Sudan University of Science and Technology

College of Graduate Studies

Assessment of Conventional X-Ray Machine Quality Control Parameters in some Hospital in Sudan.

تقييم عوامل ضبط الجودة لأجهزة الأشعة السينية التقليدية في بعض المستشفيات في السودان

A thesis submitted for the partial fulfillment of M.Sc degree in Nuclear Physics

By:

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الآيـــــــــة

قـــــــــال تعالى :

بسم الله الرحمن الرحيم

﴿ اللَّهُ نُورُ السَّمَاوَاتِ وَالْأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ شَجَرَةٍ مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ ﴾

سورة النور الاية ﴿35﴾

Dedication

Every challenging work needs self-efforts as well as guidance of elders especially those whom were very close to our heart.

My humble effort I dedicate for the soul of my mother and father.

Who reaped the thorns out of my way for me to pave the way science?

I ask Allah to mercy my dears Mother and father and forgive them and shed their soul paradise.

To Along with all hard working and respected teachers

To my dear husband and dear sister, they are in my life; I have found all the support and strength to continue on the way of science.

To my brothers, friends, and to all my family.

Thank you.

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Deep thanks to my family for their consistent support.

Finally, special thanks to Dr. Abdulla Mohamed Eldoma for his great support to me, and I wish him more success and excellence.

Abstract.

This study dealt with to evaluate the quality control parameter of X-ray tube in some hospital in Sudan, kV accuracy test, kV Reproducibility, time accuracy, time Reproducibility, output factor and HVL/Filtration tests were done and has been evaluated for all X-ray machines, the main result show that there was small variation between the nominal value, The study followed the experimental method and showed a number of results, the most important of which is that the general level of the devices used is acceptable, measurements showed HVL it was within reasonable limits.

Study recommends to medical facilities that use X-ray machines to put in place a quality control program for the benefit of their patients and workers.

ملخص البحث

تناولت الدراسة تقيم عوامل ضبط الجودة لأنبوب الأشعة السينية لبعض المستشفيات في السودان ، هدفت الدراسة لتقييم إختبار دقة جهد الأنبوب وإختبار إنتاجية جهد الأنبوب ودقة زمن التعرض وإنتاجية زمن التعرض وعوامل خرج الجهاز وقياسات طبقة القيمة المتوسطة لكل الأجهزة السينية ومقارنتها بالحدود المقبولة أظهرت النتائج الأساسية فروقات بسيطة بين القيمة الأسمية والقيمة المقاسة، اتبعت الدراسة المنهج التجريبي واظهرت عدد من النتائج أهمها أن المستوي العام للأجهزة المستخدمه مقبول وأظهرت قياسات طبقة القيمة المتوسطة في الحدود المقبولة ، توصي الدراسة المرافق الطبية التي تستخدم أجهزة الأشعة السينية بوضع برنامج لمراقبة الجودة لصالح مرضاهم وعمالهم .

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Chapter five : Discussion and Conclusion and Recommendation

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List of abbreviation

Abbreviation	Meaning
HVL	**Half Value Layer**
KV	**Kilovolt**
QA	**Quality Assurance**
QC	**Quality Control**
FDD	**Film Detector Distant**
CV	**Coefficient of Variation**
ALARA	**As Low As Reasonably**
VUV	**Vacuum Ultraviolet**
UVC	**Ultraviolet C**
UVB	**Ultraviolet B**
UVA	**Ultraviolet A**

Chapter one

Introduction

Introduction

X-ray is the most frequently used as tool in the diagnosis of diseases and constitutes a major part of man’s exposure to artificial resources (UNSCEAR2000).

X-ray imaging is an efficient diagnostic method in medicine with no suitable alternative. Based on the principle of “as low as reasonably achievable” (ALARA), X-ray examinations should provide images containing valuable diagnostic information with the lowest achievable radiation dose (ICRP2006). To achieve this goal, some legislative institutions have implemented quality assurance programs in medical imaging departments of hospitals (AAPM2000&IEAE2010&IPEM1998).

Quality control in diagnostic radiology is essential to ensuring accurate diagnostic information at optimal radiation doses (AjayiIR2000 &Willim1998), thereby making it possible to reduce unnecessary radiation hazard to patients, workers and the public. In Sudan, many x-ray machines are installed and commissioned. Considering the importance of QC tests in Patients' radiation exposure, several studies have been performed in other countries. Some of those studies revealed that QC can reduce patient dose by at least 30%.

Though X-rays were extensively used in the diagnosis of diseases and injury all over the world improper use of X-rays can produce biological damage because of its ionizing nature. As a result, it has long been appreciated that the irradiation of the patient should be kept to the lowest limit consistent with sufficient image quality (Muhogora WE2001).

Proper assessment of any disease or fracture depends on the quality of the diagnostic images (Schandorf C, Tetteh GK1998) , which are affected by many factors such as beam alignment, Film-screen contact etc. Fault in any single factor may impact the final image quality because the factors are largely interdependent. Therefore, quality control in diagnostic X-ray facilities is required for the safety and improved performance of the systems. Certain essential quality control tests, which have greater effect on the final diagnostic image quality, are investigated in the present study. Tests are conducted on some diagnostic X-ray facilities according to a quality control protocol, and the measured parameter values were compared to the relevant acceptance limits (Rehani M M1995).

1.2. Problem of the study:-

Lacking of frequent quality control assessment tool in diagnostic radiology department in most hospital in Sudan, this will lead to increase the radiation dose to patient, hence it is important to conduct such research to assure the consistency of X-ray Machine Performance.

1.3. Objectives:-

1.3.1. General objective

Evaluation of conventional X-Ray machine quality control parameters in some hospital in Sudan.

1.3.2. Specific objectives

1. To measure the voltage of X- ray tube using KV meter.
2. To calculate the voltage accuracy of X- ray machine.
3. To calculate the voltage reproducibility of X- ray machine.
4. To measure the Time exposure of X- ray tube using KV meter.
5. To calculate the Time accuracy of X- ray machine.
6. To calculate the Time reproducibility of X- ray machine.
7. To measure of output of X- ray machine.
8. To calculate the tube output reproducibility.
9. To measure HVL and evaluation of X-ray Filtration.
10. To calculate the error of KV and time exposure of X- ray machine.

1.4. Thesis Layout:-

Were conducted on five chapters. Chapter one introduction. Chapter two the literatures review cover the theoretical background and previous studies. Chapter three the materials and methods of the study and Chapter four the result and Chapter five covered discussion, conclusion, and recommendations, followed with references.

Chapter two

Literature Review

Literature Review

2.1. Radiation:

The propagation of energy from a radioactive source to another medium is termed radiation. This transmission of energy can take the form of particulate radiation or electromagnetic radiation (i.e., electromagnetic waves). The various forms of radiation originating from atoms, which include (among others) visible light, X-rays and g-rays, are grouped together under the terms “electromagnetic radiation” or “the electromagnetic Spectrum”. Radio waves, which have the longest wavelengths and thus the lowest frequencies and energies of the various types of electromagnetic radiation, are located at tone end of the electromagnetic spectrum, whereas X-rays and g-rays, which have the highest frequencies and energies, are situated at the other end of this spectrum. (James E. Martin,2006).

2.1.1. Photon:

If the smallest unit of an element is considered to be its atoms, the photon is the smallest unit of electromagnetic radiation. Photons have no mass.

2.1.2. Common features of electromagnetic radiation:

It propagates in a straight line, it travels at the speed of light (nearly 300,000 km/s), it transfers energy to the medium through which it passes, and the amount of energy transferred correlates positively with the frequency and negatively with the wavelength of the radiation.

The energy of the radiation decreases as it passes through a material, due to absorption and scattering, and this decrease in energy is negatively correlated with the square of the distance traveled through the material.

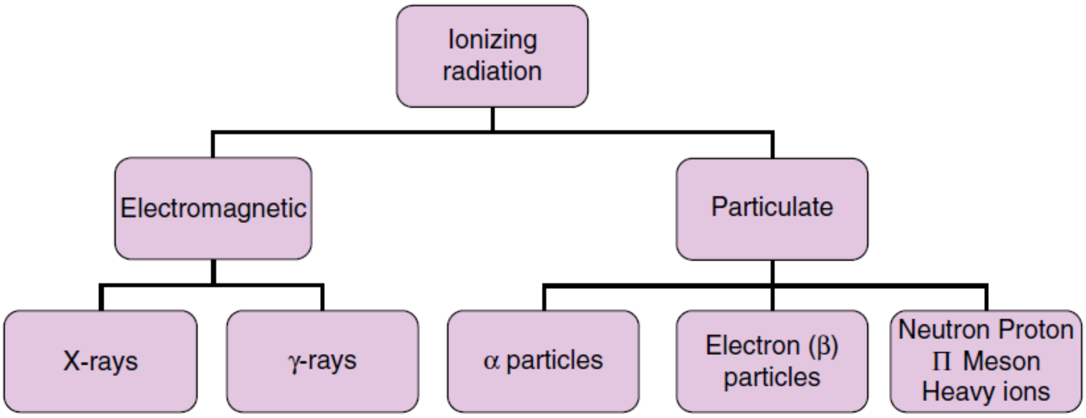
Electromagnetic radiation can also be subdivided into ionizing and non-ionizing radiations. Non ionizing radiations have wavelengths of 10^{-7} m. non-ionizing radiations have energies of <12 electron volts (eV); 12 eV is considered to be the lowest energy that an ionizing radiation can possess. (James E. Martin,2006).

