CHAPTER ONE

INTRODUCTION

1.1 Introduction

Nuclear medicine uses small amounts of radioactive material to diagnose or treat a variety of diseases, including many types of cancers or heart disease. Nuclear imaging is a method of producing images by detecting radiation from different parts of the body after small amounts of radioactive material are administered, typically by intravenous injection. The main difference between nuclear imaging and other radiologic tests is that nuclear imaging assesses how organs function, whereas other imaging methods assess anatomy, or how the organs look. It is often used to view the skeleton, thyroid gland, liver, gall bladder, kidneys and stomach. These agents highlight both normal and abnormal issues and help in the detection of abnormalities.

This is accomplished using a large scintillation device. The images are recorded and documented in the computer system.

The gamma or scintillation camera is an imaging device that is most commonly used in nuclear medicine. It is also called the Anger camera in honor of Hal O. Anger, who invented it in the late 1950s. Gamma cameras detect radiation from the entire field of view simultaneously and therefore are capable of recording dynamic as well as static images of the area of interest in the patient. Various designs of gamma cameras have been proposed and made available, but the Anger camera with a single crystal is by far the most widely used. Although many sophisticated improvements have been made on the gamma cameras over the years, the basic principles of the operation have essentially remained the same (Gopal, 2012).

To ensure dependable performance of equipment, each nuclear medicine department is required to perform a routine series of tests on each device. These tests comprise the quality control program for the department
The purpose of quality control (QC) is to detect changes in the performance of a gamma camera system that may adversely affect the interpretation of clinical studies.

A minimum level of routine QC is required to ensure that nuclear medicine equipment is functioning properly. These minimum QC tests are intended to detect problems before they impact on clinical patient studies. They are not intended to provide a full evaluation of equipment performance. Further tests may be required to trace the cause of the problem and to ensure that the equipment is performing properly after service or adjustment.

These guidelines cover both gamma cameras as well as ancillary equipment such as dose calibrators and film processors. Exact QC procedures vary between manufacturers and models, thus it is impractical to provide detailed QC procedures covering all equipment. (ANZSNM, 1999).

In this study the researcher will evaluate the performance of gamma cameras through measurements of image resolution which includes energy spectrum, energy resolution, spatial resolution and uniformity at two nuclear medicine departments in Khartoum State.

The study will also retrospectively evaluate the frequency of tests for gamma cameras including energy spectrum, uniformity, energy resolution, spatial resolution, linearity, sensitivity, center of rotation and counting rate performance.

Practices are encouraged to call on the advice of experienced nuclear medicine physicists to draw up detailed QC protocols for their specific equipment based on the guidelines presented in this document.

It is imperative that QC procedures are carried out in a consistent manner (e.g. same collimator, orientation, activity, energy window width etc) and the QC results and settings are recorded. Proper record keeping greatly facilitates detection of gradual deterioration of performance over an extended period of time. A baseline set of QC results should be recorded after installation and acceptance testing to serve as a reference for the life of the equipment.

This study was carried out in two hospital departments of nuclear medicine performing diagnostic procedures in Khartoum state, namely Royal Care International Hospital (RCIH) and El-Neelain Diagnostic Center (NMDC), and these hospitals were chosen because they have considerable number of patients referred for nuclear medicine examinations daily.

1.2 Problem of study

Quality Control tests of Gamma Cameras in both departments were not regularly performed.

1.3 Objectives of the study

1.3.1 General Objective

To evaluate the performance of quality control programme of the gamma camera with regard to image resolution at (RCIH) and (NMDC) centers.

