# Chapter one

## 1.1. Introduction:

The peak kilovoltage ($KV_p$), also known as the maximum voltage value at any time during exposure is an important parameter of an X-ray machine, which is a direct product of its generator circuit design and other components. Other important parameters of an X-ray machine are tube current (milliampere [mA]) and exposure timer (seconds/milliseconds). The $KV_p$ test provides a measurement of the peak electrical potential across the x-ray tube when it is operating. There are several common X-ray circuit generator designs in use today. They include the single phase, three phase, constant potential and medium/high-frequency inverter generators, they all use step-up transformers to generate high voltage, step down transformer to energize the filament and rectifier circuit to ensure proper electrical polarity at the X-ray tube. [Akintayo et al, 2016]

In diagnostic radiology, the $KV_p$ is one of the most important parameter affecting both radiation exposure and image contrast (the amount of difference between the black/whites on the radiograph).

The X-ray $KV_p$ is most critical; a small error of this variable will have a greater effect on the final radiographic or fluoroscopic image than an equivalent variation in any of the other parameters such as tube current (mA), exposure time, and focus to image distance (FID). It is, however, important to note that selected exposure factors such as the $KV_p$ and milliampere seconds (mAs) can only be accurate if the X-ray machine is Functioning optimally.[ Akintayo et al, 2016]

Final accurate radiograph can be obtained when appropriate $kV_p$ and mAs valued are selected, as well as proper patient positioning is observed, proper use of image intensifying screen, the use of appropriate grid to reduce patient dose where appropriate, the use of appropriate air gap technique and good processing devices (manual processing/automatic processor/ digital processor). [Akintayo et al, 2016]

Radiographers that were recruited admitted that there has been no maintenance check on the energy output of their X-ray machines, and they also reported recurrent breakdown due to power failure with no QC checks after repairs. Others pointed out that X-ray machine age could be a contributory factor to poor image quality.[Akintayo et al, 2016]

The reason why this study focused more on $KV_p$ was to carry out a QC $KV_p$ accuracy test on the energy output of X-ray generator, to encourage end user of the need to carry out $KV_p$ accuracy test each time repair works are done. This study was therefore carried out to determine energy output accuracy of ten X-ray machines by first determining the $KV_p$ accuracy of each X-ray unit and comparing them with established standard and to further establish if machine age has a significant effect on mean $KV_p$ accuracy. [Akintayo et al, 2016]

## 1.2. Problem of the study:

Most X-ray department recruited for this study admitted that there have been no maintenance checks on the energy output accuracy of their X-ray machines. Most centers complained of recurrent machine breakdown due to poor power supply, which could be a contributory factor to poor image quality.

## 1.3. Objectives of this study

### 1.3.1. General objective:

To assess peak kilovoltage accuracy for X-ray department in Khartoum State.

### 1.3.2. Specific objective

- To determine peak kilovoltage ($KV_p$) accuracy of X-ray using KV meter.
- To reduce the risk to the patient.
- To reduce the repeating of image to patient.

## 1.4. Over view of the thesis:

This study consists into five chapters, Chapter one, which is an introduction, deals with theoretical frame work of the study and (Literature review). It presents the statement of the study problems, objectives of the study, chapter two deals with radiological physics and back ground. Chapter three deal with material and method, Chapter four deals with results. Chapter five discussion, conclusion, recommendations and references.

# Chapter two

## Theoretical and literature review

## 2.1. X-rays:

X rays are a kind of super-powerful version of ordinary light: a higher-energy form of electromagnetic radiation that travel at the speed of light in straight lines (just like light waves do). If you could pin X rays down on a piece of paper and measure them, you'd find their wavelength (the distance between one wave crest and the next) was thousands of times shorter than that of ordinary light. That means their frequency (how often they wiggle about) is correspondingly greater. And, because the energy of electromagnetic waves is directly related to their frequency, X rays are much more energetic and penetrating than light waves as well. So here's the most important thing you need to remember: X rays can travel through things that ordinary light waves can't because they're much more energetic. [Chris, 2016]

## 2.2. Production of X-rays:

### 2.2.1. Bremsstrahlung Spectrum:

The conversion of electron kinetic energy into electromagnetic radiation produces x-rays. A simplified diagram of an x-ray tube. A large voltage is applied between two electrodes (the cathode and the anode) in an evacuated envelope. The cathode is negatively charged and is the source of electrons;

the anode is positively charged and is the target of electrons. As electrons from the cathode travel to the anode, they are accelerated by the electrical potential difference between these electrodes and attain kinetic energy. The electric potential difference, also called the voltage, is defined in Appendix A and the SI unit for electric potential difference is the volt. The kinetic energy gained by an electron is proportional to the potential difference between the cathode and the anode. On impact with the target, the kinetic energy of the electrons is converted to other forms of energy. The vast majority of interactions produce unwanted heat by small collision energy exchanges with electrons in the target. This intense heating limits the number of x-ray photons that can be produced in a given time without destroying the target. Occasionally (about 0.5% of the time), an electron comes within the proximity of a positively charged nucleus in the target electrode. Columbic forces attract and decelerate the electron, causing a significant loss of kinetic energy and a change in the electron's trajectory. An x-ray photon with energy equal to the kinetic energy lost by the electron is produced (conservation of energy). This radiation is termed bremsstrahlung, a German word meaning "braking radiation.”The probability of an electron's directly impacting nucleus is extremely low, simply because, at the atomic scale, the atom comprises mainly empty "space" and the nuclear cross-section is very small. Therefore, lower x-ray energies are generated in greater abundance, and the number of higher-energy x-rays decreases approximately linearly with energy up to the maximum energy of the incident electrons. A bremsstrahlung spectrum depicts the distribution of x-ray photons as a function of energy. (Jerrold et al, 2002.)

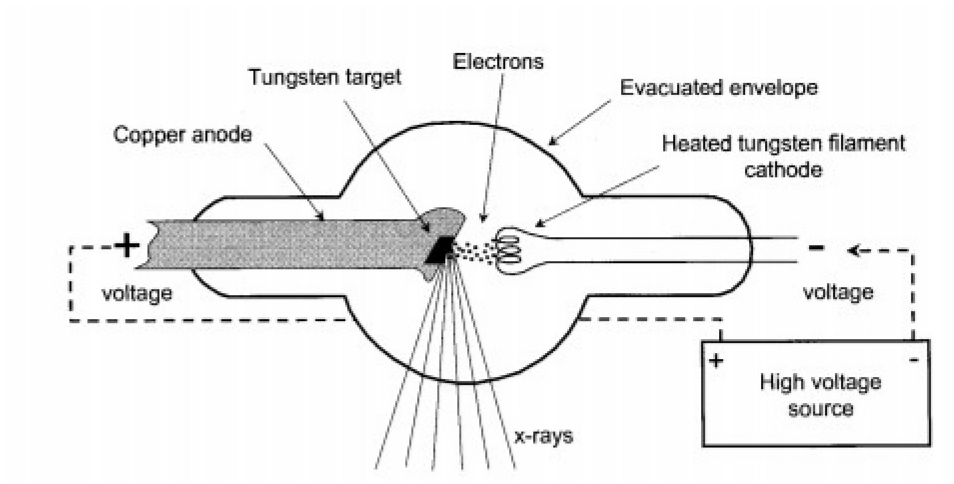


**Figure (2.1) Minimum requirements for x-ray production (Jerrold et al, 2002).**

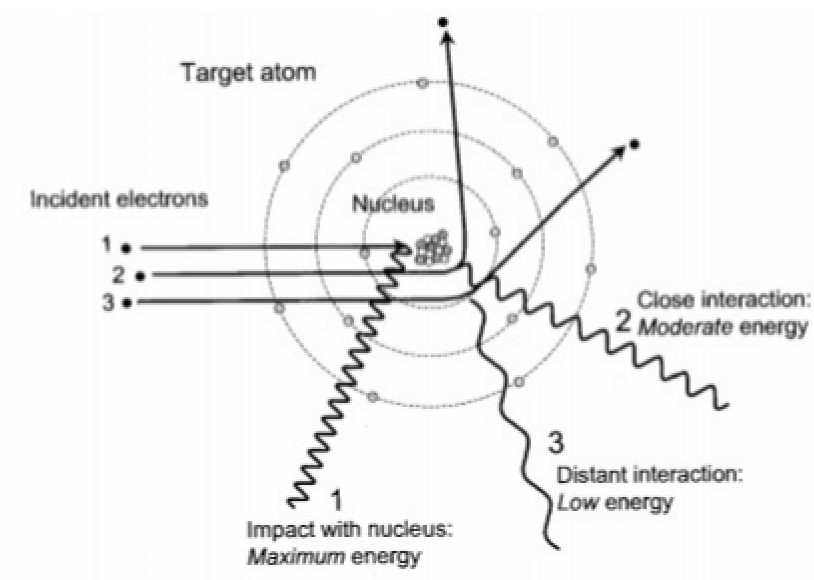


**Figure (2.2): shows Bremsstrahlung radiation arises from energetic electron interactions within atomic nucleus of the target material (Jerrold et al, 2002).**

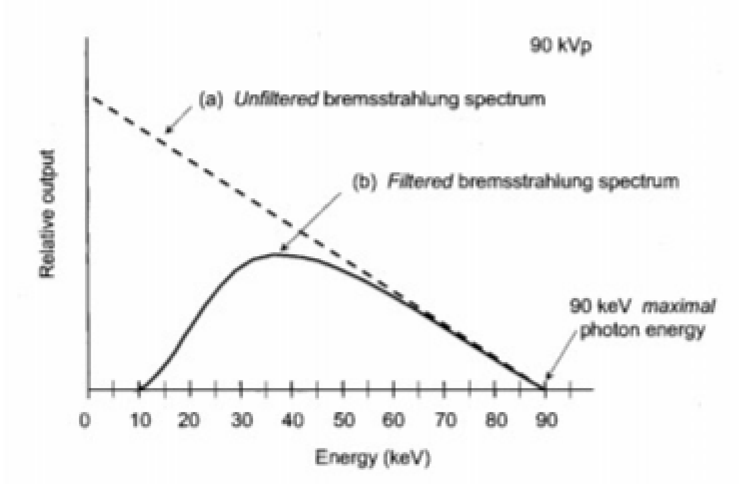


**Figure (2.3): The bremsstrahlung energy distribution for 90kVp acceleration potential (Jerrold et al, 2002).**

### 2.2.2. Characteristic X-Ray Spectrum:

Each electron in the target atom has a binding energy that depends on the shell in which it resides. Closest to the nucleus are two electrons in the K shell, which has the highest binding energy. The L shell, with eight electrons, has the next highest binding energy, and so forth. When the energy of an electron incident on the target exceeds the binding energy of an electron of a target atom, it is energetically possible for a collision interaction to eject the electron and ionize the atom. The unfilled shell is energetically unstable, and an outer shell electron with less binding energy will fill the vacancy. As this electron transitions to a lower energy state, the excess energy can be released as a characteristic x-ray photon with energy equal to the difference between the binding energies of the electron shells. (Jerrold et al, 2002).