2.1.3. Types of non-ionizing electromagnetic radiation:

1. Radio waves
2. Microwaves
3. Infrared light
4. Visible light
5. Ultraviolet light

2.2. Ionizing Radiation:

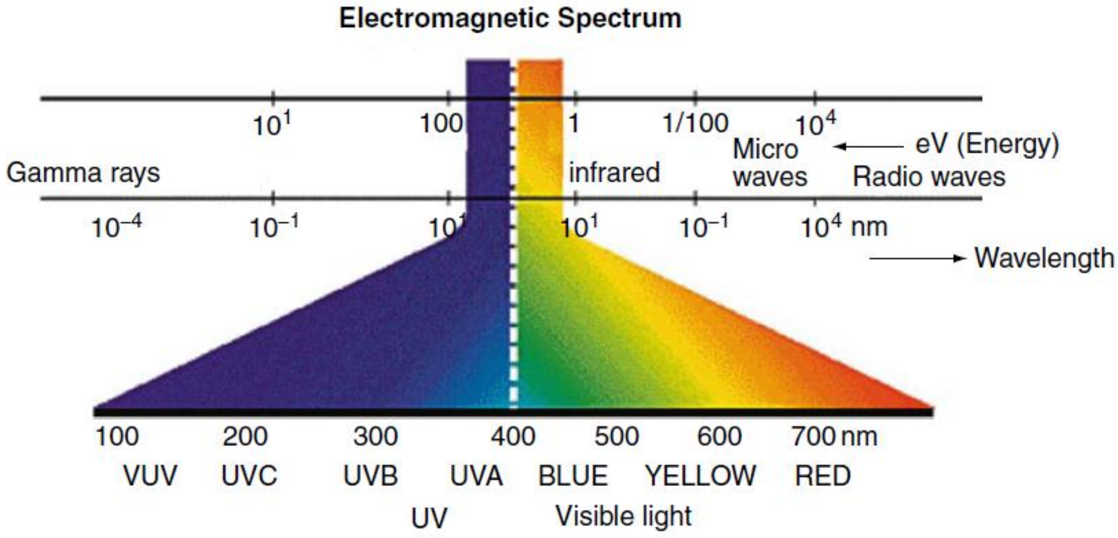
Ionizing (high-energy) radiation has the ability to remove electrons from atoms; i.e., to ionize the atoms. Ionizing radiation can be electromagnetic or particulate radiation. Clinical radiation oncology uses photons (electromagnetic) and electrons or (rarely) protons or neutrons (all three of which are particulate) as radiation in the treatment of malignancies and some benign conditions. (Murat, 2010).



The figure (2.1) show the types of ionizing radiation. (Murat, 2010).

2.3. Electromagnetic Spectrum:

The electromagnetic spectrum comprises all types of electromagnetic radiation, ranging from radio waves (low energy, long wavelength, low frequency) to ionizing radiations (High energy, short wavelength, high frequency). (James E. Martin,2006).



The figure (2.2) shows the electromagnetic spectrum. (James E. Martin, 2006).

Electrons are knocked out of their atomic and molecular orbits (a process known as ionization) when high-energy radiation interacts with matter. Those electrons produce secondary electrons during their passage through the material. A mean of energy of 33.85 eV is transferred during the ionization process, which in atomic and molecular terms is a highly significant amount of energy. When high-energy photons are used clinically, the resulting secondary electrons, which have an average energy of 60 eV per destructive event, are transferred to cellular molecules.

2.4. X-Rays:

X-rays were discovered by the German physicist Wilhelm Conrad Roentgen where The hot cathode Roentgen tube, which was developed by William David Coolidge in 1913, is a pressured (to 10−3 mmHg) glass tube consisting of anode and cathode layers between which a high-energy (106 – 108 V) potential is applied. Electrons produced by thermionic emission in the cathode are accelerated towards the anode by the potential. (James E. Martin, 2006).

2.4.1. Production of X-rays:

Roentgen was able to describe most of the known characteristics of x-rays after his monumental discovery by conducting several experiments; however, it was not possible to explain how X-rays were produced until the concepts of atoms, particles, and quanta were understood. It is now known that X-rays production occurs, as shown in Figure (2.3), when a negatively charged electron of kinetic energy eV enters the force field of the positively charged nucleus of a target atom. This force field, which is strongest for high-Z materials like tungsten, deflects and accelerates the electron, which causes the emission of electromagnetic radiation as it is bent near the nucleus. This is consistent with classical electromagnetic theory because the electron is not bound. Because radiation is emitted and energy is lost in the process, the electron must slow down, so that when it escapes the force field of the nucleus it has less energy. Overall, the electron experiences a net deceleration, and its energy after being decelerated is eV – hv where hv appears as electromagnetic radiation. Roentgen named these radiations x-rays to characterize their unknown status. (James E. Martin,2006)

This process of radiation being produced by an overall net deceleration of the electrons is called Bremsstrahlung, a German word meaning braking radiation.

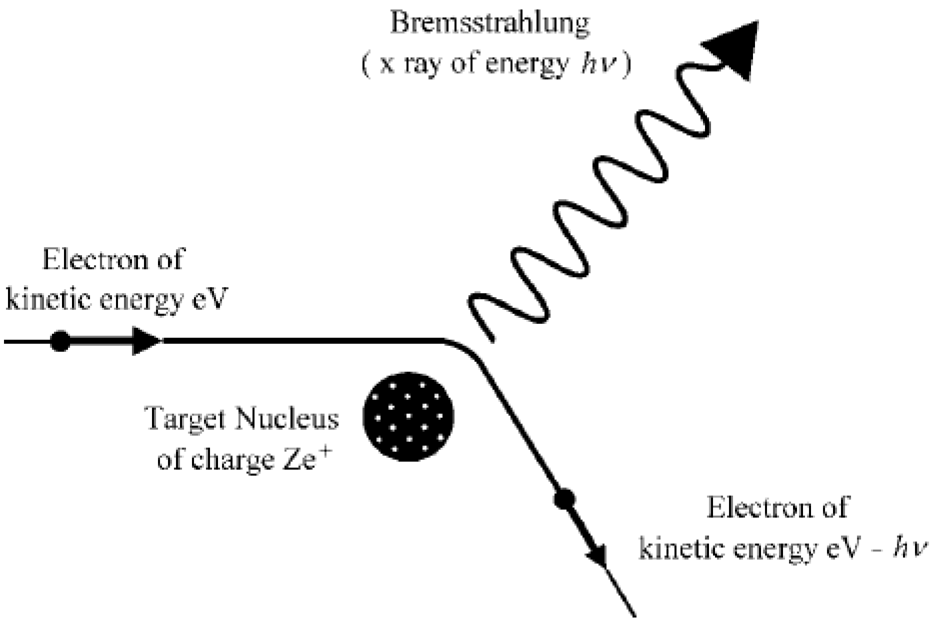


Figure (2.3) show the Production of x-rays in which accelerated electrons emit bremsstrahlung. (James E. Martin,2006).

2.4.2. Characteristic X-rays:

Figure (2.4) shows discrete lines superimposed on the continuous x-ray spectrum for molybdenum target because the 35 keV electrons can overcome the 20 KeV binding energy of inner shell electrons in the molybdenum target. However, this does not occur for the tungsten target spectrum because the inner shell electrons of tungsten are tightly bound at 69.5 keV. The vacancy created by a dislodged orbital electron can be filled by an outer shell (or free) electron changing its energy state, or, as Bohr described it, jumping to a lower potential energy state with the emission of electromagnetic radiation; the emitted energy is just the difference between the binding energy of the shell being filled and that of the shell from whence it came. And since the electrons in each element have unique energy states, these emissions of electromagnetic radiation are “characteristic” of the element, hence the term “characteristic x-rays”. They uniquely identify each element. (James E. Martin,2006).