1.3.2 Specific Objectives

- To measure the spectrum and energy resolution
- To measure the spatial resolution
- To assess the Intrinsic uniformity
- To determine the minimum frequency of QC test in both centres

1.4 Study outline

This thesis consists of five chapters. Chapter one deals with the introduction, objectives, and theses outline. Chapter two deals with the literature review. Chapter three deals with materials and methods. Chapter four deals with the results. Chapter five deals with result discussion, conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical background

Gamma Camera also called a scintillation camera or Anger camera, is a device used to image gamma radiation emitting radioisotopes, a technique known as scintigraphy. The applications of scintigraphy include early drug development and nuclear medical imaging to view and analyse images of the human body or the distribution of medically injected, inhaled, or ingested radionuclides emitting gamma rays.

A gamma camera consists of one or more flat crystal planes (or detectors) optically coupled to an array of photomultiplier tubes, this mounted on a gantry. The gantry is connected to a computer system that both controls the operation of the camera as well as acquisition and storage of acquired images. The computer reconstructs and display a tow dimensional image of the relative spatial count density on a monitor. This reconstructed image reflects the distribution and relative concentration of radioactive tracer elements present in the organs and tissues imaged (Gopal, 2012).

2.1.1 Historical background

In 1940 simple information about radioactive source distribution within the brain were taken by single detector at various locations around the head, in 1950 this method was developed by Benedict Cassin.

The forerunner of modern nuclear medicine single-photon imaging systems, developed in 1958 by Hal Anger and in the late of 1970s gamma camera through the present have been developed to correct some of the uniformities seen older images [(NEMA,1994),(Rachel,2006)].

2.1.2 Principles of the Gamma Camera

The image of the distribution of the gamma ray mitting radiopharmaceutical is produced in the scintillation crystal by a collimator. The gamma rays, which are not visible to the eye, are converted into flashes of light by the scintillation crystal. This light is, in turn, transformed into electronic signals by an array of photomultiplier tubes (PMT) viewing the rear face of the crystal. After processing, the outputs from the PMTs are converted into three signals, two of which (X and Y) give the spatial location of the scintillation while the third (Z) represents the energy deposited in the crystal by the gamma ray. To improve their quality these signals then pass through correction circuits. The Z signal goes to a pulse height analyzer (PHA), which tests whether the energy of the gamma ray is within the range of values expected for the particular radionuclide being imaged. If the Z signal has an acceptable value, then a signal is sent instructing the display to record (Peter, 2005).

2.1.3 System Components

The basic components of a gamma camera system are the collimator, detector, signal processing, pulse high analysis, correction circuits and image display.

2.1.3.1 Collimators

In all nuclear medicine equipment for imaging, a collimator is attached to the face of a sodium iodide detector to limit the field of view so that all radiations from outside the field of view are prevented from reaching the detector. Collimators are made of lead and have a number of holes of different shapes and sizes. The number of holes in a collimator is increased the sensitivity of the detector increases, but there is comparable loss of septal thickness that results in septal penetration by relatively high energy rays and hence a loss in spatial resolution. One can increase the resolution or the detail of the image by decreasing the size of the holes in a given collimator or increasing the length of the collimator. This results in a decrease in the sensitivity of the camera. The sensitivity of the collimator is a function of hole size, shape and length and is inversely related to resolution. A given design of collimator will depend on the radionuclide to be used and the nature of the clinical investigation. In static image the collimator should be designed such that it offers a high resolution at a sensitivity, which will allow adequate clinical images to be obtained in reasonable time. For dynamic study, it is normally necessary to choose collimator with higher sensitivity and thus poorer resolution (Gopal, 2010).

Four basic collimator types are used with the gamma camera: pinhole, parallel hole, diverging, and converging. They show in figure 2.1. The different types of collimator are introduced subsequently. Their effects on the spatial resolution and sensitivity of the gamma camera (Cherry, 2003).

2.1.3.1.1 Pinhole collimator

These have a single hole, the pinhole usually 2mm to 4mm in diameter. Like a camera lens, the image is projected upside down and reversed right to left at the crystal. It is usually corrected electronically on the viewing screen. a pinhole collimator generates magnitude images of a small organ like the thyroid or a joint (Rachel, 2006).

