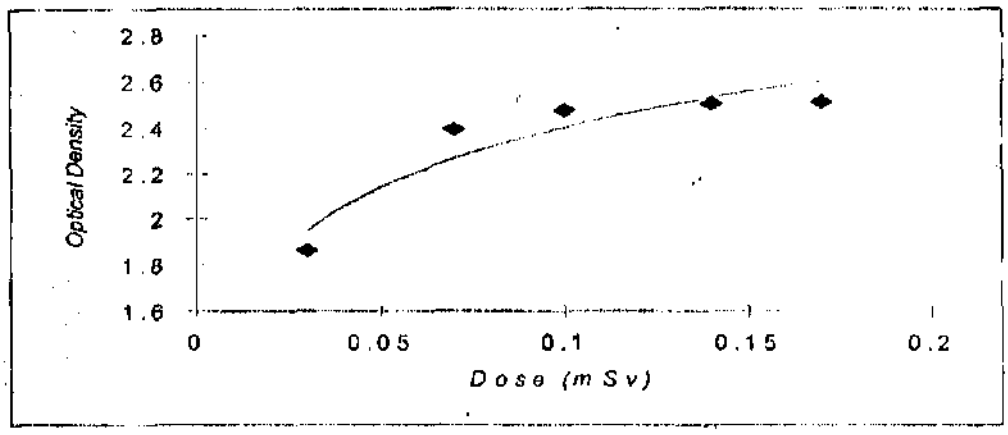


Fig 4.5 Variation of Optical Density with Dose at varying mAs for films developed for five minutes

The result of film exposed at 80 kVp, 100cm and developed for three minutes are shown in figure 4.6. The resulting curve was fitted with equation.

$$Y = 0.22441 \text{ Ln } (x) + 1.959 \qquad (4.6)$$

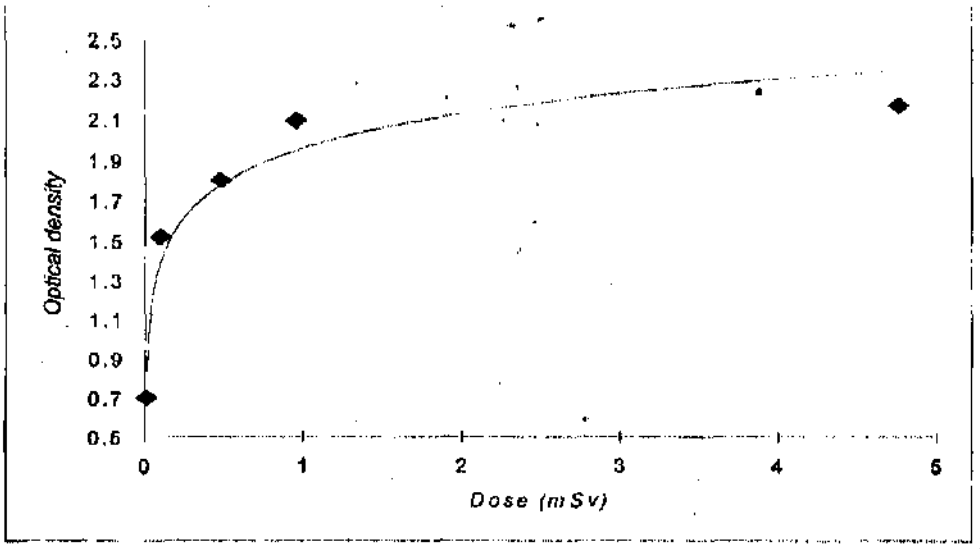


Fig 4.6 Variation of Optical Density with Dose at varying mAs of films developed for three minutes

4.3.3 Variation of Optical Density with Film Focus Distance (FFD)

Figure 4.7 present the optical density of films exposed at varying FFD. The voltage was constant at 50 kVp, and current-time at five milliampere- seconds. The films were developed for five minutes. The optical density is seen to increase as dose increases. The curve obtained was fitted with equation as