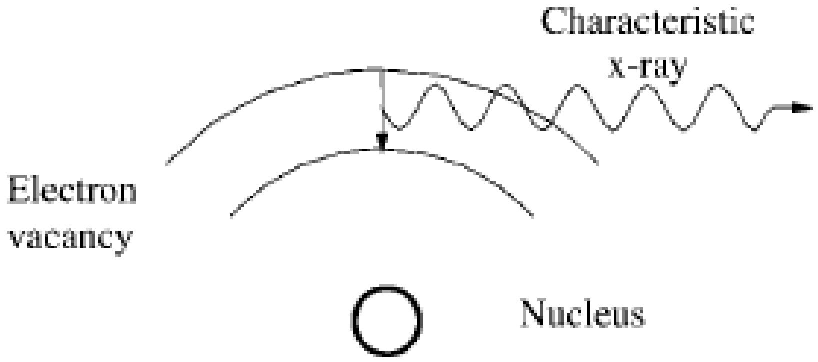


Figure (2.4) show the Emission of a characteristic x-ray due to a higher energy electron giving up energy to fill a particular shell vacancy.

2.4.3. The X-Ray Tube:

Figure (2.5) is a schematic representation of a conventional x-ray tube. The tube consists of a glass envelope that has been evacuated to high vacuum. At one end is a cathode (negative electrode) and at the other an anode (positive electrode), both hermetically sealed in the tube. The cathode is a tungsten filament that when heated emits electrons, a phenomenon known as thermionic emission. The anode consists of a thick copper rod at the end of which is placed a small piece of tungsten target. When a high voltage is applied between the anode and the cathode, the electrons emitted from the filament are accelerated toward the anode and achieve high velocities before striking the target. The x-rays are produced by the sudden deflection or acceleration of the electron caused by the attractive force of the tungsten nucleus. The x-ray beam emerges through a thin glass window in the tube envelope. In some tubes, thin beryllium windows are used to reduce inherent filtration of the x-ray beam. (James E. Martin,2006).

2.4.3.1. The Anode:

The choice of tungsten as the target material in conventional x-ray tubes is based on the criteria that the target must have high atomic number and high melting point. The efficiency of x-ray production depends on the atomic number, and for that reason, tungsten with $Z = 74$ is a good target material. In addition, tungsten, which has a melting point of 3,370°C, is the element of choice for withstanding intense heat produced in the target by the electronic bombardment. Efficient removal of heat from the target is an important requirement for the anode design. This has been achieved in some tubes by conduction of heat through a thick copper anode to the outside of the tube where it is cooled by oil, water, or air. Rotating anodes have also been used in diagnostic x-rays to reduce the temperature of the target at any one spot. The heat generated in the rotating anode is radiated to the oil reservoir surrounding the tube. It should be mentioned that the function of the oil bath surrounding an x-ray tube is to insulate the tube housing from high voltage applied to the tube as well as absorb heat from the anode. (James E. Martin,2006).

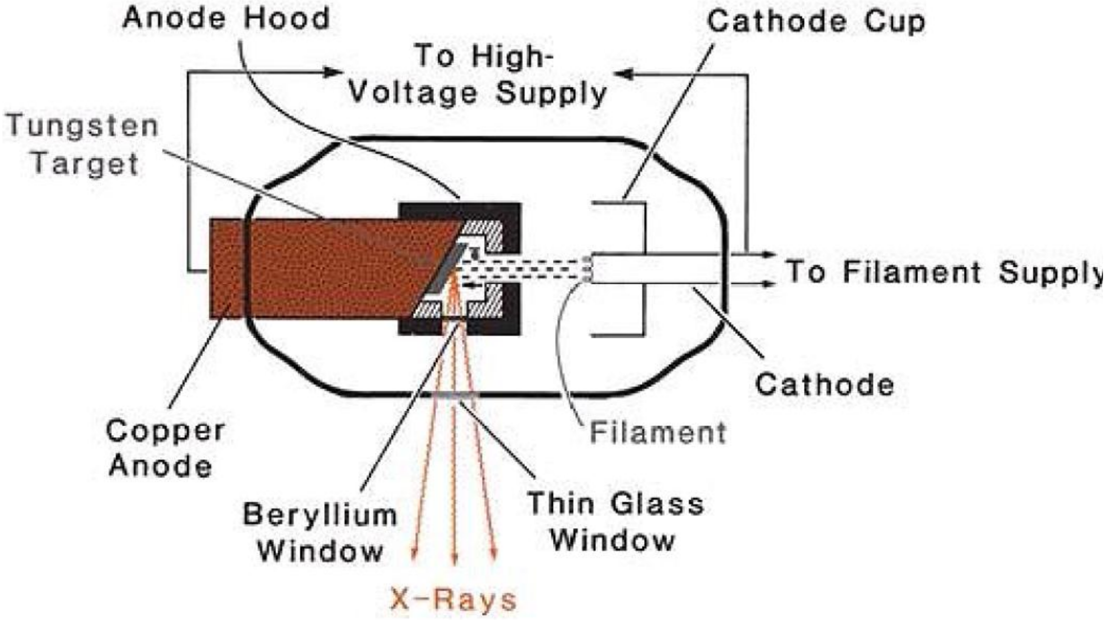


Figure (2.5) show the schematic representation of a conventional x-ray tube.

2.4.3.2. The Cathode:

The cathode assembly in a modern x-ray tube (Coolidge tube) consists of a wire filament, a circuit to provide filament current, and a negatively charged focusing cup. The function of the cathode cup is to direct the electrons toward the anode so that they strike the target in a well-defined area, the focal spot.

Since the size of the focal spot depends on filament size, the diagnostic tubes usually have two separate filaments to provide “dual focus,” namely one small and one large focal spot. The material of the filament is tungsten, which is chosen because of its high melting point. (James E. Martin,2006).

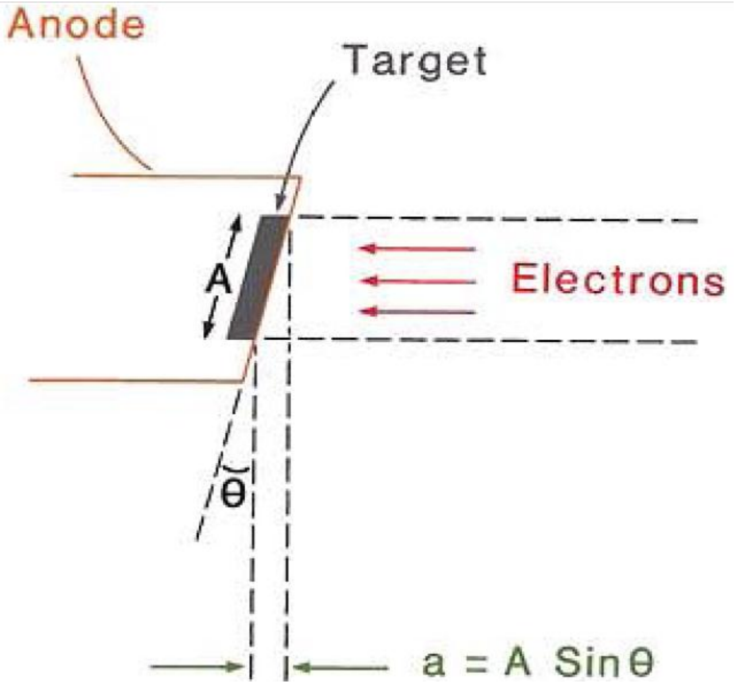


Figure (2.6) show the illustrating the principle of line focus. (James E. Martin, 2006).

2.5. The Interaction of Radiation with Matter:

Radiation is scattered and absorbed when it passes through tissue. The intensities of mono energetic X-rays or gamma rays attenuate exponentially within tissues. In other words, the intensity of radiation constantly decreases as it propagates within tissues. This decrease depends on the type of tissue and its thickness. If the wave length stays constant, the intensity of the radiation passing through a tissue can be calculated by the following formula:

$$I = I_0 . e^{-\mu t}$$

I = intensity of outgoing radiation beam

I_0 = intensity of incoming radiation beam

μ = absorption coefficient (which is positively correlated with the fourth power of the atomic number of the penetrated tissue, and the third power of the wavelength of the radiation)

t = tissue thickness

As seen in the above formula, the intensity of the radiation decreases exponentially with the absorbent thickness, and the intensity of the outgoing radiation depends on the tissue absorption coefficient and its thickness. The five types of interaction of radiation with matter shown below:

2.5.1. Photoelectric Effect:

This phenomenon, which was theorized by Albert Einstein in 1905, was actually first observed by Heinrich Rudolf Hertz in 1887, and was therefore also known as the Hertz effect. To define it simply, when any electromagnetic radiation reaches a surface (generally a metallic surface), it transfers its energy to the electrons of that surface, which are then scattered. At the atomic level, the incoming radiation knocks an electron from an inner atomic orbital, propelling it from the atom as shown in the figure (2.7). (James E. Martin,2006).