2.1.3.1.2 Parallel-hole collimator

It consists of a lead plate containing a large number of holes. The parallel- hole collimator projected image of the same size as the source distribution onto the detector. The parallel-hole collimator is used for most studies; other designs of collimator are available for more specialized application (Peter, 2005)

Table 2.1. Factors affecting the performance of a parallel-hole collimator (peter, 2005)

Parameter that is increased	**Resolution**	**Sensitivity**
Number of holes	No change	Increases
Hole diameter	Worsens	Increases
Hole length	Improves	Decreases
Septal thickness	No change	Decreases
Distance of object from collimator	Worsens	No change

2.1.3.1.3 Diverging- hole collimator

Diverging collimator achieve a wider field of view by angling the opposite way, out ward to ward the organ. This is used most often on a camera with a small crystal, such as a portable camera, using a diverging collimator a large organ such as the lung can be captured on the face of a smaller crystal (Rachel, 2006).

2.1.3.1.4 Converging- hole collimator

In the converging collimator the holes are not parallel but are angled in ward toward the organ. The organ appears larger at the face of the crystal (magnifies the image) (Rachel, 2006).

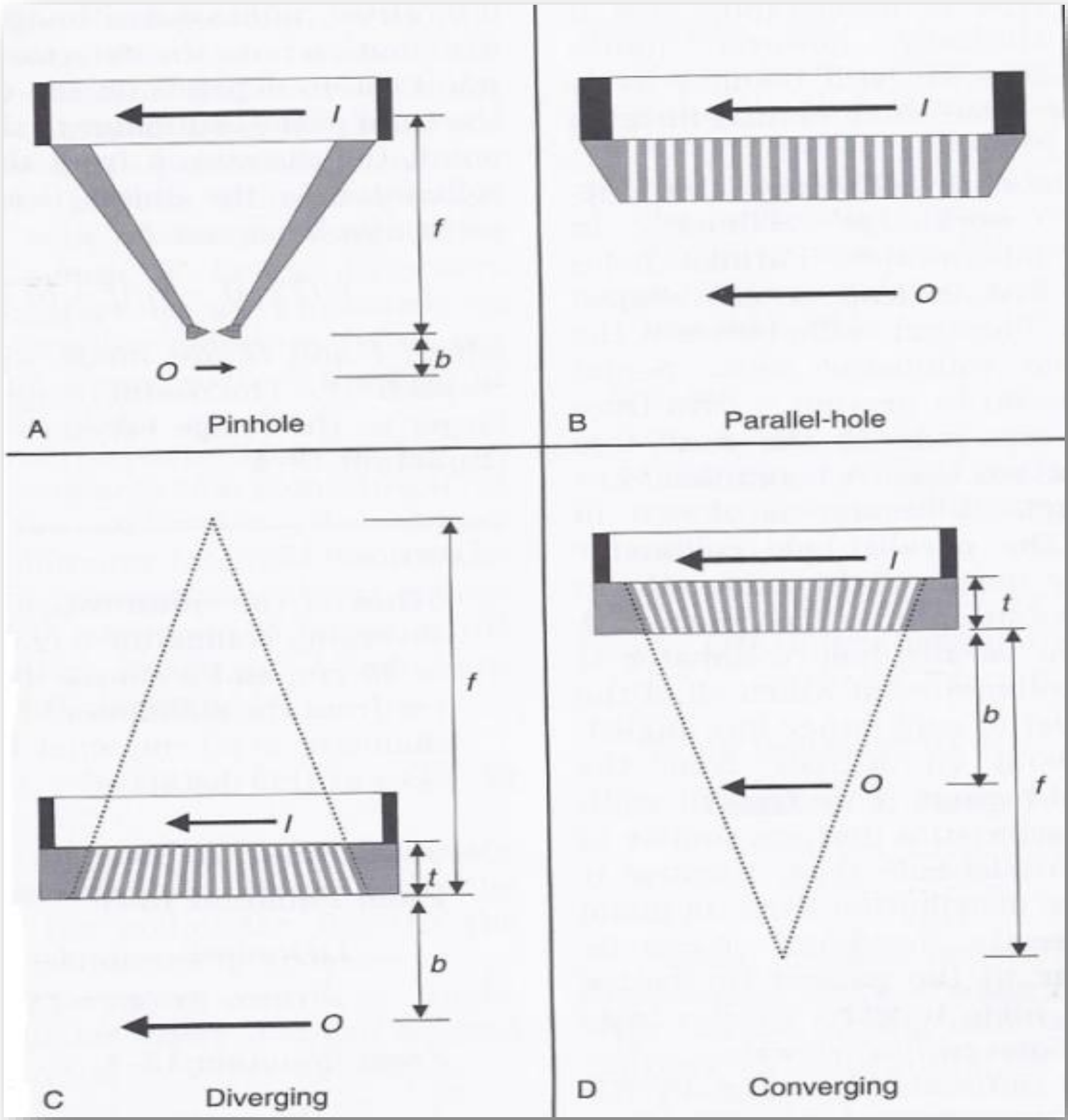


Figure 2.1. Different types of collimators

2.1.3.2 Detector

The detector head rotates around the long axis of the patient at small angle increment (3°-10°) for 180° or 360° angular sampling, producing pulse of fluorescent light proportional in intensity to the energy of the gamma ray. A sodium iodide crystal doped with a very small amount of thallium NaI (TI) is most commonly used for -ray detection. The choice of NaI (TI) crystals for -ray detection is primary due to their reasonable density (3.67g/cm^3), and high atomic number of iodine (z=53), that efficient production of light photons (one light photon/30 eV), upon interaction with -rays in the presence of a trace amount of Thallium (0.1-0.4 mole %). The NaI (TI) detectors of different sizes are used in different instruments. Increasing the thickness of a crystal increases the probability of complete absorption of rays and the sensitivity of the detector. (Gopal, 2010).