$$Y = 0.8504 \text{ Ln } (x) + 4.6748 \qquad (4.7)$$

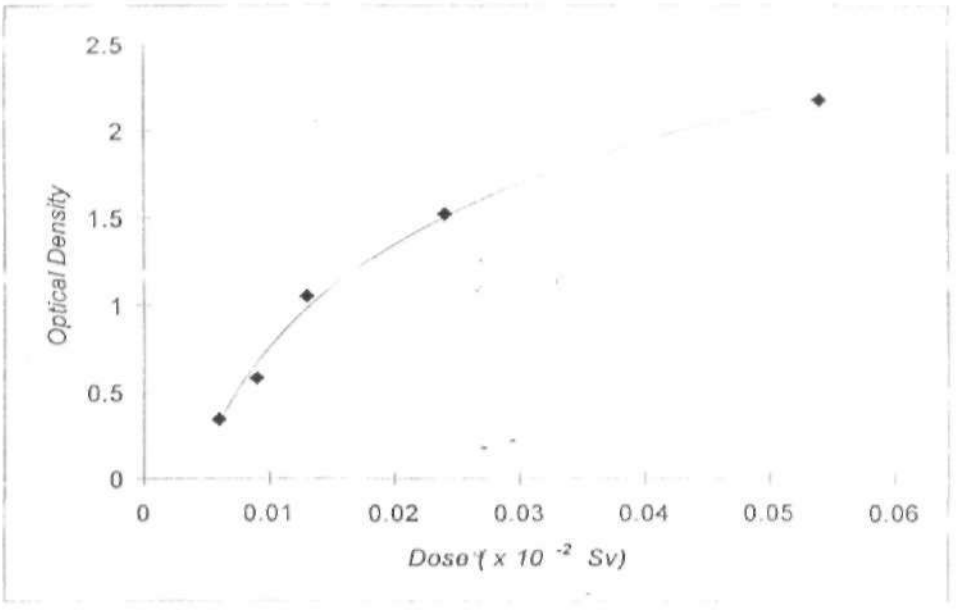


Fig 4.7 Variation of Optical Density with Dose at varying FFD for films developed for five minutes

The figure 4.7 was replotted on a semi – log scale, to have logarithm of dose on the horizontal axis. This is presented in figure 4.8. A linear curve is obtained. The slope of the line was found to be 1.64.

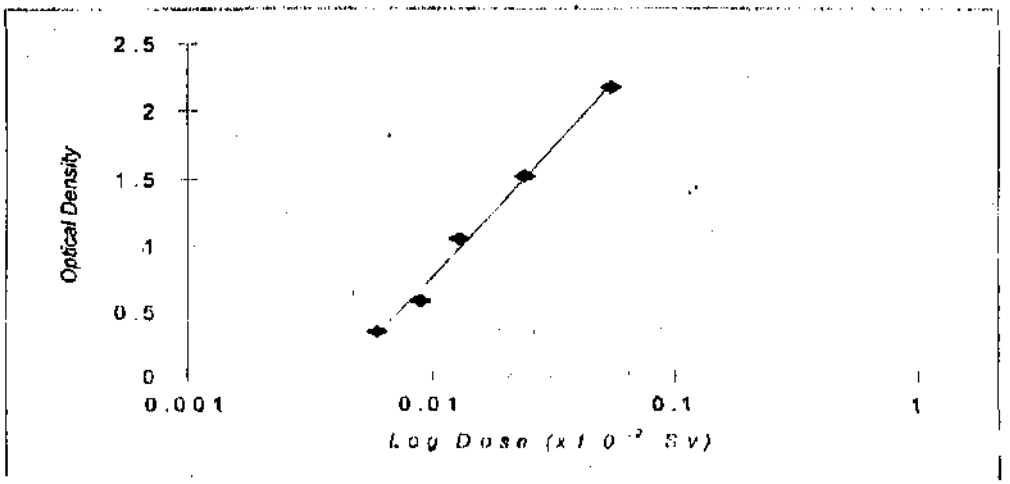


Fig 4.8 Variation of Optical Density with Dose at varying FFD (fig. 4.7 on semi log scale)

4.3.4 Optical Density of Films, for Wide Range of Doses.

Some X –ray films were exposed to cover wide range of doses. The optical density of the films plotted on vertical axis against dose is as shown in figure 4.9.