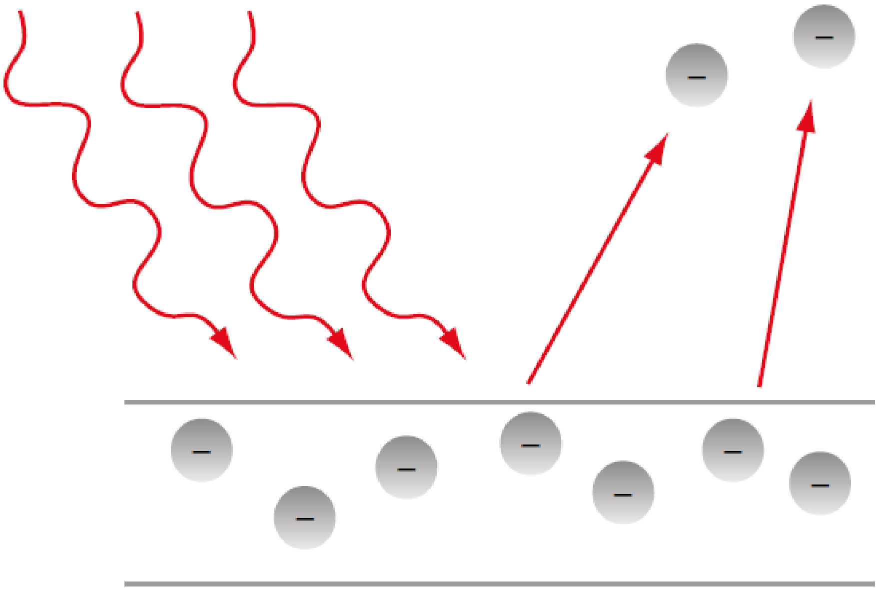
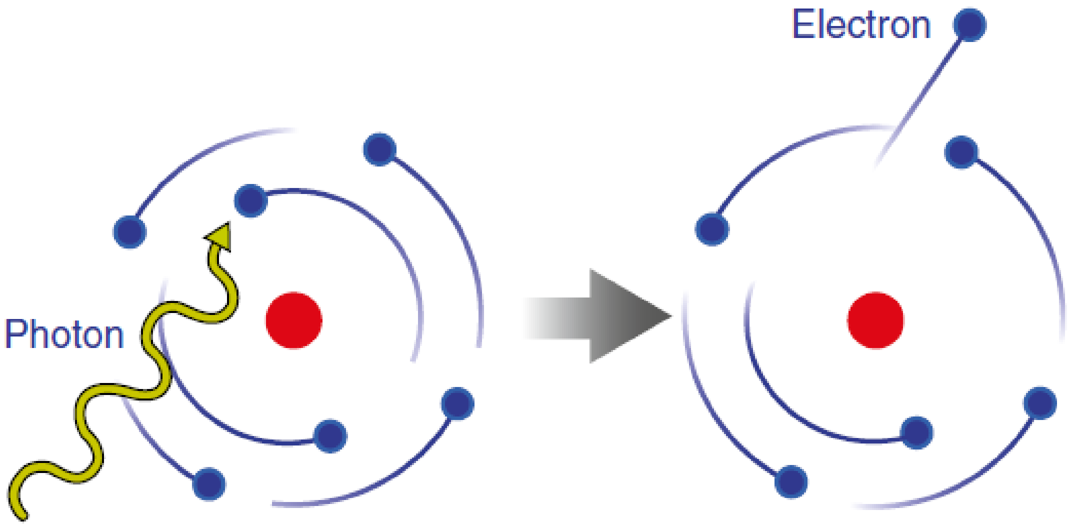


Figure (2.7) show the Photoelectric effect. (Murat, 2010).

This is the basic interaction in diagnostic radiology.

It is dominant at energies of less than 35 kV, and in atoms with high atomic numbers (*Z*). Since the atomic number of bone is higher than that of soft tissue, bone absorbs more radiation than soft tissue. This absorption difference is the basis of diagnostic radiology. This effect also explains why metals with high atomic numbers (e.g., lead) are used to absorb low-energy X-rays and gamma rays.



The Figure (2.8) shows the illustration of photoelectric effect. (Murat, 2010).

2.5.2. Compton Effect:

In the Compton Effect, a photon collides with an electron in an outer orbital, and the photon and electron are scattered in different directions (where θ is the angle between the directions) the energy of the incoming photon is transferred to the electron in the form of kinetic energy. The scattered electron also interacts with the outer orbital electrons of other atoms. (Murat, 2010).

After the interaction, the photon has a lower energy than it did beforehand.

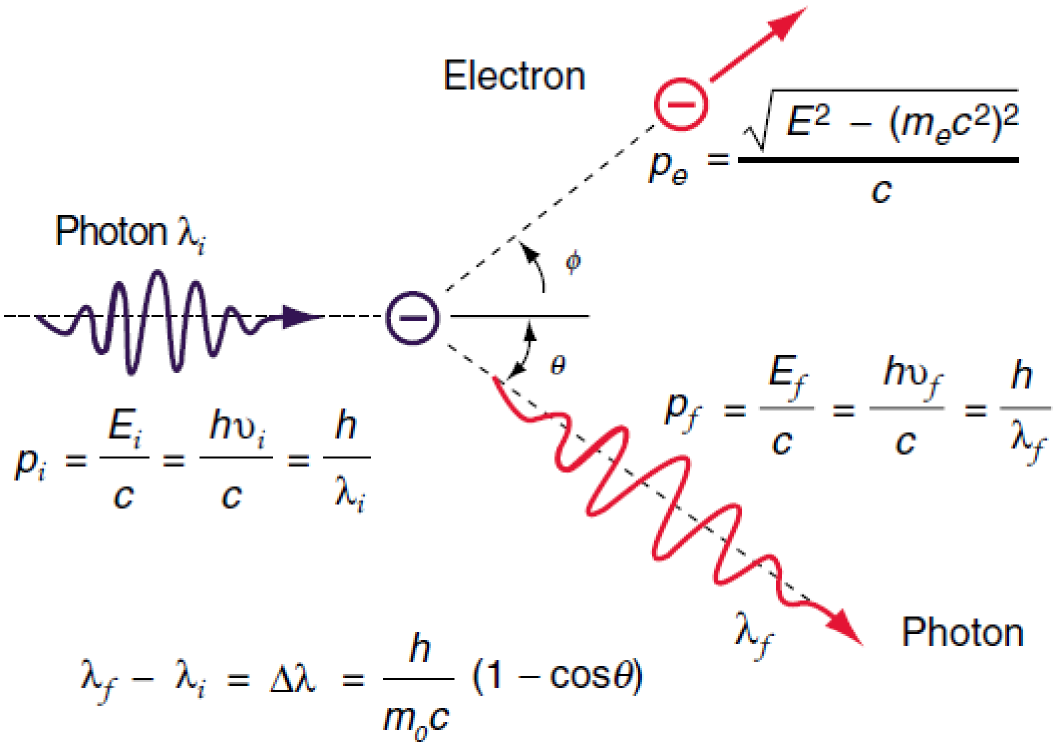
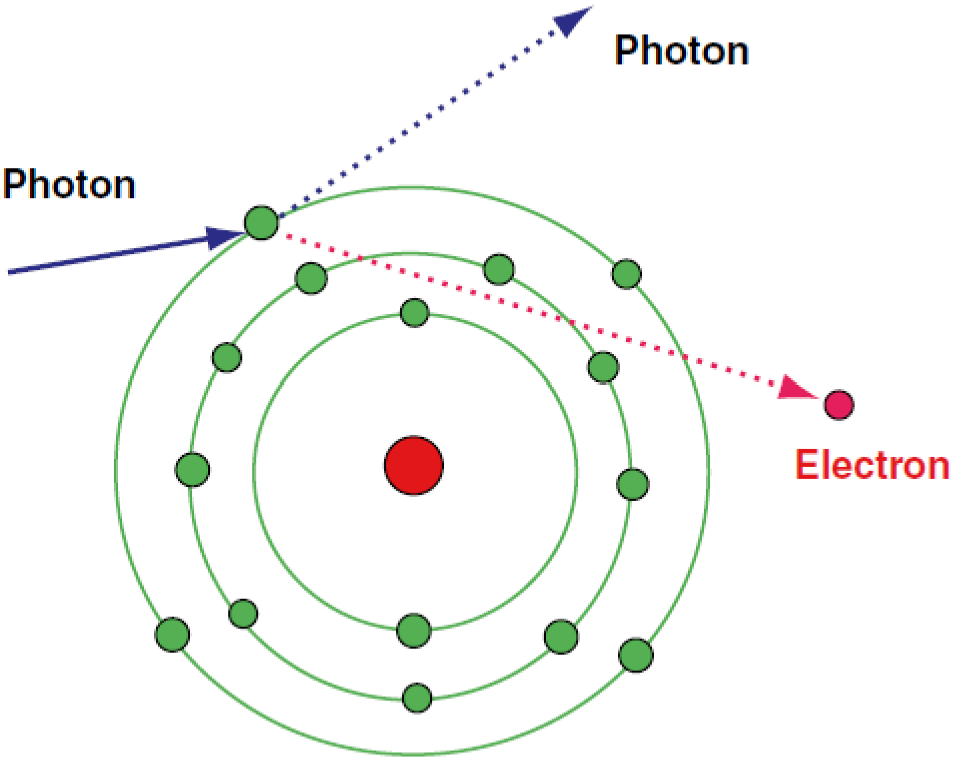


Figure (2.9) show the Math associated with the Compton Effect. (Murat, 2010).