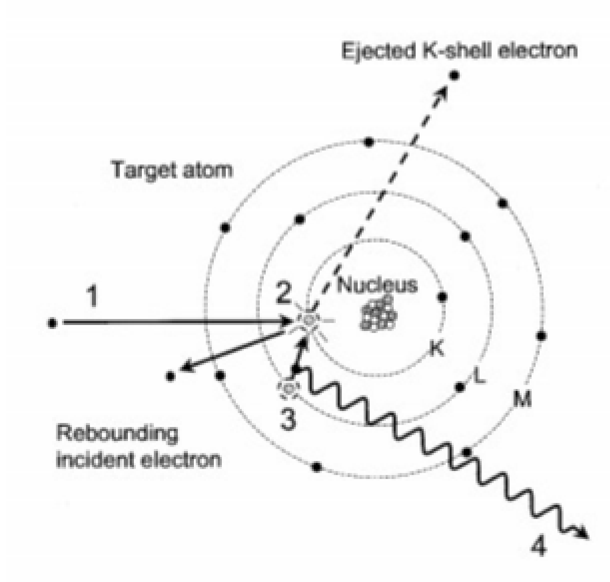


**Figure (2.4): Generation of a characteristic x-ray (Jerrold et al, 2002).**

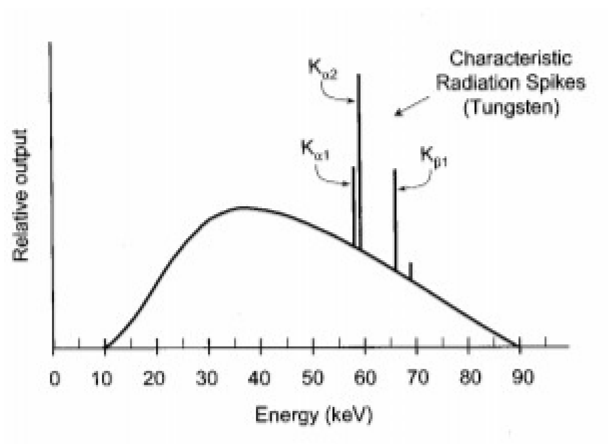


**Figure (2.5): shows the filtered spectrum of bremsstrahlung and characteristic radiation (Jerrold et al, 2002).**

## 2.3. **The X-Ray Tube:**

Figure (2.6) 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. (Martin,2006).

### 2.3.1. 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. (Martin,2006).

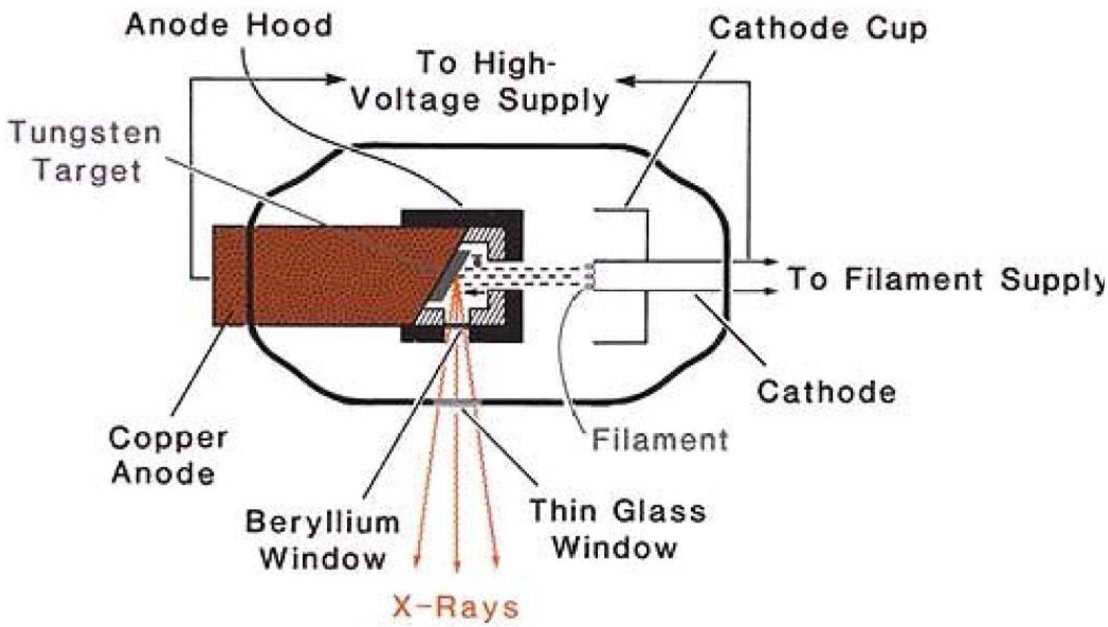


Figure (2.6) show the schematic representation of a conventional x-ray tube.

## 2.3.2. 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. (Martin,2006).

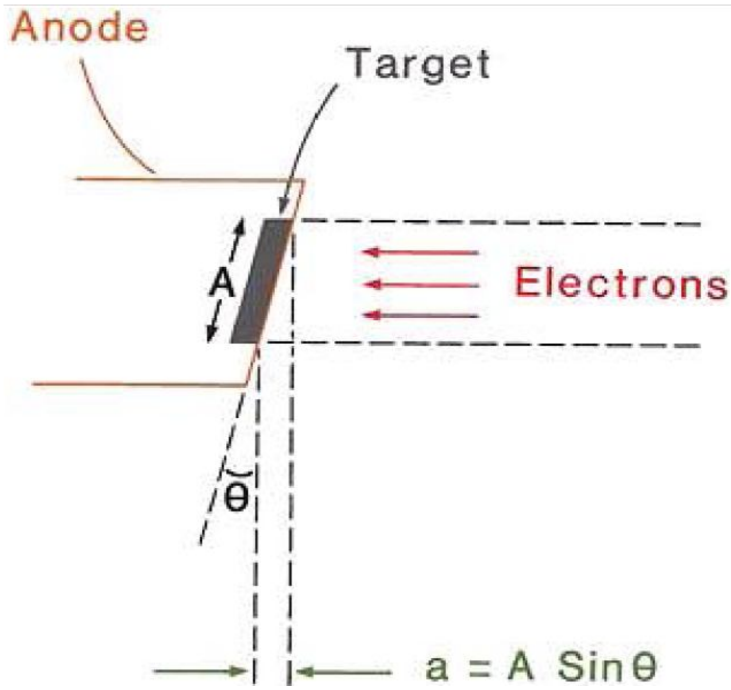


**Figure (2.7) show the illustrating the principle of line focus. (Martin,2006).**

## 2.4. Interaction with mater of photon:

X-rays have very short wavelengths, approximately $10^{-8}$ to $10^{-9}$ m. The higher the energy of an x-ray, the shorter is its wavelength. Consequently, low-energy x-rays tend to interact with whole atoms, which have diameters of approximately $10^{-9}$ to $10^{-10}$ m; moderate energy x-rays generally interact with electrons, and high-energy x-rays generally interact with nuclei X-rays interact at these various structural levels through five mechanisms: coherent scattering, Compton scattering, photoelectric effect, pair production, and photodisintegration. Two of these Compton scattering and photoelectric effect are of particular importance to diagnostic radiology. They are discussed in some detail here. (Jerrold et al, 2002.)

### 2.4.1. Compton Scattering:

In Compton scattering, the incident x-ray interacts with an outer shell electron and ejects it from the atom, there by ionizing the atom. The ejected electron is called a Compton electron. The x ray continues in a different direction with less energy. The energy of the Compton-scattered x-ray is equal to the difference between the energy of the incident x-ray and the energy of the ejected electron. The energy of the ejected electron is equal to its binding energy plus the kinetic energy with which it leaves the atom ,During Compton scattering, most of the energy is divided between the scattered x-ray and the Compton electron . (Jerrold et al, 2002.)

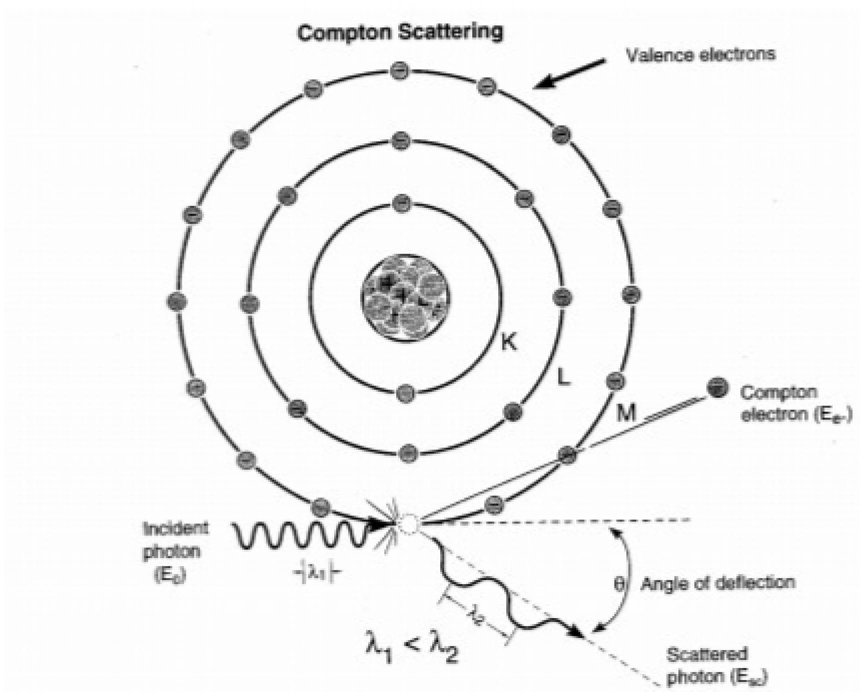


**Figure (2.8): shows the Compton scattering (Jerrold et al, 2002.)**

## 2.4.2. Photoelectric Effect:

X-rays in the diagnostic range also undergo ionizing interactions with inner-shell electrons. The x-ray is not scattered, but it is totally absorbed. This process is called the photoelectric effect, The electron removed from the atom, called a photoelectron, escapes with kinetic energy equal to the difference between the energy of the incident x-ray and the binding energy of the electron A photoelectric interaction cannot occur unless the incident x-ray has energy equal to or greater than the electron binding energy.