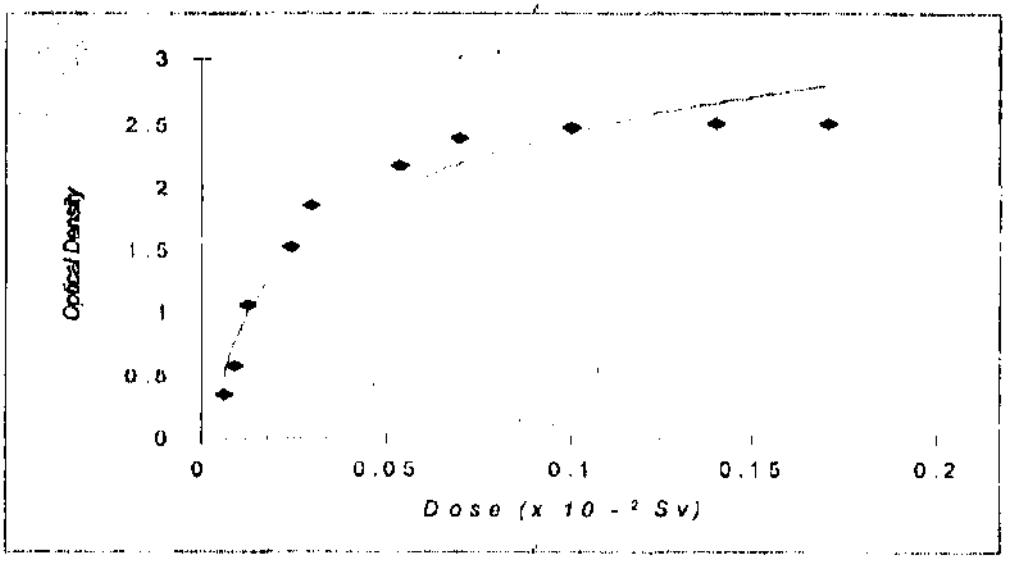


Fig 4.9 Variation of Optical Density with Dose for wide range of values

Between dose values of zero and 0.05, (figure 4.9) the optical density increases rapidly, while for doses higher than 0.05 there was little change in the optical density. The curve obtained was fitted with an equation.

$$Y = 0.6909 \text{ Ln } (x) + 4.024 \qquad (4.8)$$

In figure 4.10 logarithm of dose is plotted on the x – axis for values of doses used in figure 4.9. An S – shape curve, which is similar to the familiar characteristic curve of films, was obtained.

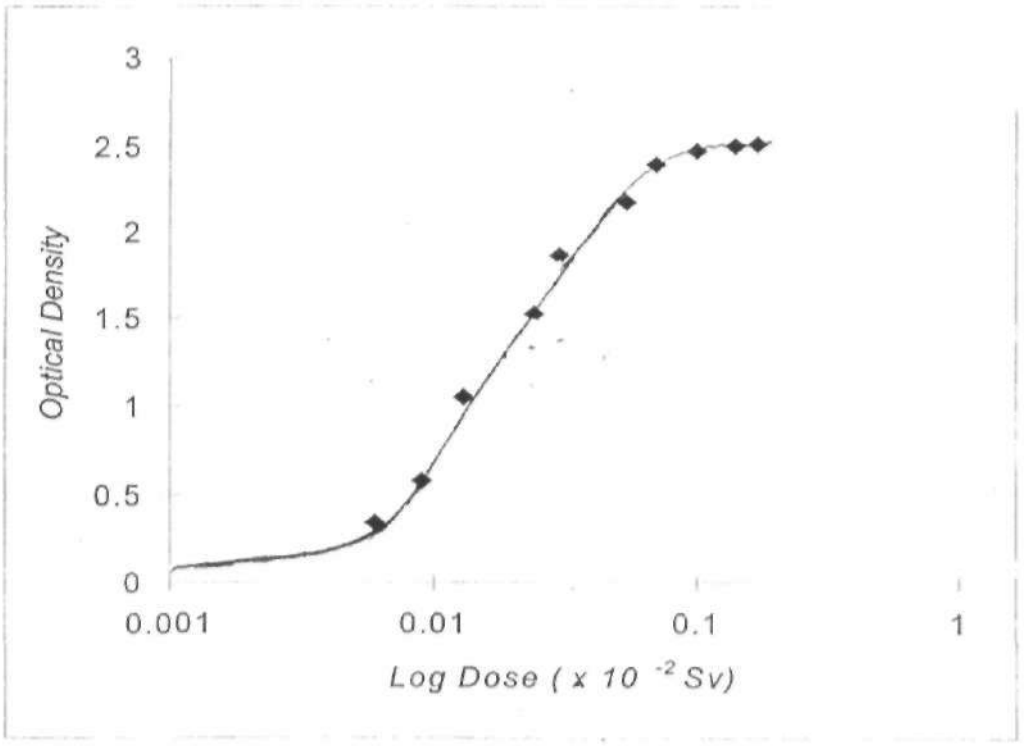


Fig 4.10, Variation of Optical Density with Dose for wide range values on semi log scale.