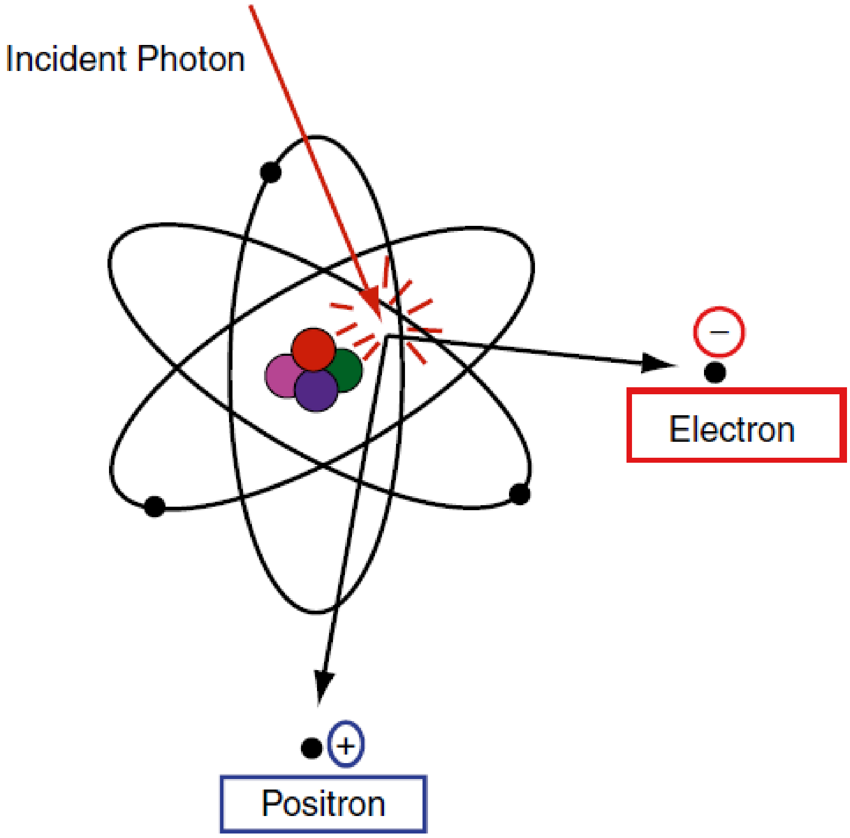
This is the main mechanism for the absorption of ionizing radiation in radiotherapy. It is the dominant effect across a wide spectrum of energies, such as 35 kV–50 MV. It has no dependency on the atomic number (*Z*) of the absorbent material, but it does depend on the electron density of the material. The absorption of incoming radiation is the same for bone and soft tissues.



The Figure (2.10) shows the illustration of Compton Effect. (Murat, 2010).

2.5.3. Pair Production:

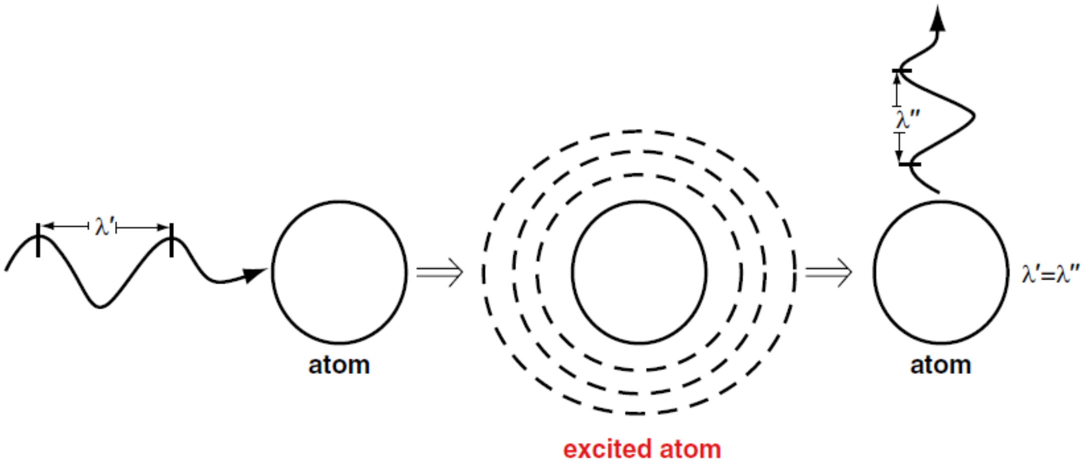
This is a relatively rare effect. In it, a photon transforms into an electron and a positron near a nucleus (Figure 2.11). The electron sheds all of its energy by the absorption processes explained above. On the other hand, the positron propagates through the medium ionizing atoms until its energy has dropped to such a low level that it pulls a free electron close enough to combine with it, in a process called annihilation. This annihilation causes the appearance of a pair of photon moving in opposite directions, and each with 0.511 MeV of energy. These annihilation photons are absorbed through either photoelectric or Compton events.



The Figure (2.11) shows the illustration of Pair production. (Murat, 2010).

2.5.4. Coherent Effect (Rayleigh scattering):

Here, an electron is scattered when an electromagnetic wave or photon passes close to it. This type of scattering is explained by the waveform of the electromagnetic radiation. There are two types of coherent scattering: Thomson scattering and Rayleigh scattering. The wave/photon only interacts with one electron in Thomson scattering, while it interacts with all of the electrons of the atom in Rayleigh scattering. In Rayleigh scattering, low-energy radiation interacts with an electron, causing it to vibrate at its own frequency. Since the vibrating electron accelerates, the atom emits radiation and returns to its steady state. Thus, there is no overall transfer of energy to the atom in this event, so ionization does not occur. The probability of coherent scattering is high in heavy (i.e., high-Z) matter and for low-energy photons. (Murat, 2010).



The Figure (2.12) shows the illustration of Rayleigh scattering. (Murat, 2010).

2.6. Kilovoltage Effective on exposure:

kVp has the greatest effect on the radiographic image when all other factors remain constant. Because kVp is the factor that gives the rays their penetrating quality, it directly influences the quality of radiation reaching the film. This, in turn, determines the radiographic contrast and density. Kilovolt age is a major agent in the production of SR that must be controlled to prevent fogging on the film. Use of low kVp may result in images deficient in details; injudicious use of high kVp may result in fogged or high-density images in which details are obscured by excessive silver deposits and a degradation of contrast.

kVp also has a limited effect on quantity of radiation. Because changing kVp varies the speed of the electrons, and therefore, the wavelength of radiation, an increase of kVp gives a corresponding increase in the number of diagnostic photons. Even though the major attribute of kVp is the variation in penetrating power kVp does affect, to a smaller degree, the quantity.

2.6.1. Kilovoltege and exposure latitude:

Exposure latitude varies with the kVp applied and is the range between minimum and maximum kVp that will produce a diagnostically acceptable scale of translucent densities. Exposure latitude is an important element in any standardized exposure system. Since "correct exposure" may be anyone within a fairly wide range if the kVp is adequate for thorough penetration, use of an optimum kVp is more likely to produce greater uniformity of radiographic results than would the use of relatively low variable kVp. A general rule is the longer the scale of radiographic contrast, the greater is the exposure latitude.

2.6.2. Influence of Kilo voltage:

The characteristics of primary radiation can be changed by kVp, with control of SR fog and favorable image quality. With the increase of kVp, the quantity of fog produced reaches a point where it exceeds many times the density produced by remnant radiation. This means that the desired image may be almost completely hidden because of the fog. The more the image is veiled by fog, the less detail is affected by factors that would normally alter it.

2.6.3. Over exposure:

When greater than necessary kVp is used, the overall density appears high with SR fog. The contrast scale is degraded and detail is obscured. Usually, a reduction of 10 to 20 kVp will correct the appearance. It may be necessary to adjust the mAs factor slightly .To avoid overexposure due to kVp.

2.6.4. Under exposure:

Use of inadequate kVp is characterized by blank, transparent areas without silver deposit and other areas having high densities--few intermediate tones of density are present. An increase of 15 to 20 kVp will usually produce sufficient penetrating radiation to obtain the necessary detail, provided the mAs is also adjusted.

2.6.5. Relation of kVp-mAs-SID-Density:

Radiographic density is not only influenced by kVp but it also varies with the mAs and SID used. In medical radiography, there is no simple mathematical method for determining kVp-mAs density ratios. Such factors as the thickness and density of the body tissues to be examined, the characteristics of the x-ray apparatus, and if the film is used with or without intensifying screens exert pertinent influences. Fairly close approximations between kVp and other exposure factors have been of necessity established by experience--by trial and error. There are two procedures that may be followed: one is used in determining the approximate change in mAs required to compensate for a change in kVp, the other in determining the change in kVp required for a given mAs change. Changing the kVp or mAs and keeping the density constant requires complex mathematical manipulations.