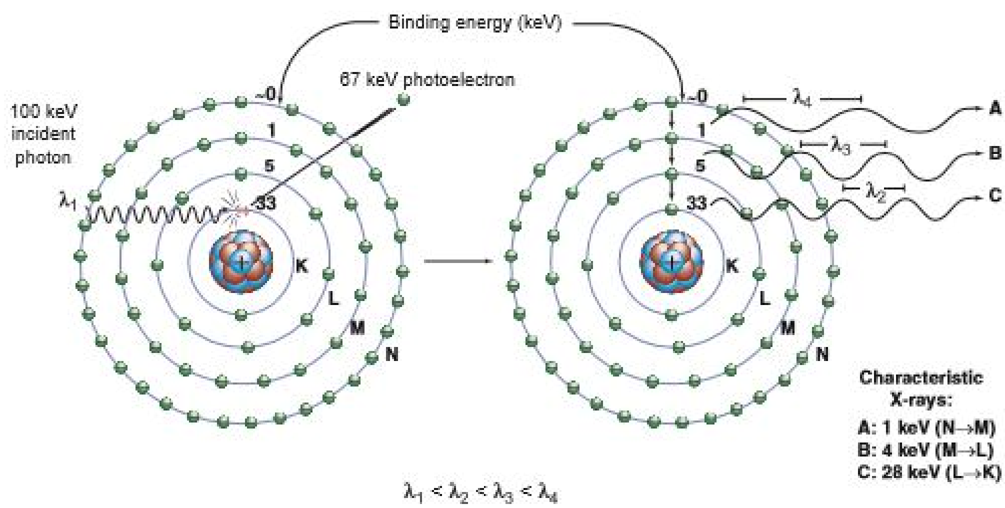


**Figure (2.9): shows photoelectric effect (Jerrold et al, 2002.)**

## 2.4.3. Pair Production

Pair production can only occur when the energies of x-rays and gamma rays exceed 1.02 MeV. In pair production, an x-ray or gamma ray interacts with the electric field of the nucleus of an atom. The photon's energy is transformed into an electron- positron pair (Fig. 2.10). The rest mass energy equivalent of each electron is 0.511 MeV, and this is why the energy threshold for this reaction is 1.02 MeV. Photon energy in excess of this threshold is imparted to the electron (also referred to as a negatron or beta minus particle) and positron as kinetic energy. The electron and positron lose their kinetic energy via excitation and ionization. As discussed previously, when the positron comes to rest, it interacts with a negatively charged electron, resulting in the formation of two oppositely directed 0.511-MeV annihilation photons (Fig. 2.10). Pair production does not occur in diagnostic x-ray imaging because the threshold photon energy is well beyond even the highest energies used in medical imaging. In fact, pair production does not become significant until the photon energies greatly exceed the 1.02-MeV energy threshold.

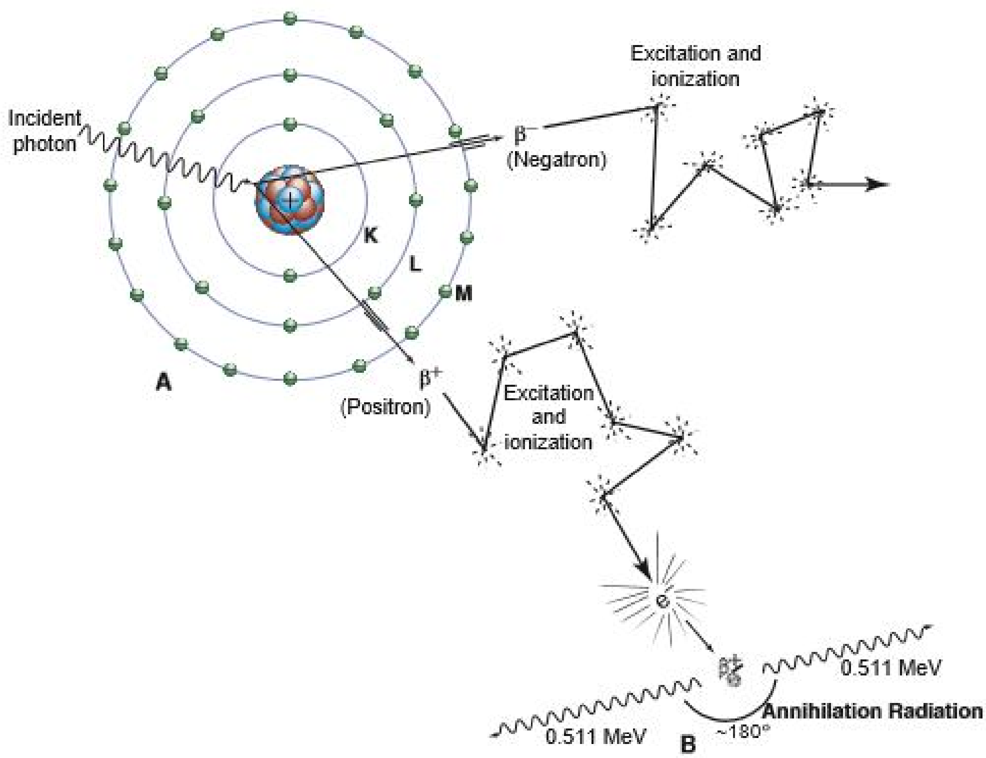


**Figure (2.10): Shows the illustration of Pair production (Jerrold et al, 2002.)**

## 2.4.4. Coherent Scattering:

X-rays with energies below approximately 10 keV interact with matter by coherent scattering, sometimes called classical scattering or Thompson scattering. J.J. Thompson was the physicist to first describe coherent scattering. In coherent scattering, the incident x-ray interacts with a target atom, causing it to become excited. The target atom immediately releases this excess energy as a scattered x-ray with wavelength equal to that of the incident x-ray ($\lambda = \lambda'$) and therefore of equal energy. However, the direction of the scattered x-ray is different from that of the incident x-ray. The result of coherent scattering is a change in direction of the x-ray without a change in its energy. There is no energy transfer and therefore no ionization. Most coherently scattered x-rays are scattered in the forward direction.

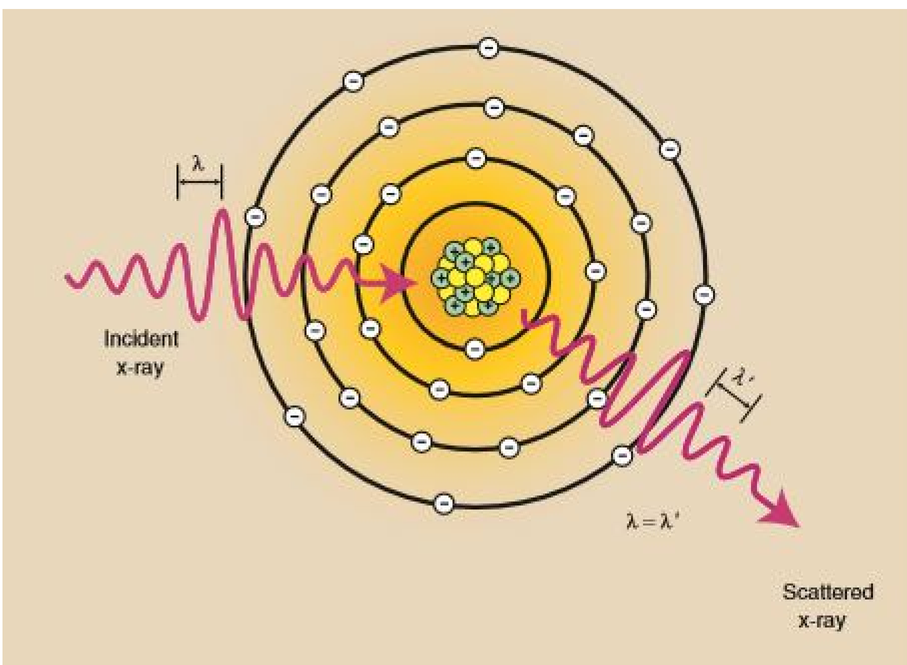


**Figure (2.11): Shows the illustration of coherent scattering (Jerrold et al, 2002.)**

### 2.4.5. Photodisintegration:

X-rays with energy above approximately 10 MeV can escape interaction with electrons and the nuclear field and be absorbed directly by the nucleus. When this happens, the nucleus is raised to an excited state and instantly emits a nucleon or other nuclear fragment. This process is called photodisintegration (Figure 2.12).

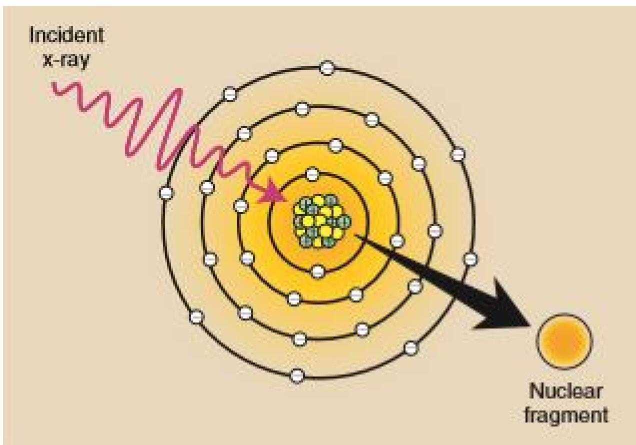


**Figure (2.12): Shows the illustration of photodisintegration (Jerrold et al, 2002.)**

## 2.5. Quality assurance:

The principle goal of quality assurance of x-ray machine is to obtain accurate and timely diagnosis. The secondary goals are minimization of radiation exposure and obtain high image quality. This can be assess by performance the x-ray machine by optimum operating parameters such as reproducibility of tube voltage, dose output, time , x-ray tube efficiency , Accuracy of kVp , mA , time , focal spot size . and half value layer.

Many authors published work concerning quality assurance of x-ray machine, describes quality assurance protocol for diagnostic x-ray equipment at the radiologic technologist level. Some important parameters in diagnostic x-ray such as film processor monitor, exposure time, mAs reciprocity, peak tube potential, and x-ray output and beam quality, and focal spot size were described. (Bosnjak et.al 2008) has been systematically performed quality control surveys of diagnostics imaging equipment.

(Johns, 1961) had been expressed the quality of x-ray in terms of the half value Layer. Contribution of radiology to better diagnoses and treatments is evident. In parallel, efforts were oriented towards the improvement and control of equipment. The importance of quality assurance (QA) of diagnostic X-ray equipment is well recognized.

Application of QA program is very important when optimization of image quality and reduction of patient exposure is desired.

For Diagnostic purposes, the optimizations of exposure involve the relationship of three core aspects:

i) Choice of radiographic technique

ii) Radiation dose to the subject.

iii) Diagnostic quantity of the radiographic image.

These three aspects are critical for the diagnostic quantity of the radiographic image.

The four main exposure parameters are:

tube potential (kV), tube intensity (mA), exposure time (s) and focus to detector distance (cm). Exposure time and tube intensity could be a unique exposure factor (mAs).The kVp is the factor which controls the energy of the electrons as they move across the tube or the speed of the electrons. The higher the kVp the greater the impact of the electrons with the target or anode. The greater the kVp the greater the penetration. The "p" stands for peak, therefore kVp means kilo voltage peak. Peak denotes highest voltage attained in a given electrical alternating current. By controlling the energy of the x-ray beam, kVp controls the quality of the beam. Other factor which is mAs means the rate of flow of electrons for a preselected time. The mAs also mean mA × time (seconds). We can arrive at specific mAs value with various combinations of mA and s.