The linear region of the figure 4.10 was extracted and examined in figure 4.11, which yielded a slope of 1.98.

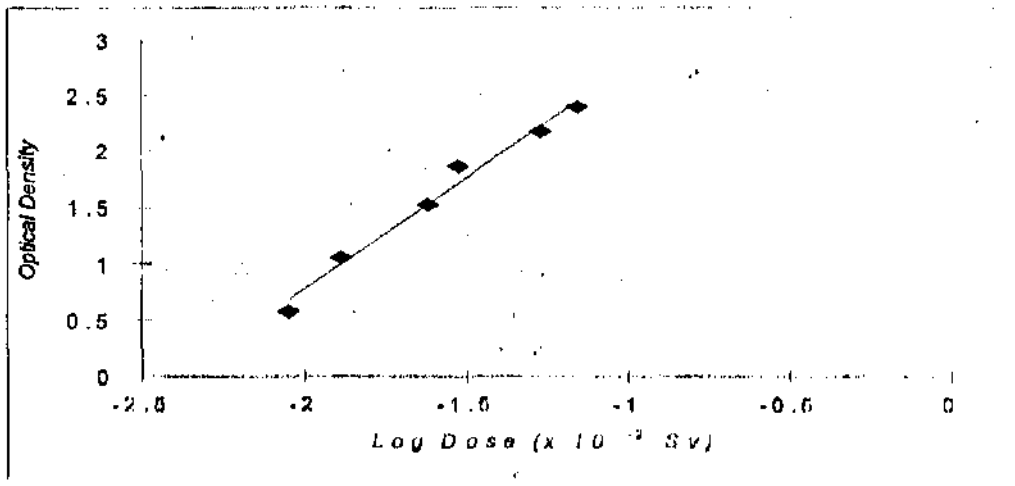


Fig. 4.11 Linear Region of fig. 4.10

4.3.5 Optical Density of Film Base

Since transparent film base contribute to the optical density and is one of the reason for presence of fog level in the characteristics curves of films, the optical density of the base were examined at various portions of unexposed parts of the film used. The table 4.1 below shows the measurements.

Table 4.1 Optical Density of Film Base

I_o/mA ± 0.01	I /mA ± 0.01	Optical Density ± 0.001
13.35	09.41	0.239
13.32	10.02	0.193
13.34	10.14	0.188

The average value for three different parts of the film was found to be 0.207.

4.4. FORMULAE FOR X-RAY DOSES

The doses measured at various peak voltages when other parameters were constant, and the one measured at varying mAs when peak voltage and other parameters were constant, are compared with the varying parameters as shown in figures 4.12 and 4.13.

In figure 4.12, Dose was compared with peak voltage. The curve obtained showed that Dose varies but not linearly as peak voltage. The curve was fitted by equation

$$y=10^{-6}X^{2.62} \qquad (4.10)$$

This experiment was carried out at 5mAs, 50cm FFD. The total filtration was 2.2mm. The same applies to figure 4.13 where variation of dose with mAs was observed. There is a linear relationship between dose and mAs. This curve was fitted with equation as:

$$Y=0.007X-0.005 \qquad (4.11)$$

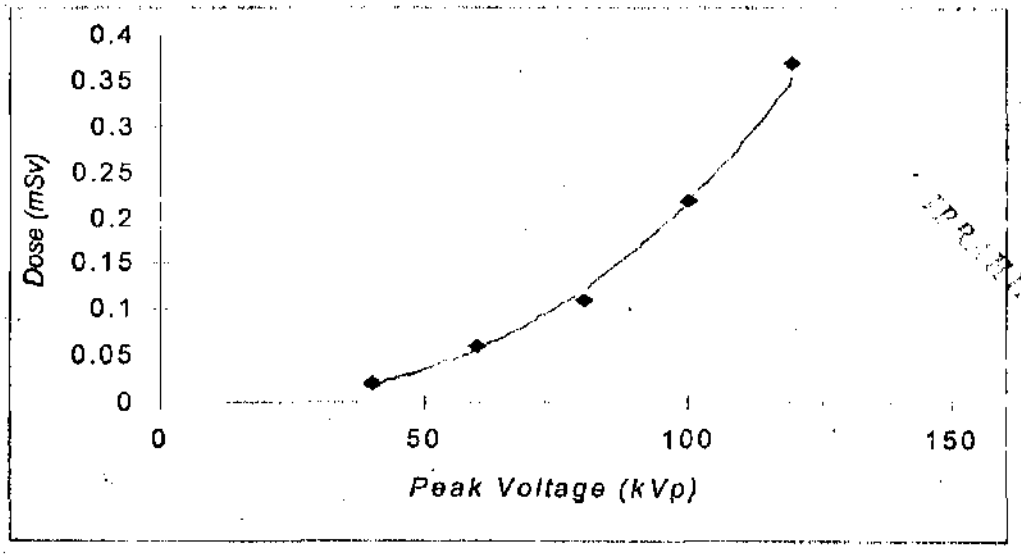


Fig 4.12 Variation of Dose with Peak Voltage at Constant mAs

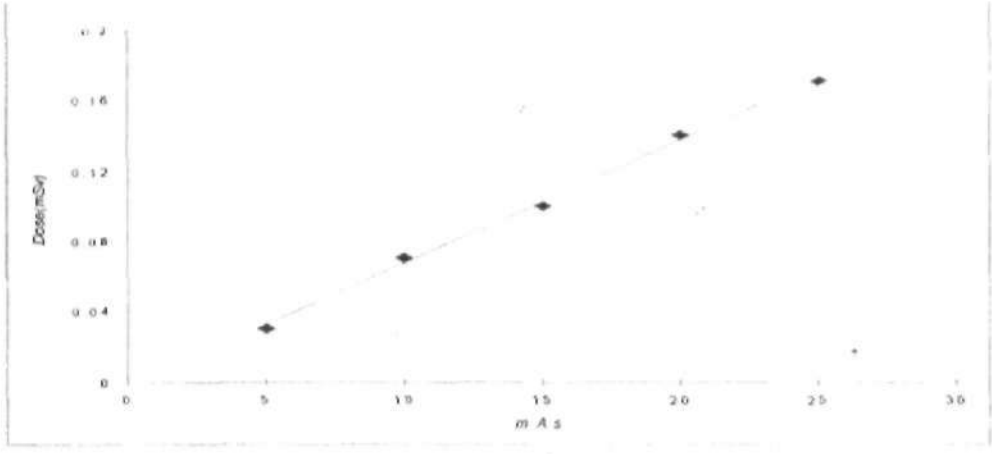


Fig. 4.13 Variation of Dose with mAs at constant kVp

4.5 SUMMARY OF RESULT

The characteristic of LDR was presented in figure 4.1 on a linear scale, and in figure 4.2 on a log scale. Graphs of optical density versus dose are shown in figure 4.3 to figure 4.11. Each of the curves was fitted with an equation. The optical density of film base was presented in table 4.1, while in figure 4.12 and 4.13 the dependence of energy output of an X – ray machine on kilovoltage and current – time were presented.

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 DISCUSSION

5.1.1 Optical Density of X –ray Films.

The Optical Density measured in this work were evaluated with the formula

$$OD = 1.578\log (i_o/i) \qquad (5.1)$$

Where i_o and i are electric current read on milliameter for two illuminations L_o(incident beam) and L (transmitted beam) respectively. All films which densities were measured in this work show that optical density increases as dose increases. Meanwhile, there are differences in the optical density and gamma values for different films that were exposed to the same doses but developed under different conditions.

Comparing figure 4.3 and 4.4, it was observed that optical density reach saturation much more quickly at values less than 2.2 in figure 4.4 while the saturation level is close to 2.5 in figure 4.3. The films of figure 4.3 are relatively darker because they stayed longer in the chemicals during development. This comparison was also made between figure 4.5 and 4.6. Saturation is quickly reached in figure 4.6 than 4.5, which means that films in 4.5 are relatively darker than that of 4.6 because they stayed longer in chemical during development.

A complete characteristics curve of film was obtained in figure 4.10. The linear region of these curves ranged between OD of 0.5 and 2.3, and dose of $0.01\text{x}10^{-2}$ to $0.09 \text{ x } 10^{-2}$ Sv. The optical density of film base, which was found to be 0.207 ± 0.001, contributes to the fog level in figure 4.10. The range of optical density for all

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exposure ranged between 0.35 and 2.5. This compares with Meredith, (1977). The gamma values obtained are 1.64 ± 0.05 (figure 4.8) and 1.98 ± 0.05 (figure 4.11). The values are not the same since these sets of films were not from the same pack. The gamma value is a measure of the speed of X-ray film. The film which gamma was found to be 1.98 is fast compared to the one with gamma value of 1.64.