2.7 Parameters of x-ray:

In radiography, dose and image quality are dependent on radiographic parameters, dose optimization for the Quality Control Tests of X-Ray Equipment effect on patient dose and image quality.

2.7.1. Absorbed dose

Absorbed dose is the quantity that expresses the radiation concentration delivered to a point, such as the entrance surface of patient’s body. Absorbed dose in air is recognized as air kerma and it is a measure of the amount of radiation energy, in the unit of joules (J), actually deposited in or absorbed in a unit mass (kg) of air. Therefore, the quantity, kerma,
is expressed in the units of J/kg which is also the radiation unit, the gray (G) (Sprawls, 1987;Hendee et al., 1984).

2.7.2. kVp:

The high energy of the x-ray spectrum is determined by the kilovoltage applied to the x-ray tube. The maximum photon energy is numerically equal to the maximum applied potential in kilovolts. The maximum photon energy is determined by the voltage during the exposure time. This value is generally referred as the kilovolt peak (kVp) and is one of the adjustable factors of x-ray equipment (Sprawls, 1987).

2.7.3. mAs:

The x-ray cathode is heated electrically by a current from a separate low voltage power supply. The output of this supply is controlled by the mA selector on the x-ray unit. Additionally, the duration of the x-ray exposure is controlled by the time selector. mAs is described by multiplying of these two values (mA x second) (Hendee et al., 1984).

2.7.4. Half Value Layer (HVL)

Half value layer describes both the penetrating ability of specific radiations and the penetration through specific objects. HVL is the thickness of material that reduces the Sprawls intensity of an x-ray beam by half, and is expressed in unit of distance (mm) (, 1987).

2.8. Measurement of X-ray tube Output and exposure time product

X-ray tube output is the amount of exposure, in millirontgens (mR) delivered to a point in the center of the useful X-ray beam at a distance of 1 meter from the focal spot for 1 mAs of electron passing through the tube. The output expresses the ability of the tube to convert electronic energy into X-ray exposure. X-ray tube output is the single most important parameter to quantify radiation yield (Zoetelief et al, 2006). The free-in-air exposure, FAE (mR) was measured using factory calibrated KV meter (US made Victorian X-ray test device, model 4000 M+) obtained from the Department of Physics (DOP) University of Ibadan. The consistency of X-ray tube output with the tube current (mA) or tube current exposure-time product (mAs) was measured for the range of mA or mAs values used in practice. The detector (KV meter) measures the mean, effective and maximum peak tube voltage, power phase, exposure and exposure time. This system determines the tube voltage with accuracy of ± 2% (Victoreen, 1995). The internal ionization chamber that measures exposure has volume of 36 cm3. The exposure time is measured to an accuracy of ± 2%. The FAE (mR) measured is converted into output in mGy (mAs)-1 by multiplying by a factor 0.00877/ mAs (Chang Jong and Hui-Yu, 1999) where mAs in the denominator is the product of the tube current and exposure time set at the time of measurement of the output.

2.9. Quality Assurance (QA)

A quality assurance program in diagnostic radiology, as defined by the WHO, is an organized effort by the staff to assure that the diagnostic images are of sufficiently high quality to provide adequate diagnostic information at the lowest possible cost and with the least possible patient radiation exposure.

QA programs are designed to ensure that the radiology equipment can yield the desired information. (Geneva, 1982)

2.10. Quality control (QC)

It is part of the QA Program that deals with techniques used to test the components of the radiological system and verify that the equipment is operating satisfactorily.

QC therefore is part of the QA Program that deals with instrumentation and Equipment Radiology imaging equipment should produce images that meet the needs of the radiologist or other interpreters without involving unnecessary radiation dose to the patient.

Quality control contributes to the production of diagnostic images of a consistent quality by reducing the variations in performance of the imaging equipment Quality control programs directed at equipment and operator performance can be of great value in improving the diagnostic information content, reducing radiation dose, reducing medical costs, and improving departmental management. Quality control programs contribute to the provision of high quality health care (Geneva, 1982)

2.11. Previous studies:

AL-Jasim Ali Kareem 2017, In his study the seven tests (beam alignment, beam collimation, reproducibility, accuracy of kVp, time accuracy, half value layer (HVL) and leakage) were carried out for the newly installed General X-Ray machine at Nuclear Malaysia and were in the acceptable limits. Such a test will be the responsibility of a qualified physicist or engineer. The status test is carried out in order to establish the functional status of the equipment. The test is performed immediately after the acceptance test or as an integrated part of it. The test will be repeated when repair influencing the functional status has taken place like the acceptance test; the status test will comprise absolute measurements and will likewise be the responsibility of a qualified physicist or engineer.

Quality control tests were performed due to replacement of new x-ray machine at Nuclear Malaysia to evaluate the performance of the equipment. kV accuracy test, kV Reproducibility, time accuracy, X-Ray Beam Collimation, HVL/Filtration, and Leakage Radiation all these tests were done and complied with the requirements of the standards and manufacture's specifications. Even though the tolerances limit for time accuracy is ± 20 % for 10 ms $\leq t \leq$ 100 ms, the measured value is higher than the tolerance, ± 27.3 % for 10 ms $\leq t \leq$ 100 ms. But this value can be accepted, because that is not use in the clinical procedures for imaging

Calvin Didier NJIKI2018,in his work, ten standard QC tests, including voltage accuracy and reproducibility, exposure time accuracy and reproducibility, tube output linearity (time and milliampere), filtration (half-value layer or HVL), tube output (70 kV at FSD=100 cm), tube output reproducibility and beam alignment were performed to assess the devices performances. QC tests were performed, based on the protocol proposed in Report No.77 by the Institute of Physics and Engineering in Medicine (IPEM). The higher poor results were obtained for certain tests like the tube output at 70 kV (43.48 % of the units), the tube output linearity of the current (23.3%) and the voltage accuracy (21.73 % of the units. Moreover 43.48% of the units passed all the tests performed. Based on the poor result of the tube output at 70kV an investigation was made that enable to conclude that though 43.48% of the X-ray machines showed a poor result for the tube output test only 21.74 % of all the X-ray machines effectively needed a replacement of the X-ray tube.

Mehrdad Gholami12015, his cross-sectional study was performed on seven stationary X-ray units in six hospitals of Lorestan province. The measurements were performed, using a factory-calibrated Barracuda dosimeter (model: SE43137) According to the results, the highest output was obtained in A Hospital (M1 device), ranging from 107×10-3 to 147×10-3 mGy/mAs. The evaluation of tube voltage accuracy showed a deviation from the standard value, which ranged between 0.81% (M1 device) and 17.94%

(M2 device) at A Hospital. The deviation ranges at other hospitals were as follows: 0.30-27.52% in B Hospital (the highest in this study), 8.11-20.34% in C Hospital, 1.68-2.58% in D Hospital, 0.90-2.42% in E Hospital and 0.10-1.63% in F Hospital. The evaluation of exposure time accuracy showed that E, C, D and A (M2 device) hospitals complied with the requirements (allowing a deviation of ±5%), whereas A (M1 device), F and B hospitals exceeded the permitted limit.

N.B. Akaagerger2016, The quality control assessment of the diagnostic X-ray machines were carried out using Radiographic/Fluoroscopic kit, model Gammex 184D, in the Radiological Departments of some major Hospitals in Benue State. Three X-ray machines in the Radiological departments were monitored and the Hospitals were abbreviated as H-1, H-2 and H-3. Three quality control Test Tools were employed in this research work, and they include; mAs Linearity Test, Collimator and Beam Alignment Test, and kVp Reproducibility Variance Test. The mAs linearity test for H-1 was found to be within the acceptable tolerance limit of 0.1 (10%) as recommended by American Association of Physicist in Medicine (AAPM) while H-2 and H-3 were above the tolerance limit; the Collimator and Beam Alignment Test show that H-1, H-2 and H-3 were within the tolerance as defined by National Center for Devices and Radiological Health (NCDHR) to be 1.50 from the perpendicular. Finally, the kVp Reproducibility Test and coefficient of variance were found to be 0.1% at H-1, 0% at H-2 and 0.3% at H-3 which are within ±5% as recommended by Conference of Radiation Control Program Directors (CRCPD). This quality control parameters were to ensure that exposure to radiation from X-ray machines is justified and optimized in keeping with ALARA principle and to also ensure that high quality image are produced.