2.1.3.3 Photo Multiplier Tubes (PMT)

A photo multiplier tube (PMT) consists of alight sensitive photo cathode at one end, a series (usually 10) of metallic electrodes called dynodes in the middle, and an anode at the other end. All enclosed in a vacuum glass tube. The PMT is a fixed on to the NaI (TI) crystal with the photo cathode facing the crystal with special optical grease. The number of photo multiplier tubes in scintillation cameras it varies from 9 to 94 which are attached on the back face of the NaI (TI) crystal. When alight photon from NaI(TI) crystal strikes the photocathode, photoelectrons are emitted, which are accelerated toward the immediate dynode by the voltage difference between the electrodes. The accelerated electrons strike the dynode and more secondary electrons are emitted which are further accelerated. The process of multiplication of secondary electrons continuous until the last dynode is reached, where a pulse of 105-108 electrons is produced, and the pulse is then attracted to the anode and finally delivered to the preamplifier. (Gopal, 2010)

2.1.3.4 Preamplifier

The pulse from the PMT is small in amplitude and must be amplified before further processing; it is initially amplified with preamplifier that is connected to the photomultiplier tube PMT. A preamplifier is needed to adjust the voltage of the pulse shape and match the impedance levels between the detector and subsequent components so that the pulse is appropriately processed by the system. (Gopal, 2010)

2.1.3.5 linear amplifier

The output pulse from the preamplifier is further amplified and properly shaped by a linear amplifier. The amplified pulse is then delivered to a pulse high analyzer for analysis to its voltage. the amplification of the pulse is defined by the amplifier gain given defined of the amplitude of the outgoing pulse to that of the incoming pulse, and the gain can be adjusted in the range of (1- 1,000) by gain controls provided on the amplifier. The amplitude of output pulses normally are of the order of (0-10) V (Gopal, 2010).