5.1.2 The Densitometer

The densitometer which dimensions are 17x11x2½ cm is portable. The current in LDR is determined by level of illumination. The currents were measured in milliampere with sensitivity of up to one hundredth ($^1/_{100}^{th}$) of milliampere. Small difference in light intensities not perceptible to eye were easily and quickly detectable by the densitometer. A more accurate result was obtained when values of currents were measured on micrometer scale. A rechargeable accumulator or a rectified low voltage from mains supply provided a more steady current which gave stable intensity of light. Maintenance of this densitometer is very easy.

5.1.3 Variation of Dose with kVp and mAs in X-ray Machine

Figures 4.12 and 4.13 show curves obtained when Doses were compared with kVp and mAs. In figure 4.12 a graph of Dose versus kVp results into a curve that was fitted with equation

$$Y = 10^{-6}x^{2.62} \qquad (5.2)$$

This implies that dose varies as kVp with a power of 2.62 ± 0.01. Similarly figure 4.13 showed that Dose has a linear relationship with mAs. The experiment was carried out at constant values of five mAs and five centimetres FFD. Total filtration

of the machine is 2.2mm and the machine is a three-phase unit. Substituting these values into equation for X-ray unit output, the dose from the machine was deduced as

$$\text{Dose (mSv)} = \frac{2.21 \times 10^{-4} \, kV^{2.62} mAs}{FFD^2 \times T \times P} \qquad (5.3)$$

The index of kV, 2.62 ± 0.01 were comparable with some previous works as follows: Meredith, (1977) obtained a value of 2, but explained further that the value may lie between 2 and 4 for various X-ray machines. Edmonds, (1984) obtained a value of 1.74. Kumar, (1991) obtained a value of 2.558. Chougule, and Hussaini, (1993) obtained 1.985. Kumar, (1996) obtained two values depending on total filtration; that is 2.749 for filtration less than 3mm, and 2.79 for filtration greater than 3mm. The value obtained in this work was 2.62 ± 0.01 for a machine which filtration is 2.2mm.

5.2 CONCLUSION

The LDR has no linear response to intensity of light. The current flowing in the resistor is related to intensity of light as

$$i = BL^K$$

The value of K in this work was found to be 0.6339. This has been useful in calculating values of optical density of X-ray films with formula:

$$\text{Optical Density} = 1.578 \log (i_0/i)$$

Where i_0 and i are the currents in LDR corresponding to two level of illuminations L_0 and L. The optical densities were obtained which varies as doses vary. The optical density was also affected by the developing conditions. The range of optical density

in radiography as obtained in this work was between 0.35 and 2.50. This compares with Meredith (1977) whose value range between 0.25 and 2.50. The shape of all characteristic curves obtained resembles the familiar characteristic curves of X-ray films. Optical density calculated to three decimal places is accurate within a tolerance of ± 0.001. Gamma values of 1.64 ± 0.05 and 1.98 ± 0.05 were obtained. A fast film is expected to have gamma of about 4 (Meredith, 1977). The films used here are not fast films. The dose output of an X-ray machine was found to depend on film-focus-distance (FFD), milliampere-second (mAs), and peak kilovoltage (kVp) as:

$$\text{Dose (mSv)} = \frac{2.21 \times 10^{-4} \text{kV}^{2.62} \text{mAs}}{\text{FFD}^2 \times \text{T} \times \text{P}}$$

5.3 RECOMMENDATIONS

To improve on this work, a linear electronic system comprising integrated circuit (IC) may be used to obtain a linear relationship between illumination and electric current in the circuit. The equipment will also become more efficient if some electronic system could be incorporated to evaluate and display directly the value of optical density instead of using a calculator. This will eliminate the possibility of any gross error in using the instrument.

A standard lamp (whose intensities are known) with a standard light meter for investigating the characteristics of LDR is required for an reliable improved result. The densitometer can be better calibrated using a commercial model with well-defined characteristics. The effect of storage on X-ray films and the effect of concentration of the developer on optical density need further investigation.