The mAs control the number of electrons produced at the cathode and subsequently the number of x-rays produced at the anode. The mAs control the quantitative character of the exposure factor. Exposure factors influence and determine the quantity and quality of the x-ray beam. The exposure of subjects is part of their medical diagnosis or treatment.

The quality assurances of diagnostic x-ray are based on the Basic Safety Standard BSS and International Commission of Radiological Protection, the use of diagnostic reference levels (ICRP- Report, 1966). The aim of the present is to investigate some factors affecting on quality assurance of conventional x-ray such as reproducibility of tube voltage, dose output, time , X-ray tube efficiency Accuracy of  kVp , mA , time, and check the focal spot size and half value layer.

## 2.6. Peak Tube Potential – kVp:

Definition: This test provides a measurement of the peak electrical potential across the x-ray tube when it is operating.

The x-ray tube kVp is most critical. A small error of this variable will have a greater effect on the final radiographic or fluoroscopic image than will an equivalent variation in any of the other parameters such as tube current (mA), exposure time, target film distance. The x-ray intensity reaching the image receptor after the beam passes through the patient varies approximately as the fifth power of kVp. The kVp affects not only the intensity reaching the image receptor but also the subject contrast of the image. ( AAPM Report No.4 , 1977)

## 2.7. Quality control and dose optimization:

Radiation is a major risk in diagnostic and therapeutic medical imaging. The problem is caused from incorrect use of radiography equipment and from the radiation exposure to patients much more than required. Exposure of different dose values for the same clinical examination is an enough reason to draw attention to this issue. International Commission on Radiation Protection (ICRP), the International Atomic Energy Agency (IAEA) and other various independent institutions has been making publications in relation to ionizing radiation protection for more than fifty years. Report 60 of the ICRP and the Basic Safety Standards that was published in the IAEA report have three basic principles related to the radiation protection (ICRP, 1991; IAEA, 1996).

The most important issue in these principles is the optimization of radiation. In the mentioned policy, the lowest dose is aimed by considering the country's economic and social factors for acceptable applications. Personnel already receive low dose with protection systems in the working areas. However, the patient doses must be taken under control based on the principle of optimization as much as possible.

There are two important points when performing a radiological procedure:

- To obtain the best possible image for a clear diagnosis of the disease,
- To apply the lowest dose for protecting the patient while getting the best image.

The second point indicates that the patient’s radiation dose level must be kept at the lowest possible dose. In other words, it indicates dose optimization. The dose optimization meaning "the minimum radiation dose of the optimum image quality", is achieved by applying quality control procedures, calibration and dosimetric measurements. In the Radiology Quality Control systems, the biggest problem is dose control and dose optimization. Neither patient nor users knows how much dose is exposed because there is no any system in the x-ray device for measuring or showing dose during exposure. Since there is no dose adjustment on the equipment, the systems are operated by using the usual parameters; kVp and mAs. Because dose cannot be adjusted, the patient may receive more dose than the aimed dose.

For dose optimization, all exposures should be kept at the minimum dose level in according to the ALARA principle (ALARA-as low as reasonably achievable). The aim of the optimization is not to download the risks of irradiation to zero. It is to reduce them to an acceptable level. This can be possible only by examining all parameters that affect the X-ray, by investigating the relationship between dose and these parameters, on the basis of this relationship, by performing the necessary regulations.

In all x-ray equipment, the operator can control the quantity and the quality of the radiation with kVp and mAs controls. If the equipment is not properly controlled, it will not be possible to control the radiation output. For this reason, optimization consists of not only improving of image quality and low dose but also establishing quality assurance and quality control programmes to ensure a proper performance of the x-ray equipment.

As frequently documented in the scientific literature, patient dose and image quality are basic aspects of any quality control (QC) tests in diagnostic radiology. Image quality must be adequate for diagnosis and it must be obtained with low doses.

The following QC tests are performed for both patient dose and image quality evaluation:

- kVp Accuracy and Repeatability
- Dose-kVp Linearity Test
- Dose-mAs Linearity Test
- X-ray Tube Output-kVp Relation
- HVL (Half Value Layer)
- Image Quality (Beam alignment, collimation alignment, contrast and resolution)

The quality control tests’ methods, as well as the criteria for scoring the results, are in full agreement with those specified in the American

Association of Physicists in Medicine. (AAPM, 1981; IEC 61223-3-1, 1999).

## 2.7.1. X-ray Generators

The accuracy of the technique indicators is crucial to the consistent production of high-quality radiographs from room to room and from patient to patient. Depending on intended use, the range of techniques to be measured may vary. For example,a generator placed in a room intended for dedicated chest radiography need only function with high accuracy between 100 and 140 kVp, and at tube currents necessary to give proper film density in 5 to 30 msec. The same generator used in a general radiography room must maintain its accuracy over a much wider range (e.g., 50 to 120 kVp, and at 20% to 100% rated power). Performance should be spotchecked across the entire selectable range with particular attention paid to the most commonly used techniques. The reader is referred to AAPM Report No. 1418 for a thorough explanation of generator performance concepts. All generator parameters should be evaluated at acceptance and at least annually.

### 2.7.1.1. Kilovoltage Calibration

Accuracy of the kilovoltage indicator is most easily evaluated by use of a noninvasive kVp meter. Caution must be exercised in orienting the device in the beam to avoid systematic errors. One must avoid errors due to kV meter frequency response when evaluating medium-frequency generators. Noninvasive kVp meters do not directly measure kVp, but rather measure the beam hardness and relate it to actual kilovoltage used under the calibration conditions in the laboratory. Other variables such as anode angle, degree of anode pitting, and added and inherent filtration can influence the noninvasive kV measurement. Particular attention should be paid to some angio and cardiac units that are designed with very heavy added filtration. Some of these units employ copper filtration to match the energy spectrum to the k-edge of contrast media. This type of filtration can have a considerable effect on the noninvasive kV measurement. Noninvasive kV device results may require the manual application of HVL-dependent correction factors to achieve published accuracy. (Jerrold et al, 2002.)

## 2.7.2. 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.

### 2.7.2.1. 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).

#### 2.7.2.2. 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).

#### 2.7.2.3. 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 × second) (Hendee et al., 1984).

#### 2.7.2.4. 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 intensity of an x-ray beam by half, and is expressed in unit of distance (mm) (Sprawls, 1987).

#### 2.7.2.5. Image quality

The purpose of the radiographic image is to provide information about the medical condition of the patient. A quality image is one that provides all the information required for diagnosis of the patient’s condition. (Hendee et al., 1984).

Image quality is not a single factor but is described with beam alignment, collimation alignment, contrast and resolution. Contrast means differences in the form of gray scales or light intensities, whereas the resolution is a measure of its ability to differentiate between two objects a small distance apart; such that they appear distinct from one another.

An image is acceptable as qualified only if it has high resolution and high contrast.

## 2.8. Consistency of radiation output using a digital kv meter:

### 2.8.1. Equipment:

Digital radiation output meter rule.

### 2.8.2. Procedure:

- Place the radiation output meter on the tabletop with the detector facing the x-ray tube.
- Position the x-ray tube at a standard distance from the cassette such as 100 cm.
- Center the tube accurately to the sensor area and collimate the beam to its edges.
- Switch on the output meter and allow it to warm up. Ensure it is working correctly.
- Set the same exposure each time the test is carried out e.g. 70 KVP .20 mAs, referring to the operating instruction of digital meter for correct exposure conditions.
- Make exposure.
- Record reading on display. Repeat the exposure twice (to check the consistency).
- Record the three readings on the result sheet. (Philip, 1991).

### 2.8.3. Assessment and evaluation:

From the sample result, if any of the result differ by more than 5% from the mean, further test should be carried out to check for a fault condition. (BIRL, 1988)

## 2.9. Assessment of kilovoltage applied to the x-ray tube using digital meter:

### 2.9.1. Purpose of test:

A digital KVP meter is used to compare the effective kilovotage applied to an x-ray tube with that selected at the control panel.

### 2.9.2. Equipment:

KV meter and Meter rule.

### 2.9.3. Procedure:

- Read the operating instructions supplied with the KVP meter and carry out the test following these instructions. It is important that KVp limits and requirements relating to mA time and distance set out in the operating instructions are followed.
- Remember to check the battery in the meter to ensure that it does not need changing.
- Ensure that the meter is placed on a flat surface, perpendicular to the reference axis of the x-ray beam, and center the detector collimate as necessary.
- Repeat the test three times for each Kvp tested to check for consistency.
- Record the average of the three reading on the result sheet.

### 2.9.4. Assessment and evaluation:

If any results vary more than 5% from the baseline, contact the service engineer (Philip, 1991).

## 2.10. Previous Studies:

Study by T.M.Taha Radiation Protection Department, Nuclear Research Center, Atomic Energy Authority, Cairo.P.O.13759 Egypt.2010, KV accuracy for different settings of six x-ay machines voltage was examined by setting the source to detector distance at 66 cm of exposure, for different KV intervals from 50-120 KV and average of KV accuracy was presented as shown in table 1.

**Table(2.1) KV accuracy for different settings of six x-ray machines**

| Machine No. | Mean kVp Accuracy % Error |
|---|---|
| M1 | 1.50 |
| M2 | 20.00, Recalibrated and adjusted to 5.00 |
| M3 | 5.00 |
| M4 | 1.74 |
| M5 | 4.00 |
| M6 | 1.30 |

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.

Other study by M. A. Alnafea, K. Z. Shamma et al (2014), In the kVp accuracy test for radiographic and fluoroscopic units, the different between the initiated and measured kVp should be within ±5%. The kVp accuracy was performed between 40 and 130 kVp. Table (2.2) summarizes the result of this performance test. The minimum percentage difference that has calculated using (1) was found to be -1.85% at 100 kVp, while the maximum percentage difference was 0.91% at 90 kVp. It is clear from these results that this machine has passed the test successfully.

**Table(2.2) Radiology accuracy test**

| **KVp** | **$KVp_m$** | **$KVp_{diff}$** | **$KVp_{error\ diff\ \%}$** |
|---|---|---|---|
| 40 | 39.7 | 0.3 | 0.76 |
| 50 | 50 | 0.0 | 0.00 |
| 60 | 60.3 | -0.3 | -0.50 |
| 70 | 70.6 | -0.6 | -0.85 |
| 80 | 81.3 | -1.3 | -1.60 |
| 90 | 91.7 | -1.7 | -1.85 |
| 100 | 99.1 | 0.9 | 0.91 |
| 110 | 109.8 | 0.2 | 0.18 |
| 120 | 120.4 | -0.4 | -0.33 |
| 130 | 131.1 | -1.1 | -0.84 |

$$\text{Error of kVp } \% = (\text{kVp} - \text{kVpm}) / \text{kVpm}$$

# Chapter Three

## Materials and Methods

### 3.1Materials:

#### 3.1.1. X-ray machines:

In the study, 15 different units of X-ray machines from different manufactures were included.