Taha.M.T2013, his study was carried out to obtain optimum operation conditions for X-ray machines. We investigated some factors affecting on quality assurance of conventional Siemen X-ray machine, in one of Mansoura Hospitals such as reproducibility of dose output, time and applied high voltage, Kilo-voltage accuracy, mA accuracy, time accuracy, and linearity. We measured these factors using Non-Invasive kilo voltage meter, The NERO Max 8000 connected with suitable ionization chambers that located at 100 cm source to image detector. Reproducibility of dose output was ranged from 0.1 to 0.7 %, of time was ranged from 0.2 to 3.1 and of high voltage was ranged from 0.1% to 0.7% which is lower than the tolerance limit of the American Association of Physicist in Medicine reference values. Kilo-voltage accuracy percentage was ranged from 1.5 to 3.5 % and time accuracy percentage was ranged from 0.5 to 4.1 % respectively. This study concluded that as the kilo-voltage increases by one, the dose increases by 28%.

T.M.Taha, 2010, the study aimed to investigate some factors affecting on quality assurance of conventional x-ray such as reproducibility of tube voltage, dose output, time, and x-ray tube efficiency, Accuracy of kVp, mA, time, and focal spot size. And half value layer. Examinations of these factors are studied using noninvasive kV meter Nero Max 8000 which connected with suitable ionization chambers. KV accuracy is good at all KVp stations for six machine except one of the examined machines gave accuracy of 20 % which is higher than the tolerance limit.(± 5%). That mean this machine needs calibration. It recalibrated and adjusted to 5% KV accuracy. Time accuracy is good at all-time settings stations for all examined machine which is lower than the tolerance limit. (± 10%). HVL is exceed the minimum value, passed above 2.3 mm Al at 70 KeV. This is within the accepted value of IAEA.

WilsonM.Ngoye 2015, his study was a large number of respondents were not implementing the following QC tests: tube output, kV, mAs and timer (94%), collimation (53.5%), and densitometry and sensitometry (87.7%). The tests for film viewing box and lead rubber protective apparel were not implemented by 64.2% and 59% of the respondents, respectively. The cassette inspection and darkroom inspection were re- ported as being implemented by most respondents, although the testing was not observing the recommended schedule. Furthermore, the departments had no records and procedures for the QC programmer and only the locally improvised QC test tools were reported to be available.

M. Begum2011, in his study important performance tests in diagnostic radiology in Bangladesh are carried out according to a quality control protocol and the measured parameter values are compared to the relevant acceptance limits. In this work, beam alignment, field congruence, nominal focal spot, film-screen contact and half value layer for diagnostic x-ray facilities are measured by using beam alignment test tool, RMI/Victoreen collimator test tool, Bar pattern focal spot test tool, film/screen contact test tool (RMI143D), Gammex RMI step wedge and densitometer from forty different diagnostic x-ray facilities in Bangladesh. For congruence between optical and radiation fields, 77.5% are found to be within limit and 60% of facilities are within the beam alignment limit. For most of the installations, 92.5% nominal focal spot size of diagnostic x-ray machines is matched perfectly with the rating of focal spot size. In an effort to improve image quality, this study has checked the film-screen contacts of multiple facilities and found 65% to have the expected uniformity. While investigating half value layers (HVL), a measure of x-ray beam quality, it is found that none of the diagnostic x-ray installations can achieve the recommended levels.

Chapter Three

Materials and methods

Materials and methods

3.1. Instruments and tools

3.1.1 X- ray machine.

Figure (3.1) show the x-ray instrument

Table (3.1) Show the x-ray Instruments specification

Instrument	SERIAL NUMBER	FOCAL SPOT SIZE(mm)	INHERENT FILTERATI-ON(mm)	ADDED FILTER-ATION (mm)	TOTAL FILTERATIO-N(mm)	MAXIMUM KVp (kv)	MXIMUM TIME(sec)
1	532-24315	1.2	1.5	1	2.5	125	200
2	563-55051-30	1.2	1.5	1	2.5	-	160
3	1J036	-	1.5	1	2.5	-	400
4	532-104556	-	-	1	-	150	200
5	2XY0000060	-	1.5	1	2.5	150	200
6	503-54010	1.2-0.6	-	-	2.5	125	80
7	-	-	1.5	-	-	100	400
8	CM6F3B016005	0.6-1.2	1.5	1	2.5	150	220
9	44150hl1	0.6-1.2	0.7	1.5	2.2	-	225
10	5A037F	1.0-2.0	0.7	1.2	-	150	200

3.1.2 KV meter (RMI240A Multi-Function Meter).

he kVp meter and exposure timer measures the peak x-ray accelerating voltage from tungsten x-ray generators.

3.1.4 RAD CHECK PLUS (06-526).

Entrance skin exposure measurements (ESE)Fluoroscopy exposure measurements Exposure checks; radiographic (mR/mAs)Beam quality; half value layer (HVL)mAs reciprocity; mA station checks...plus many others

Figure (3.4)

3.2. Methods of test and measurement:

3.2.1. Voltage accuracy:

At FDD=75cm and different values of mAs, kVp was measured from 50 to 90 in 10kV increment. For every kV was made one exposure and then calculated the relative difference between the nominal and the measured values using the following equation.

$$\text{Voltage accuracy}= \frac{kV(measured) - kV(nominal)}{kV(nominal)}$$

3.2.2Voltage reproducibility:

At FDD=75cm, a mAs equal to (10 and 20) and a selected kVp equal to 70 , were made three exposures of kVp and then the Coefficient of Variation (CV) of the measured values and voltage reproducibility was calculated.

$$CV = \frac{SD}{\bar{X}} \qquad SD = \sqrt{\frac{\sum(X_{i-\bar{x}})^2}{n-1}}$$

3.2.3Time Accuracy:

At FDD=75cm and different values of mAs. For every mAs we made one exposures and then calculated the relative difference between the nominal and the measured values using the following equation.

$$\text{Time Accuracy}= \frac{t(measured) - t(nominal)}{t(nominal)}$$

3.2.4Time reproducibility:

At FDD =75 cm, a mAs equal to [70-20], were made three exposures of Time and then we calculated the Coefficient of Variation (CV) of the measured values using the following equation. .

$$CV = \frac{SD}{\bar{X}} \qquad SD = \sqrt{\frac{\sum(X_{i-\bar{x}})^2}{n-1}}$$

3.2.5 Output Factor accuracy:

At FDD=75cm, and KV=70, were measure two measured value at mAs=10 and mAs=20 using the following equation.

$$output = \frac{mA}{Dose} \quad mAsec/mGy$$

$$\text{Op Accuracy}= \frac{Op(measured) - Op(nominal)}{Op(nominal)}$$

3.2.6 Output Factor reproducibility:

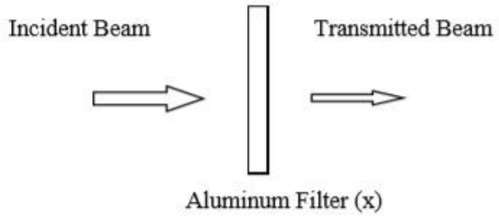
At FDD=75cm, and different values of mAs And selected KVp 70 were made measured the dose (D_1) and (D_2) and then we calculate the coefficient of variation using the following equation.

$$CV = \frac{SD}{\bar{X}} \qquad SD = \sqrt{\frac{\sum(X_{i-\bar{x}})^2}{n-1}}$$

3.2.7Filtration (HVL):

At clinical tube voltages, the HVL was directly measured with our MPD.

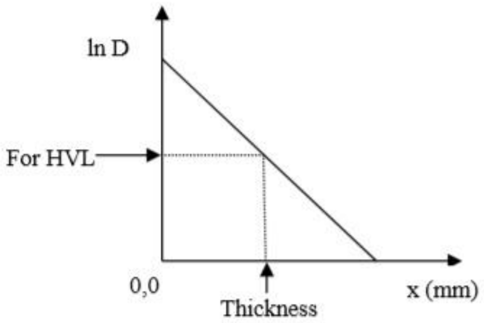
Filtration (HVL at 70kV) = Thickness of aluminium filter reducing X-ray intensity to half



Set up for HVL.

$I = I_0 e^{-\mu x}$

where: I - Intensity of the transmitted beam.
I_0 - Intensity of the incident beam.
μ - Attenuation Coefficient.



3.3. Methods of data evaluation

Parameters	Good	Normal	Poor
Voltage accuracy	≤5%	5-10%	>10%
Voltage reproducibility	≤5%	5-10%	>10%
Time accuracy	≤5%	5-10%	>10%
Time reproducibility	≤5%	5-10%	>10%
Tube output Accuracy At kvp = 70 SSD = 100 cm	43-52 µGy/mAs	26-43 , 52-69 Gy/mAs	< 26 µGy/mAs > 69 µGy/mAs
Tube output reproducibility	≤5%	5-10%	>10%

(Calvin Didier NJIK2018)

3.4. Methods of data analysis:-

The data will analysis using Excel programme.

Chapter Four

The Results

The Results

This study involved evaluating the quality control parameters of 10 x-ray equipment; the table shows the KV, Time, output factor and HVL measurements of x-ray machines.

Table (4.1) The tube Kilovoltage measurements of the instruments.