The formula for estimating the output of X-ray units depends on kVp, mAs, phase and filtration of the X-ray machine, investigation of their relationship for a wide range of machine use in Nigeria can be an area of interest for follow up research.

REFERENCES

Cember, H., (1983) *Introduction to Health Physics*. Pergamon Press, New York.

Chougule, A.A., and Hussain, S., (1993) *Verification of an Empirical Formula for Estimation of Skin Exposure During Radiography. Indian Journal of Radiological Imaging*. 3,Pg 49-50.

Collins, T. H., (1987) *Analogue Electronics Handbook*. A. Wheaton and Co. Limited. Exeter

Cooper, W. D., and Helfrick, A. D., (1989). *Electronic Instrumentation and Measurement Techniques*. Prentice Hall of India Private Limited, New Delhi.

Edmonds, I.R., (1984) *Calculation of Patient Skin Dose from Diagnostic X-Ray Procedures. Britain Journal of Radiology*. 57, 733 - 734

Edwin, C. M., and John, R. C., (1970) *Exposure Rates from Diagnostic X-ray Units. Britain Journal of Radiology*, volume 43 page 448

Edwin, G. A., (1975) *An Introduction to Medical Physics*. William Heinemann Medical Books Ltd. London

Eugene, P. B., (1978) *Introduction to X-ray Spectrometric Analysis*. Plenum press, New York.

Francis, T. G., (1981) *Electrical Installation Work*. Longman Group Limited. Burnt Mill.

Gwyneth, C. W., (1983) *Reducing Radiation Doses to the Breast, Thyroid and Gonads during Diagnostic Radiology. Journal of the College of Radiographers*, volume 49, No 583,page 23

Harley, C., and Martine, D., (1963) *Photoelectric Devices In Theory and Practice*. Phillips Technical Library, London.

Henry, S., and John, A., (1972) *Introduction to Atomic and Nuclear Physics*. Fletcher and Sons Limited. Norwich

IAEA, and WHO, (1968) *Radiation Protection Monitoring*. Proceedings of a Regional Seminar for Asia and the Far East on Radiation Protection Monitoring jointly organised by IAEA and WHO. Bombay.

IAEA, (1995) *Practical Radiation Technical Manual*. Personal monitoring. International Atomic Energy Agency, Vienna

IAEA, (1970) *Radioisotope X-ray Fluorescence Spectrometry*. Technical report, series No 115. International Atomic Energy Agency, Vienna.

IAEA, (1970) *Personnel Dosimetry System for External Radiation Exposures*. Technical report, series No 109. International Atomic Energy Agency, Vienna.

Joshua, I. D., (1987) *Design of Film Badges*. Unpublished B.Sc. Thesis, Ahmadu Bello University, Zaria. Nigeria.

Kaye, G.W.C., and Laby, T.H., (1978) *Tables of Physical and Chemical Constants*. Longman Group Limited, London.

Kiefer, J., (1990) *Biological Radiation Effects*. Springer-Verlag Berlin Heidelberg, Germany

Kumar, P., *et al*, (1996) *Two New Formula for Estimating the Output of X-ray Units. Journal of Medical Physics* 21, 2, page 68

Kumar, P., Yadav, R.C., and Rehani, M.M., (1999) *Quality Assurance Tests of View Boxes by a Home -made Light Meter. Journal of Medical Physics*. 24, 2, pg 65

Meredith, W. J., and Massey, J. B., (1977) *Fundamental Physics of Radiology*. John Wright and Sons Limited, London.

Nelkon, M., and Parker, P., (1987) *Advanced Level Physics*. Heinemann Educational Books. Paslic Nigerian LTD. Lagos

Rehani, M. M., (1995) *Diagnostic Imaging Quality Assurance*. Jaypee Brothers. Medical Publishers LTD. New Delhi.

APPENDICES

Appendix 1 The prove of equation used to examine the characteristics of Light Dependent Resistor

The relations between resistance of an LDR and illumination is

$$R = BL^{-k}$$

Where B and K are constants to be determined. Illumination L of an object at a distance x from a source of light S is, according to inverse square law of light,

$$L = \frac{S}{x^2}$$

Where S is a constant depending on the intensity of the source. The absorption of the light in air between source and illuminated object at close distances used in this experiment (5cm to 35cm) is negligible. Combination of the two equations above with ohms law of electrical resistance (V=iR) gives

$$i = VBS^k x^{-2k}$$

And taking log of the equation,

$$\text{Log } i = \text{Log } (VBS^k) + k \text{ Log } x^{-2}$$

A graph of log i versus $\log x^{-2}$ therefore yield the values of k and (VBS^k) as slope and intercept respectively.