#### 3.1.2. kV Meter:

A digital KVP meter is used to check accuracy of kilovoltage applied to an x-ray tube with that selected at the console.

### 3.2. Methods:

#### 3.2.1. Study duration:

This study performed in period of May 2017 to September 2017.

#### 3.2.2. Study place:

This study was conducted in 15 hospitals in Khartoum State hospitals

#### 3.2.3. Method of data collection:

In the data collection the KV meter was Placed on the tabletop with the Detectors facing the x-ray tube positioned at 1 meter of the focal spot of the X-ray tube and centered the tube accurately to the sensor area and collimate the beam to its edges, Switched on the KV meter and allow it to warm up, ensure it is working correctly. Exposure factor KV was selected from the console each time the test is carried out, referring to the operating instruction of digital meter for correct exposure conditions. And Recorded the reading on KV meter display, for each kVp meter were made measurements in the range from 50kV to 90kV. The measurements were increased in steps of 10kV. For each selected X-ray equipment were take 5 measurements, all readings were recorded on the result sheet.

Table (3.1) the KVp accuracy test was performed with the following exposure factors for each unit

| KVp |
|---|
| 50 |
| 60 |
| 70 |
| 80 |
| 90 |

The KVp error was calculated using the formula.

$$\textbf{Error of kVp \%} = \left(kVp_{(Setting)} - kVp_{(Measured)}\right) / kVp_{(Measured)} \times 100$$

## 3.2.5. Method of data analysis:

The data analyzed by Microsoft Office Excel Program.

# Chapter Four

## The Results:

This study included the measurements were performed to assess the kVp Accuracy for 15 X-ray Machines, carried out at Khartoum State.

The tables and figures below show the kV accuracy of x-ray machines.

Table (4-1) shows the setting and measured Kvp machine (1).

| Kilovoltage | | kVp difference | kVp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 50.1 | -0.1 | -0.19 |
| 60 | 59.2 | 0.8 | 1.35 |
| 70 | 68.8 | 1.2 | 1.74 |
| 80 | 79.8 | 0.2 | 0.25 |
| 90 | 88.1 | 1.9 | 2.16 |

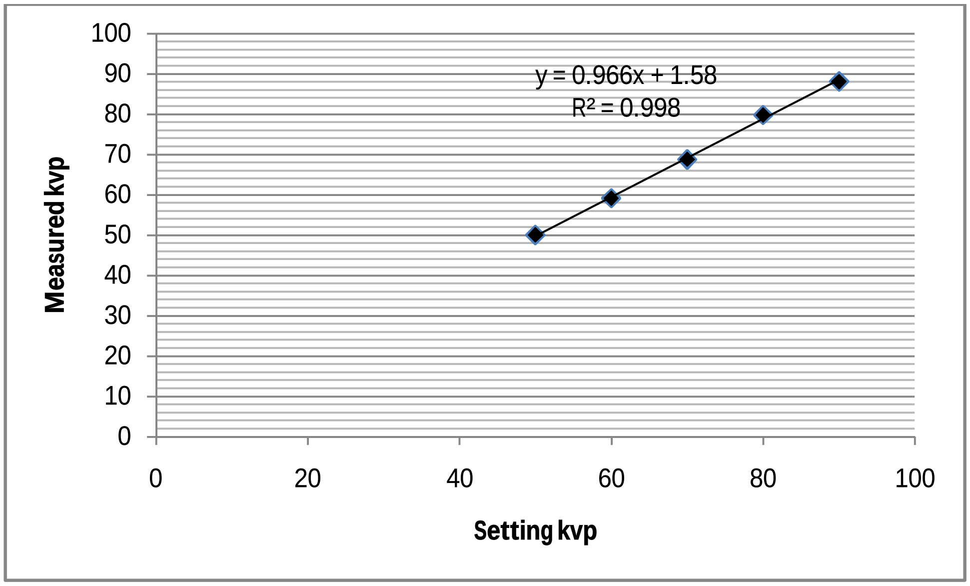


Figure (4-1) show the relationship between setting Kvp and measured Kvp for machine (1).

Table (4-2) shows the setting and measured Kvp machine (2).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 51.7 | -1.7 | -3.3 |
| 60 | 63.3 | -3.3 | -5.2 |
| 70 | 74.2 | -4.2 | -5.7 |
| 80 | 82.7 | -2.7 | -3.3 |
| 90 | 91.3 | -1.3 | -1.4 |

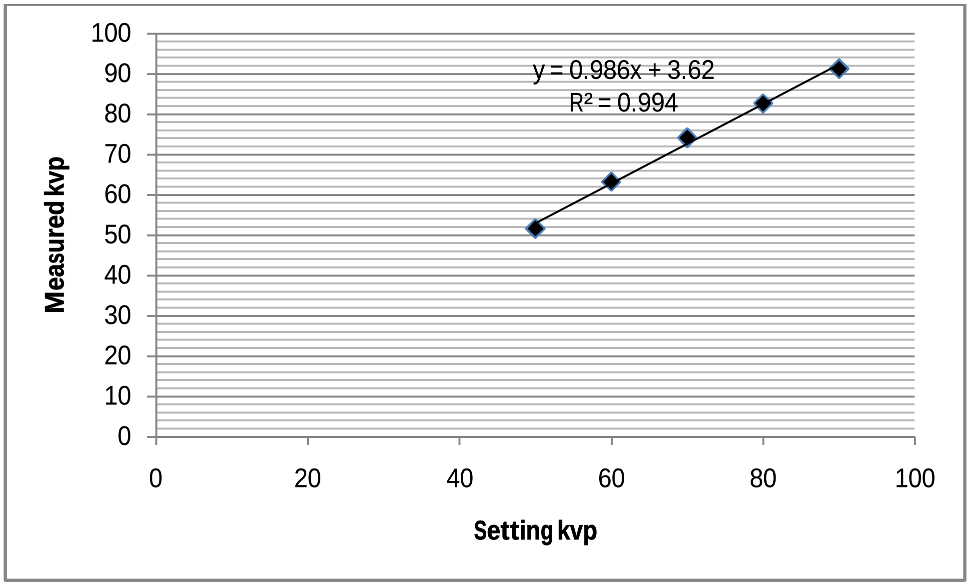


Figure (4-2) show the relationship between setting Kvp and measured Kvp for machine (2).

Table (4-3) shows the setting and measured Kvp machine (3).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 53.5 | -3.5 | -6.5 |
| 60 | 63.9 | -3.9 | -6.1 |
| 70 | 73.9 | -3.9 | -5.3 |
| 80 | 85.3 | -5.3 | -6.2 |
| 90 | 92.7 | -2.7 | -3 |

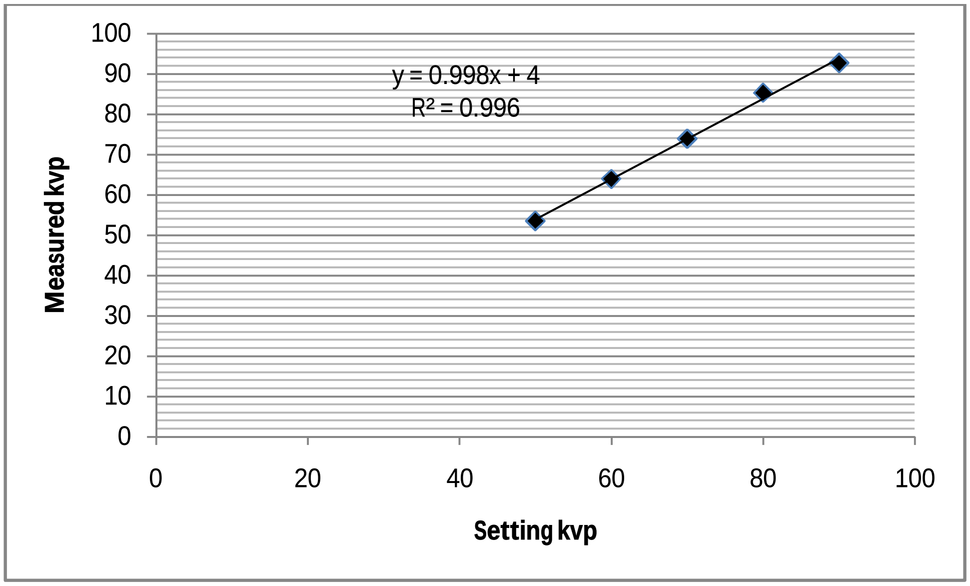

Figure (4-3) show the relationship between setting Kvp and measured Kvp for machine (3).

Table (4-4) shows the setting and measured Kvp machine (4).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 47.4 | 2.6 | 5.5 |
| 60 | 59.7 | 0.3 | 0.5 |
| 70 | 69.7 | 0.3 | 0.4 |
| 80 | 80.5 | -0.5 | -0.6 |
| 90 | 90.3 | -0.3 | -0.3 |

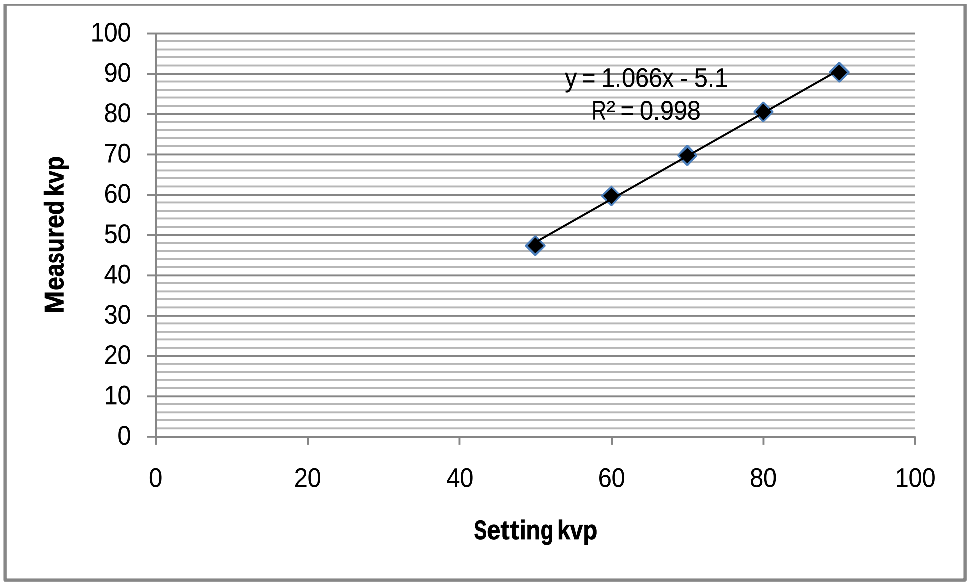


Figure (4-4) show the relationship between setting Kvp and measured Kvp for machine (4).