2.1.3.6 Signal Processing

Three types of signal processing are to be found in use at present. Analogue circuitry was used in cameras exclusively until about the mid-1990s. Even though so-called digital cameras have been marketed since the mid-1980s, in practice they used analogue circuits to produce the X, Y, and Z signals and digitized them prior to them entering the signal correction and display.

2.1.3.7 Analogue Systems

The signals from the PMTs are processed to give the three signals required, X and Y providing spatial information and Z the energy. The energy signal is produced simply by summing the outputs from all of the tubes, so measuring the total light produced by the scintillation. The spatial information is more difficult to produce. required is that the processed signal should be proportional to the X or Y location of the scintillation. This is achieved by weighting the signals from each tube by passing the output from the PMTs through resistors or capacitors (Peter, 2005).

2.1.3.8 Digital Systems

Modern camera systems now rely heavily on digital technology, both for correction of the spatial, energy, and temporal information and for the analysis of image data. Since this requires the analogue signal to be digitized, the signals from the PMTs being digitized before the X, Y, and Z signals are computed. In the latter case each PMT has an analogue to digital converter located after the preamplifier, and the signal position is calculated from the centroid of the signals from a group of PMTs. The Z signal is calculated by summing the outputs from the group of tubes.

2.1.3.9 Pulse high Analyzer (PHA)

The pulse coming out of the amplifier may then be different in amplitude due to differing -ray energies. The Pulse High Analyzer is a device that selects for counting only those pulses falling with preselected voltage amplitude intervals and rejects all other. This selection of pulses is made by control knobs, called the lower and upper level, or (the base and window) provided on the PHA. In scintillation cameras, the two knobs are normally replaced by a peak voltage control and a percent window control. A PHA normally selects only one range of pulses and is called a single channel analyzer (SCA). A multi-channel analyzer (MCA) is a device that can simultaneously sort out pulses of different energies into a number of channels. In scintillation cameras the energy selection is made automatically by push-button type isotope selectors designated for different radionuclides such as ^{131}I – ^{99m}Tc (Gopal, 2010).

2.1.3.10 Correction Circuits

To improve image quality, it is only possible to correct where the cause of the distortion is not random. So, non-linearity can be corrected but not possible to improve the intrinsic spatial resolution of the camera.

2.1.3.11 Display or Storage

Information processed by the PHA is normally given in the form of pulses and counts that are stored for further processing Counts can be recorded for preset counts or time. In scintillation cameras, these counts are stored in a computer and processed further to form image. (Gopal, 2010).