			Error				Accuracy			
City	KVP Range	KVp Measured Range	Mean	Max	Min	SD	Mean	Max	Min	SD
Khartoum	50-110	46.6-106	4.49	4.0	-3.4	17.28	0.03	0.452	-0.155	0.142
El-Obeid	50-90	50.8-90.3	0.8	0.9	0.3	0.230	0.010	0.016	0.003	0.004
El-Fao	60-90	59.7-89.8	0.22	0.1	0.3	0.100	0.003	0.001	0.005	0.002
River Nail	50-90	49-91.6	0.14	1.6	-1	1.117	0.001	0.017	0.020	0.016

Table (4.2).The tube time Accuracy measurements of the instruments.

			Error				Accuracy			
City	Time Range	Time Measured Range	Mean	Max	Min	SD	Mean	Max	Min	SD
Khartoum	5.6-400	5.8-492	2.071	92	-55.9	20.982	0.004	0.221	0.388	0.095
El-Obeid	0.8-2.25	0.8-0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
El-Fao	0.08-0.2	0.075-0.193	0.005	0.002	0.007	0.0021	0.039	0.013	0.067	0.022
River Nail	0.1-0.3	0.0935-0.296	0.005	0.004	0.007	0.0010	0.033	0.014	0.070	0.22

Table (4.3) The tube Reproducibility Kilovoltage, Time and output measurements of the instrument in Khartoum city.

	KVP Range	Time Range	Dose1 Range	Dose2 Range	Output1 Range	Output2 Range
Khartoum	67.88-107.5	234.7-10.3	299-17	549-37	0.588-0.033	0.556-0.036
Mean	77.67471	107.9944	107.6667	215.5556	0.189833	0.179333
STD	14.62185	67.3827	93.38976	169.7684	0.188364	0.17389
STD/Mean	0	0	0	0	0	0

Table (4.4).The tube Reproducibility Kilovoltage, Time and output measurements of the instrument in El-Obeid city.

	KVP Range	Time Range	Dose1 Range	Dose2 Range	Output1 Range	Output2 Range
El-Obeid	71.2-71.1	160.4-160.3	308-305	485-480	0.0033-0.032	0.041-0.042
Mean	71.17	160.33	306.33	483.00	0.03	0.04
STD	0.058	0.058	1.528	2.646	0.000	0.000
STD/Mean	0.000811	0.0003601	0.00499	0.00548	0.00498	0.00549

Table (4.5).The tube Reproducibility Kilovoltage, Time and output measurements of the instrument in El-Fao city.

	KVP Range	Time Range	Dose1 Range	Dose2 Range	Output1 Range	Output2 Range
El-Fao	69.8-69.6	0.99	83	174	0.112	0.115
Mean	69.70	0.10	89.00	174.00	0.11	0.11
STD	0.100	0.000	0.000	0.000	0.000	0.000
STD/Mean	0.001435	0.0	0.00000	0.00000	0.00000	0.00000

Table (4.6).The tube Reproducibility Kilovoltage, Time and output measurements of the instrument in River Nail city.

	KVP Range	Time Range	Dose1 Range	Dose2 Range	Output1 Range	Output2 Range
River Nail	66-67.6	0.0945-0.0948	54-57	95-96	0.175-0.185	0.208-0.211
Mean	66.50	0.09	55.00	95.33	0.18	0.21
STD	0.954	0.000	1.732	0.577	0.006	0.001
STD/Mean	0.014345	0.002332	0.03149	0.00606	0.03093	0.00604

Table (4.7) The Added Filtration and Dose measurements of the instruments.

Added filter(t) (mm)	0	0.5	1	1.5	2	2.5	3	HVL
I_1 (R) Khartoum1	135	113	98	88	76	68	62	2.8mmAL
I_1 (R) Khartoum2	281	242	211	188	176	148	134	2.7mmAL
I_1 (R) Khartoum3	137	113	101	89	80	75	67	2.9mmAL
I_1 (R) Khartoum4	37	32	30	27	24	22	20	3.4mmAL
I_1 (R) Khartoum5	157	133	119	104	91	81	73	3.4mmAL
I_1 (R) Khartoum6	549	472	410	360	316	252	549	2.6mmAL
I_1 (R) Khartoum7	84	76	69	58	53	41	84	2.55mmAl
I_1 (R) El-Obeid	480	415	357	318	281	257	225	2.7mmAL
I_1 (R) Elfao	137	120	107	94	86	77	70	3.0mmAL
I_1 (R) River Nail	174	147	128	-	99	-	79	2.8mmAL

Table (4.8) The mean and standard deviation of error and accuracy for the measured Kvp**.**

			ERROR				Accuracy			
Instruments	Kvp Rang	Kvp Measured Rang	Meam	Max	Min	SD	Meam	Max	Min	SD
Khartoum(1)	50-90	50.8-91.7	1.28	1.7	0.8	0.409	0.018	0.021	0.016	0.002
Khartoum(2)	50-90	51.4-90.3	0.22	1.4	0.7	0.766	0.004	0.027	-0.010	0.014
Khartoum(3)	50-90	68.7-164.1	41.56	74.1	18.7	21.571	0.354	0.458	0.272	0.069
Khartoum(4)	70-98	68.8-91.3	-1.96	0.2	-6.7	2.748	-0.023	0.002	-0.073	0.030
Khartoum(5)	55-90	54.5-88.5	-0.86	-0.5	-1.5	0.378	-0.012	-0.009	-0.017	0.003
Khartoum(6)	50-110	49.35-106	-1.92	-0.65	-4	1.340	-0.024	-0.013	-0.038	0.010
Khartoum(7)	50-88	46.6-76.2	-6.86	-3.4	-11.8	3.103	-0.106	-0.073	-0.155	0.030
El-Obeid(1)	50-90	50.8-90.3	0.66	0.9	0.3	0.230	0.010	0.016	0.003	0.004
El-Fao (1)	60-90	59.7-89.8	-0.22	-0.1	-0.3	0.100	-0.003	-0.001	-0.005	0.002
River Nail(1)	50-90	49-91.6	-1	1.6	-1	1.117	-0.001	0.017	-0.020	0.016

Chapter Five

Discussion, Conclusion and Recommendation

Discussion, Conclusion and Recommendation

5.1 Discussions:

This study aimed to evaluate the quality control parameter of x-ray tube in some hospital in Sudan, kVp accuracy test, kVp Reproducibility, time accuracy, time Reproducibility, output factor and HVL/Filtration tests were done and has been evaluated for all x-ray machines, the main result show that there was small variation between the nominal value.

For Khartoum all KVP measurement points with accuracy ≤5% (good limit), the reproducibility of KVP is 0.0 %, the reproducibility of time exposure is 0.0 %, the reproducibility of output factor is 0.0% and 0.0%, all time exposure measurement points with accuracy ≤5% (good limit) except the measurement point 5.6 with accuracy 9.5% (normal limit), the Half value Layer (HVL) is (2.5-3.4) mm which is in the good limit.

For El-Obeid all KVP measurement points with accuracy ≤5% (good limit), the reproducibility of KVP is 0.0811%, the reproducibility of time exposure is 0.036%, the reproducibility of output factor is 0.49% and 0.549%, all time exposure measurement points with accuracy ≤5% (good limit) except the measurement point 0.8 with accuracy 0% (normal limit),

For El-Fao all KVP measurement points with accuracy ≤5% (good limit), the reproducibility of KVP is 1.435%, the reproducibility of time exposure is 0.0%, the reproducibility of output factor is 0.0% and 0.0%, all time exposure measurement points with accuracy ≤5% (good limit) except the measurement point 0.8with accuracy 2.2% (normal limit), For River Nail all KVP measurement points with accuracy ≤5% (good limit), the reproducibility of KVP is 1.435%, the reproducibility of time exposure is 0.2332 %, the reproducibility of output factor is 3.093% and 0.604%, all time exposure measurement points with accuracy ≤5% (good limit) except the measurement point 0.3 with accuracy 2.2% (normal limit),

5.2 Conclusion:

Most of the conventional X-ray machines controlled showed satisfactory results despite the lack of quality control program for X-ray machines within those medical facilities. For all instrument in Khartoum KVP measurement points with accuracy ≤5% (good limit) and between (5-10%) (normal limit) the reproducibility of KVP and exposure time is ≤5%, the reproducibility of output factor is ≤5%, all time exposure measurement points with accuracy ≤5% (good limit) and between (5-10%) (normal limit) except the instrument. And the calculated HVL is in the acceptable range.

5.3 Recommendation:-

Establishment of QC teams this to include the QC technologist, radiation protection officer, and medical physicist for controlling the quality.

Proper training courses should be established to improve staff skills regarding quality control.

Essential test tools must be available in all departments.

Establishment of staff regular meeting to discuss image quality.

Controlling the exposure factor by introduce anatomical setting and exposure chart.

It is therefore highly recommending to medical facilities that use X-ray machines to put in place a quality control program for the benefit of their patients and workers.

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