Table (4-5) show the setting and measured Kvp machine (5).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 49.8 | 0.2 | 0.4 |
| 60 | 59.6 | 0.4 | 0.6 |
| 70 | 68.9 | 1.1 | 1.5 |
| 80 | 80.7 | -0.7 | -0.9 |
| 90 | 89.4 | 0.6 | 0.7 |

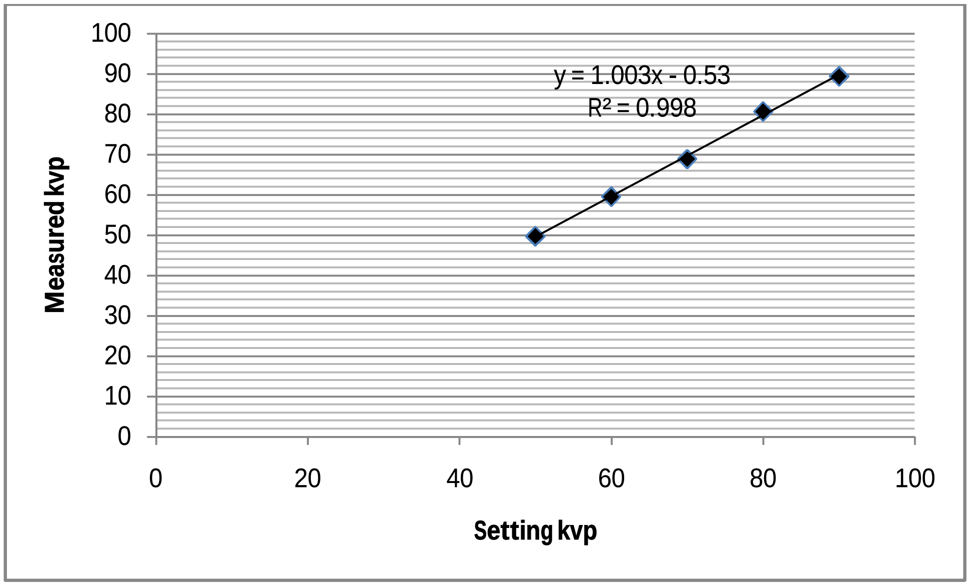


Figure (4-5) show the relationship between setting Kvp and measured Kvp for machine (5).

Table (4-6) show the setting and measured Kvp machine (6).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 45.8 | 4.2 | 9.2 |
| 60 | 54.4 | 5.6 | 10.3 |
| 70 | 63.8 | 6.2 | 9.7 |
| 80 | 68.7 | 11.3 | 16.4 |
| 90 | 79.4 | 10.6 | 13.4 |

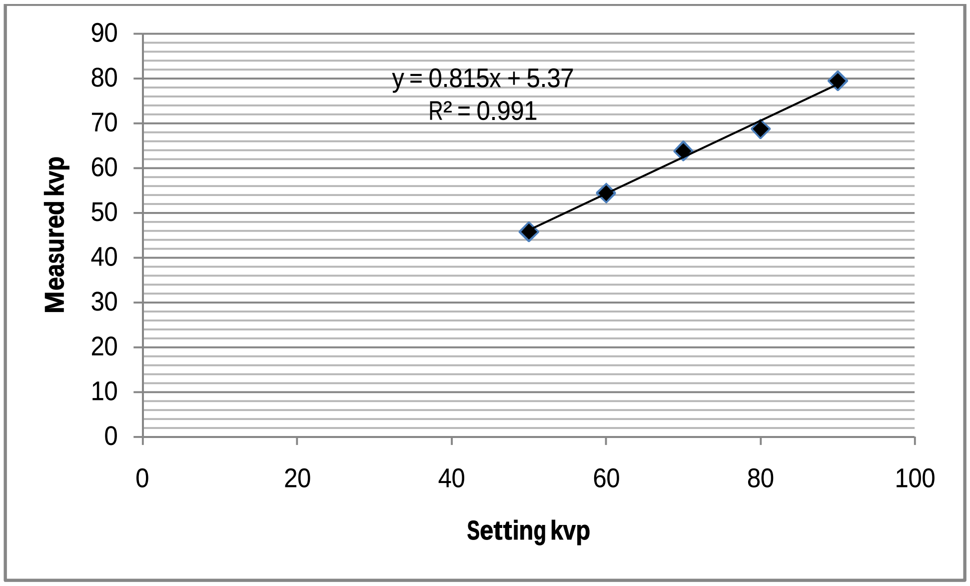


Figure (4-6) show the relationship between setting Kvp and measured Kvp for machine (6).

Table (4-7) show the setting and measured Kvp machine (7).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 46.8 | 3.2 | 6.8 |
| 60 | 56.1 | 3.9 | 6.9 |
| 70 | 67.1 | 2.9 | 4.3 |
| 80 | 77.3 | 2.7 | 3.5 |
| 90 | 86.9 | 3.1 | 3.6 |

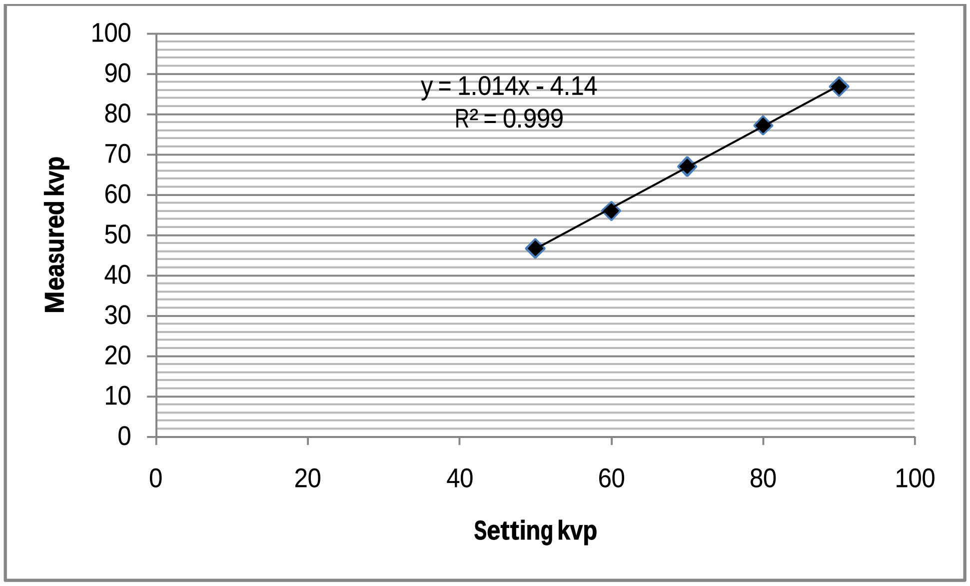


Figure (4-7) show the relationship between setting Kvp and measured Kvp for machine (7).

Table (4-8) show the setting and measured Kvp machine (8).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 50.3 | -0.3 | -0.6 |
| 60 | 59.8 | 0.2 | 0.33 |
| 70 | 70.5 | -0.5 | -0.7 |
| 80 | 81 | -1 | -1.2 |
| 90 | 90.3 | -0.3 | -0.33 |

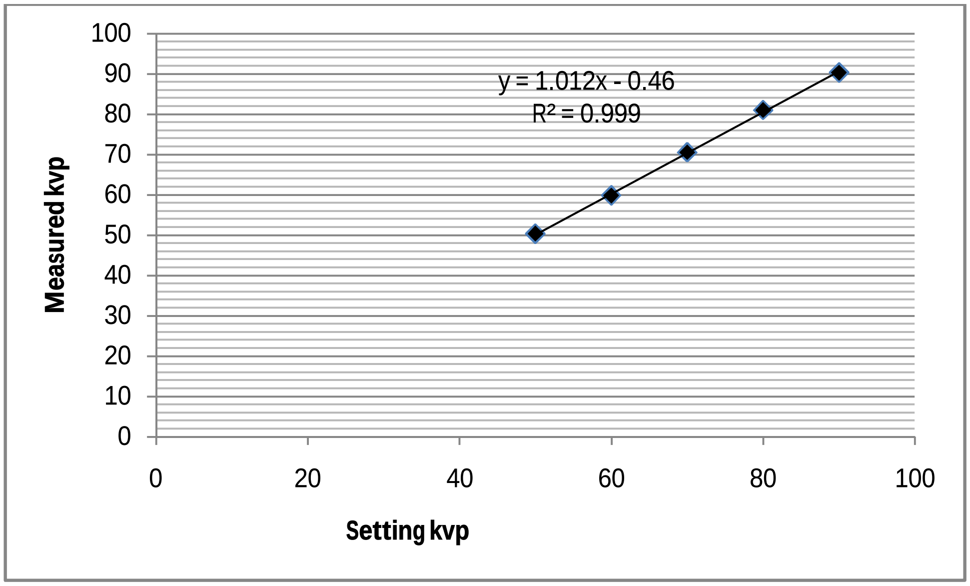


Figure (4-8) show the relationship between setting Kvp and measured Kvp for machine (8).

Table (4-9) show the setting and measured Kvp machine (9).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 50.2 | -0.2 | -0.4 |
| 60 | 59.9 | 0.1 | 0.2 |
| 70 | 69.7 | 0.3 | 0.4 |
| 80 | 80.2 | -0.2 | -0.2 |
| 90 | 89 | 1 | 1.1 |

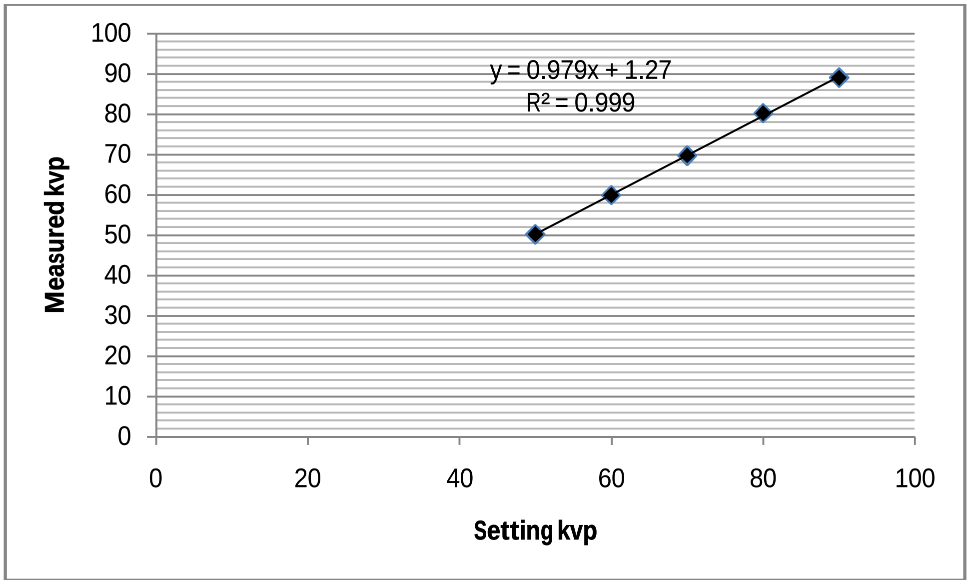


Figure (4-9) show the relationship between setting Kvp and measured Kvp for machine (9).