The current flowing in the LDR when light was being moved away from it was shown in figure 4.1. It was seen that the current reduces as light intensity reduces at longer distances. Light intensity at distance x, according to inverse square law is proportional to x^{-2}. When this was compared with $x^{-1.268}$ obtained in equation 4.1, it

was deduced that the current in the LDR has a response that is not linear with light intensity. The current was therefore re-plotted in figure 4.2, on a logarithm scale. A linear curve was obtained, which slope is 0.6339. The current i in LDR was proportional to illumination L as

$$i = BL^k$$

Where B is a constant and k = 0.6339.

The value of k was used to derive a formula for calculating optical density, using electric currents in the LDR. For two illuminations L_o and L there were two currents i_o and i respectively. Definition of optical density is OD =Log (L_o/L), Using electric current in this LDR, Optical Density was defined as

$$OD = 1/k \ \text{Log} \ (i_o/i)$$

Where 1/k is 1.578. The optical density measured in this work were evaluated with the formula

$$OD = 1.578 \log (i_o/i)$$

Appendix 2 Table of observations

Table A.1 Characteristics of LDR

LDR-light source Distance (X) (meters) ± 0.001	LDR current (I) $X10^{-4}$ Ampere ± 0.01	Log X^{-2}	Log I
0.050	5.35	2.602	-3.272
0.100	2.95	2.000	-3.530
0.200	1.12	1.398	-3.951
0.300	0.67	1.046	-4.174
0.400	0.46	0.796	-4.337
0.500	0.34	0.602	-4.469
0.600	0.27	0.444	-4.569
0.700	0.21	0.310	-4.678
0.800	0.18	0.194	-4.745
0.900	0.15	0.092	-4.824

The tables below show the result of experiment to test the densitometer. The optical densities were calculated using $OD = 1.578 \log (i_o/i)$

Table A.2 Variation of optical density with varying X-ray peak voltage (kVp), at 5mAs, 50cm and development time of 5 minutes

kVp	Dose (mSv) ± 0.05	Optical Density ± 0.001
40	0.02	1.491
60	0.06	2.018
80	0.11	2.380
100	0.22	2.464
120	0.37	2.492

Table A.3 Variation of optical density with varying X-ray peak voltage, at 30mAs, 100cm and development time of 3minutes

kVp ± 0.01	Dose (mSv) ± 0.05	Log Dose ± 0.05	Optical Density ± 0.001
40	0.023	-1.638	1.564
50	0.042	-1.377	1.690
60	0.067	-1.174	1.744
70	0.101	-0.996	2.057
80	0.143	-0.845	2.079
90	0.194	-0.712	2.092
100	0.256	-0.592	2.140
110	0.329	-0.483	2.176

Table A.4 Variation of optical density with varying mAs, at 50kVp, 50cm and development of 5 minutes

mAs ± 0.01	Dose (mSv) ± 0.05	Optical Density ± 0.001
05.00	0.03	1.862
10.00	0.07	2.394
15.00	0.10	2.475
20.00	0.14	2.504
25.00	0.17	2.514

Table A.5 Variation of optical density with varying mAs, at 80 kVp, 100cm and development of 3 minutes.

mAs ± 0.01	Dose (mSv) ± 0.05	Optical Density ± 0.001
2.0	0.010	0.702
20.0	0.095	1.520
100.0	0.47	1.800
200.0	0.952	2.095
1000.0	4.760	2.167

Table A.6 Variation of optical density with varying film-focus-distance (FFD), at 5mAs, 50 kV and development time of 5 minutes

FFD ± 0.05	Dose ± 0.05	Optical Density ± 0.001
40	0.054	2.173
60	0.024	1.521
80	0.013	1.052
100	0.009	0.581
120	0.006	0.344

Table A.7 Variation of optical density with dose for wide range of doses.

Dose (x 10^{-2} Sv) ± 0.05	Optical Density ± 0.001
0.006	0.344
0.009	0.581
0.013	1.052
0.024	1.521
0.030	1.862
0.054	2.173
0.070	2.394
0.100	2.475
0.140	2.504
0.170	2.514