Table (4-10) show the setting and measured Kvp machine (10).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 55.5 | -5.5 | -9.9 |
| 60 | 65.4 | -5.4 | -8.3 |
| 70 | 74.9 | -4.9 | -6.5 |
| 80 | 83.3 | -3.3 | -3.9 |
| 90 | 92.7 | -2.7 | -3 |

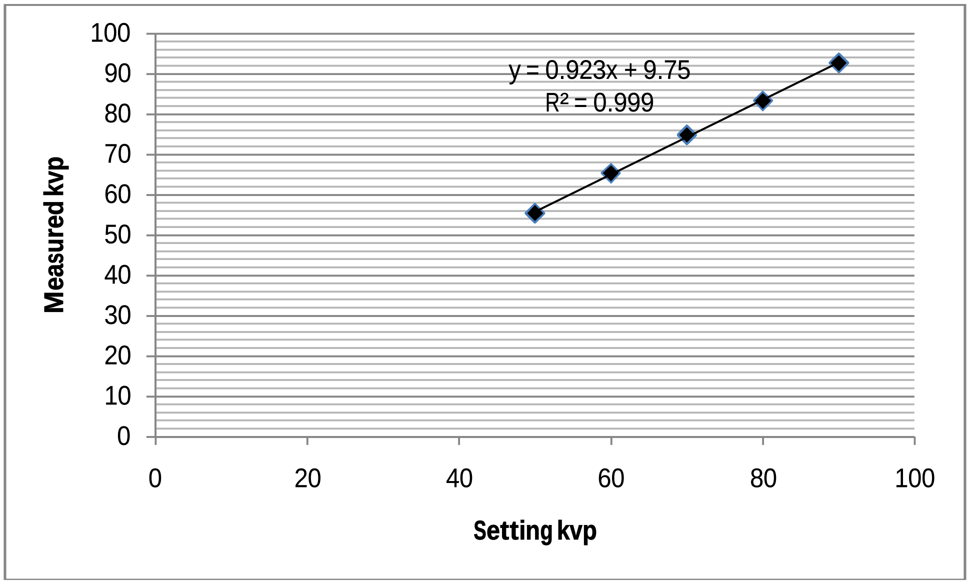


Figure (4-10) show the relationship between setting Kvp and measured Kvp for machine (10).

Table (4-11) show the setting and measured Kvp machine (11).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 49.8 | 0.2 | 0.4 |
| 60 | 59.2 | 0.8 | 1.4 |
| 70 | 69.4 | 0.6 | 0.9 |
| 80 | 80.4 | -0.4 | -0.5 |
| 90 | 90.3 | -0.3 | 0.3 |

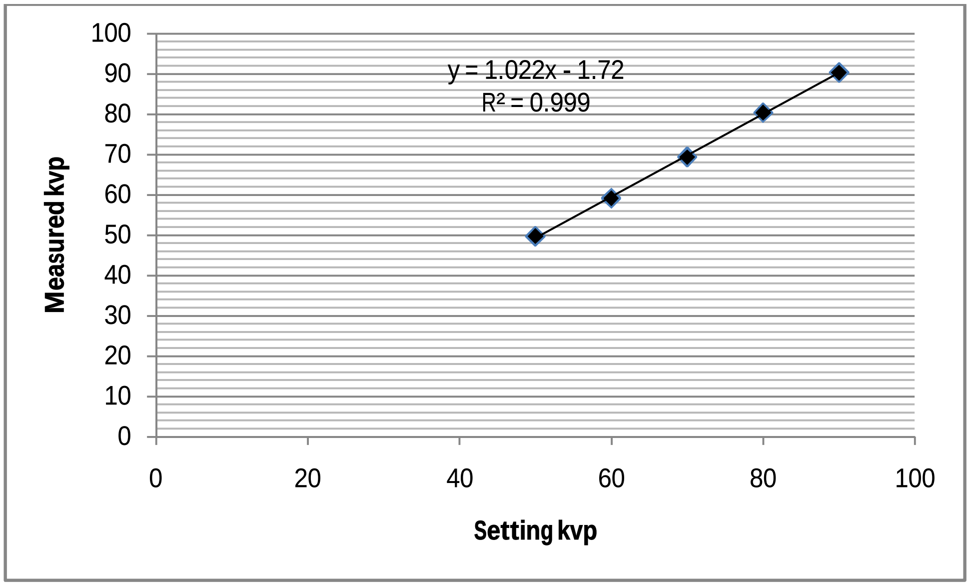


Figure (4-11) show the relationship between setting Kvp and measured Kvp for machine (11).

Table (4-12) show the setting and measured Kvp machine (12).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 52.5 | -2.5 | -4.7 |
| 60 | 62.3 | -2.3 | -3.7 |
| 70 | 71.3 | -1.3 | -1.8 |
| 80 | 82 | -2 | -2.4 |
| 90 | 91.9 | -1.9 | -2.1 |

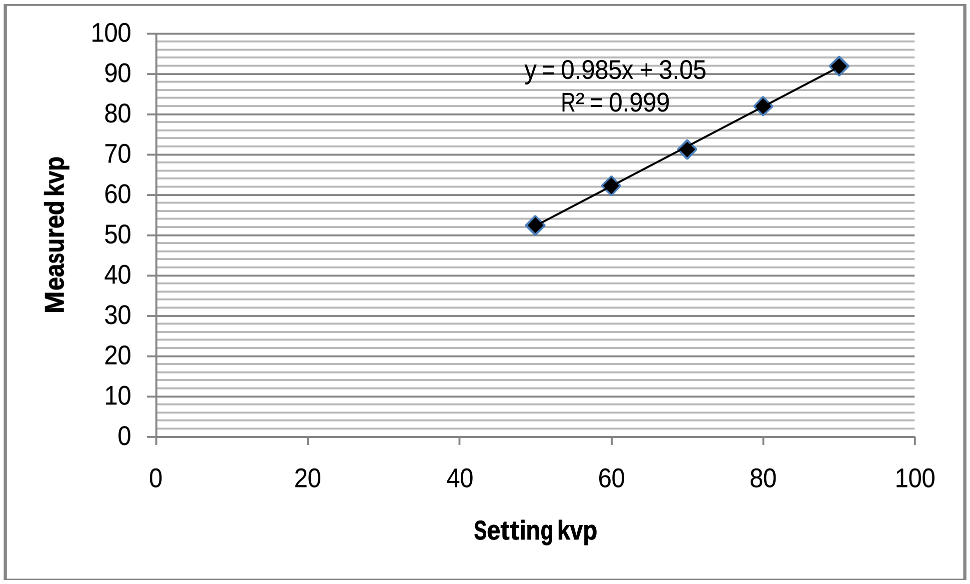


Figure (4-12) show the relationship between setting Kvp and measured Kvp for machine (12).

Table (4-13) show the setting and measured Kvp machine (13).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 52.1 | -2.1 | -4 |
| 60 | 61.6 | -1.6 | -2.5 |
| 70 | 71.2 | -1.2 | -1.7 |
| 80 | 80.3 | -0.3 | -0.4 |
| 90 | 90.7 | -0.7 | -0.8 |

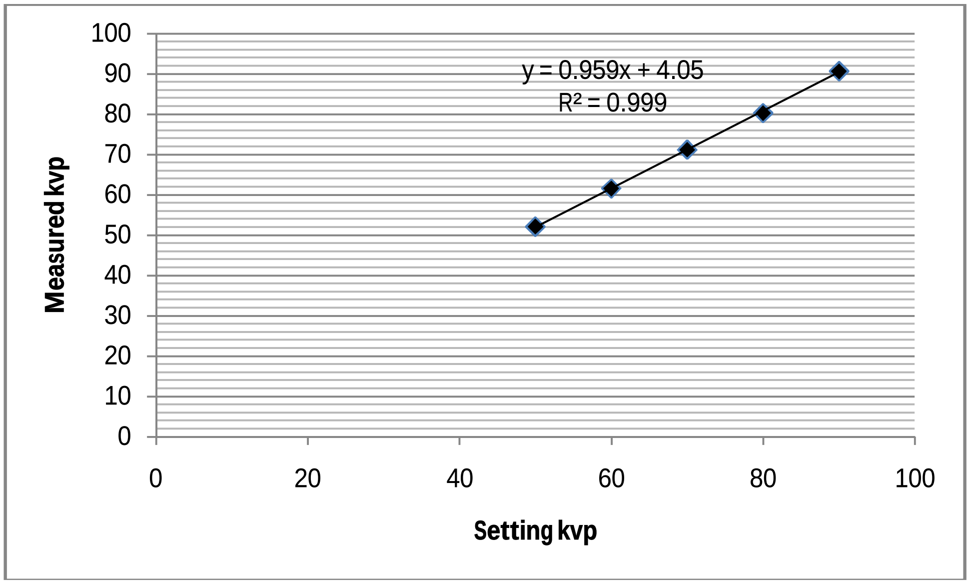


Figure (4-13) show the relationship between setting Kvp and measured Kvp for machine (13).

Table (4-14) show the setting and measured Kvp machine (14).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 50.2 | -0.2 | -0.4 |
| 60 | 59.6 | 0.4 | 0.7 |
| 70 | 70.4 | -0.4 | -0.6 |
| 80 | 81.2 | -1.2 | -1.5 |
| 90 | 89.4 | 0.6 | 0.8 |

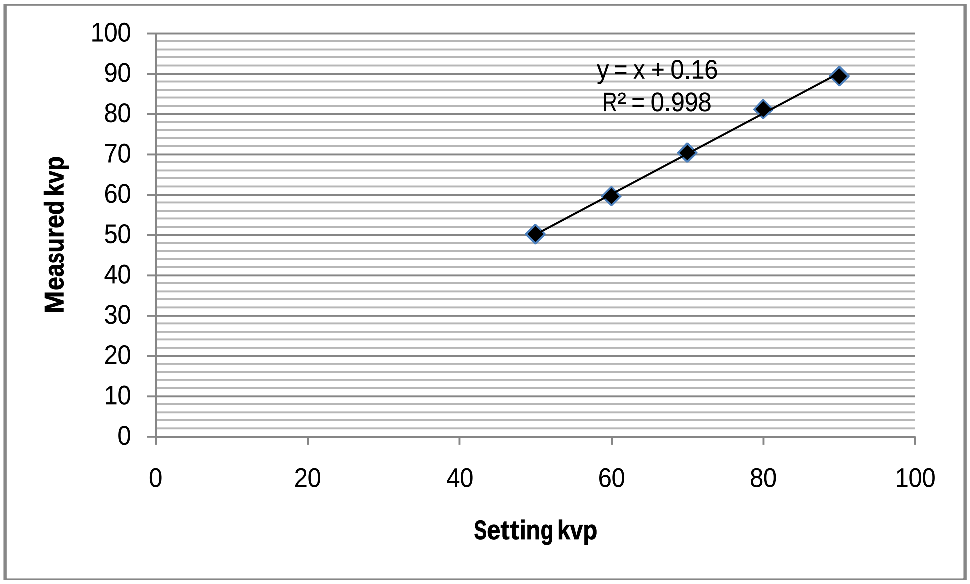


Figure (4-14) show the relationship between setting Kvp and measured Kvp for machine (14).

Table (4-15) show the setting and measured Kvp machine (15).

| Kilovoltage | | Kvp difference | Kvp error difference % |
|---|---|---|---|
| Setting | Measured | | |
| 50 | 50.6 | -0.6 | -1.2 |
| 60 | 60.4 | -0.4 | -0.7 |
| 70 | 70.7 | -0.7 | -0.9 |
| 80 | 81.7 | -1.7 | -2 |
| 90 | 90.3 | -0.3 | -0.3 |

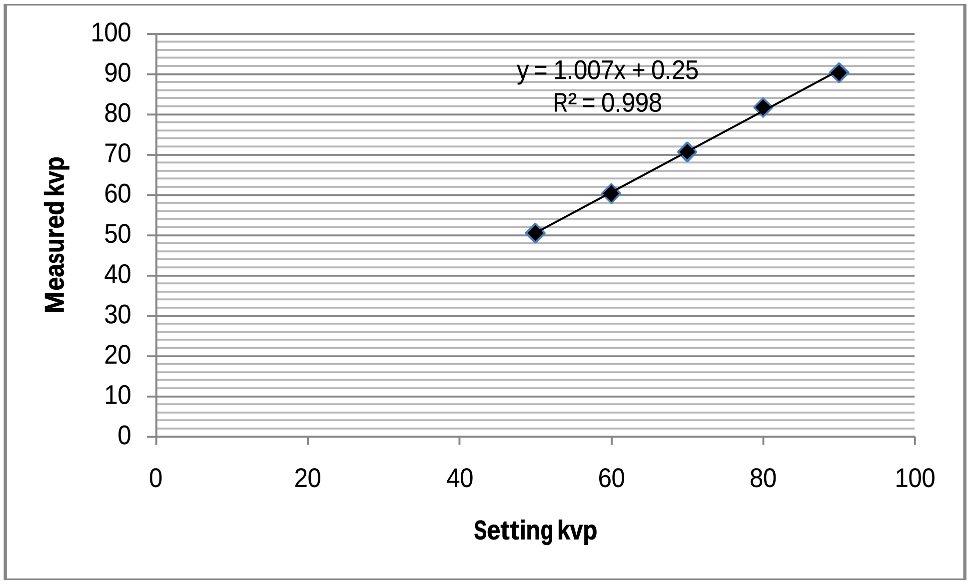


Figure (4-15) show the relationship between setting Kvp and measured Kvp for machine (15).

Table (4.16) KV accuracy for different settings of 15 x-ray machines.

| No. of machine | Mean kVp Accuracy % Error |
|---|---|
| M1 | 1.1 |
| M2 | -3.8 |
| M3 | -5.4 |
| M4 | 1.1 |
| M5 | 0.5 |
| M6 | 11.8 |
| M7 | 5 |
| M8 | -0.5 |
| M9 | 0.22 |
| M10 | -6.3 |
| M11 | 0.5 |
| M12 | -2.9 |
| M13 | -1.9 |
| M14 | -0.2 |
| M15 | -1 |

Table (4.17) the percentage of acceptable & unacceptable for kVp accuracy.

| Classifications | Number of machines | Percentage |
|---|---|---|
| Acceptance | 12 | 80% |
| Un acceptance | 3 | 20% |
| Total | 15 | 100% |

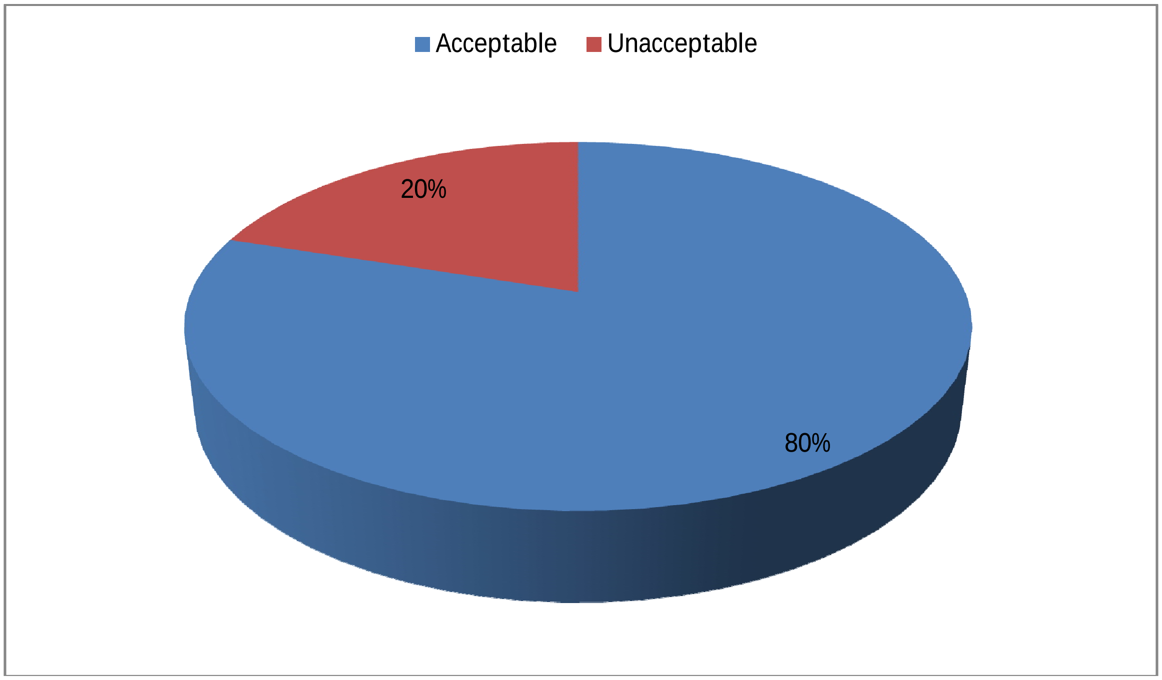


Fig (4.16) shows the percentage of acceptable & unacceptable for kVp accuracy.

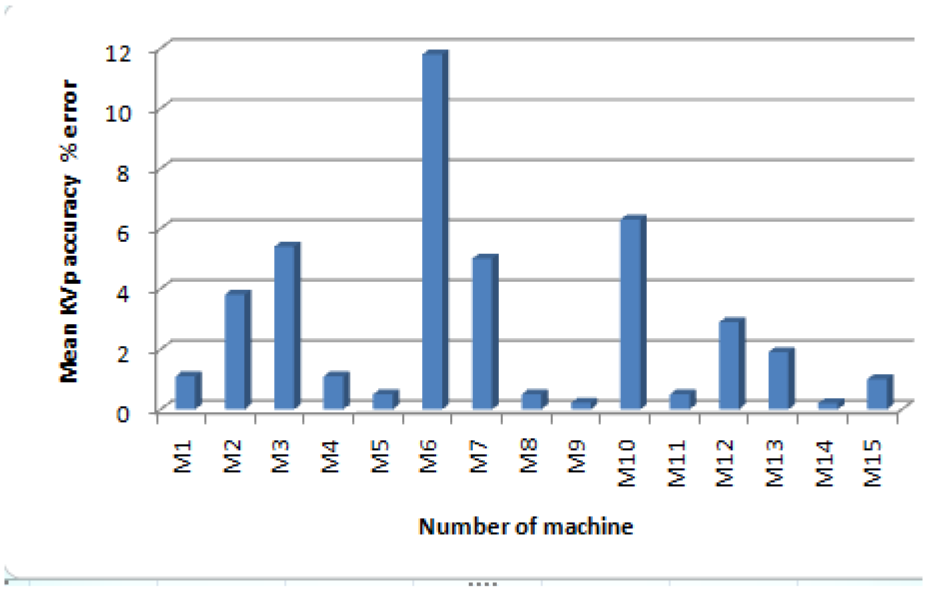

Fig (4.17) KV accuracy for different settings of 15 x-ray machines.

# Chapter five

## Discussion, Conclusion and Recommendation

## 5.1. Discussion:

This study has been done on 15 radiology departments in Khartoum state. The main objective was to assess the kVp accuracy for x-ray machines in radiology departments.

This study showed that there high percentage of acceptable (80%) for x-ray machines while percentage of unacceptable was (20%) . for study sample that expressed in table and figure(4.16), compare with study by T.M.Taha Radiation Protection Department, Nuclear Research Center, Atomic Energy Authority, Cairo.P.O.13759 Egypt.2010, KV accuracy is good at all KVp stations for fifteen machine except three of the examined machines gave accuracy of 11.8%,6.3% and 5.4% which is higher than the tolerance limit.(± 5%). That mean this machine needs calibration. It recalibrated and adjusted to 5% KV accuracy. Compare other study by M. A. Alnafea, K. Z. Shamma et al (2014), In the kVp accuracy test for radiographic units, the different between the initiated and measured kVp should be within ±5%. The kVp accuracy was performed between 50 and 90 kVp. Tables (4.1) to (4.15) summarize the result of this performance test. The minimum percentage difference that has calculated using equation **{**Error of kVp % = (kVp – kVpm) /( kVpm)**}** was found to be -9.9% at 50 kVp, while the maximum percentage difference was 13.4% at 90 kVp. It is clear from these results that these machines have passed the test successfully except three of the examined machines gave accuracy of 11.8%, 6.3% and 5.4% which is higher than the tolerance limit.(± 5%).

## 5.2. Conclusion:

The unapplication of the quality control program, in addition to the absence of essential advance testing tools, this made most x-ray department units in Khartoum state not calibrated which result in poor image quality. By applying of kv accuracy program many benefits can be reached. Saving of money by reducing material usage, save time, and reduce the radiation dose to both patient and the staff. Finally it is clear that implementation of QC program concerning kV accuracy is very important to the production of image quality.

## 5.3. Recommendation:

-Recommend that the assessment of the quality control test apply periodically.

-Essential test tools must be available in all departments.

-The future studies should include a large number of x-ray machines in the radiology departments in Khartoum state in addition to all quality control tests for equipment.

## 5.4. Reference:

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