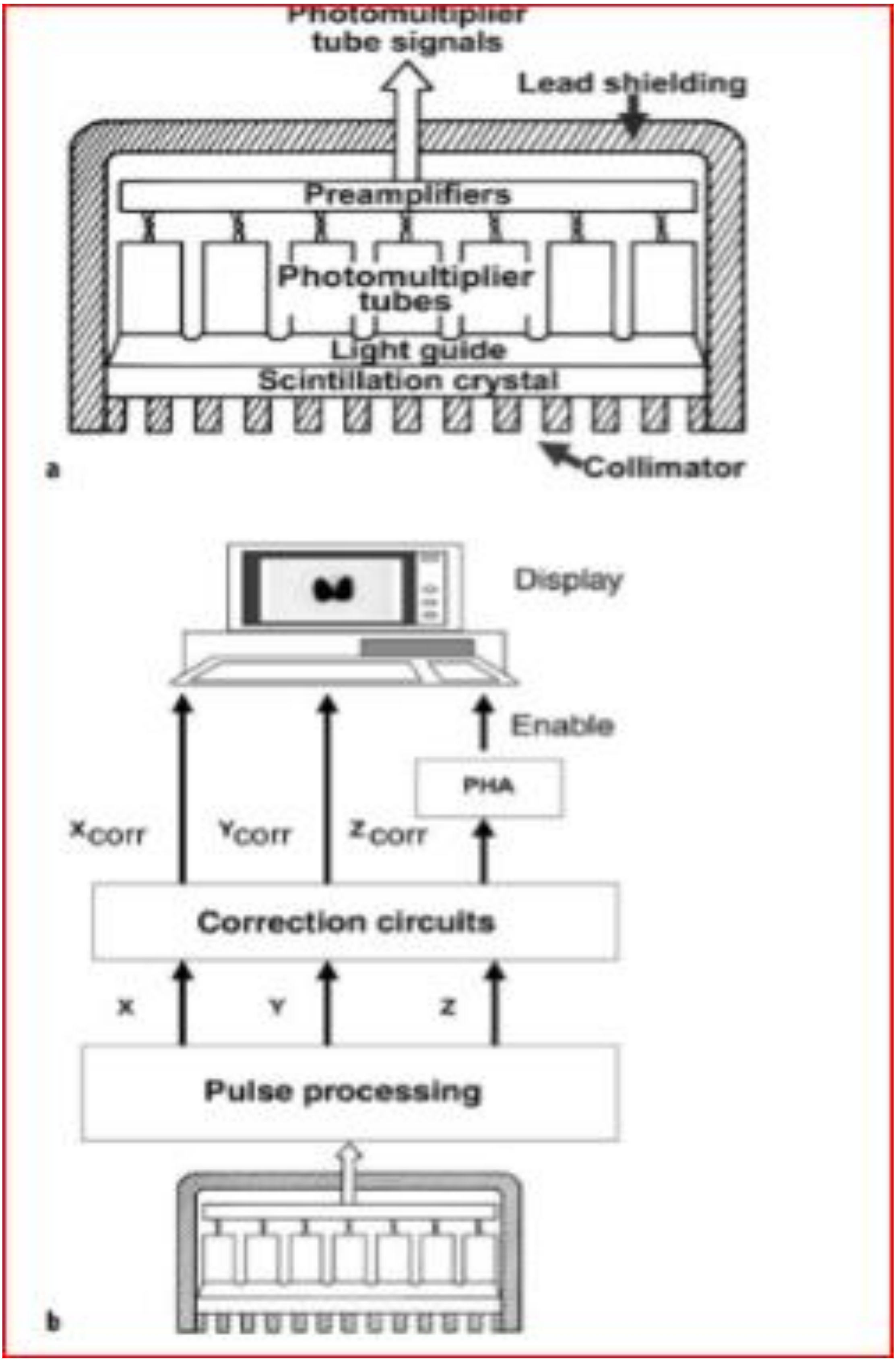


Figure 2.2. a) Detector head of gamma camera. b) Process of image obtained (peter, 2005).

2.1.4 Gamma Camera performance and quality control

The performance of gamma camera is characterized by six parameters included spatial resolution, uniformity, linearity, sensitivity, count rate characteristic and energy resolution. To understand gamma camera performance and routine QC, several terms like intrinsic versus extrinsic (or system) performance and useful versus the central field of view must be illustrated. Intrinsic performance refers to gamma camera performance without a collimator in place. While extrinsic performance refers to gamma camera performance whit collimator. The useful field of view (UFOV) of gamma camera is essentially the entire detector (crystal) area while the central field of view (CFOV) corresponds to the inner, or central, ¾ of the crystal area, the CFOV is the portion of the detector actually used in clinical imaging [(Peter, 2005), (Hans, 2007)].

2.1.4.1 Spatial Resolution

The spatial resolution is related to the smallest separation between two point sources which will permit them to be distinguished as two distinct sources and is measured by imaging a point or line source it is more usually, the line source is placed parallel to the collimator face and at a given distance from it. The measured quantities are the full width at half maximum (FWHM) is the width of the curve at half the peak count and full width at tenth maximum (FWTM) is the width of the curve at one tenth of the maximum counts of the resulting curve [(Peter, 2005), (Hans, 2007)].

2.1.4.2 Sensitivity

Sensitivity regarded to the detection efficiency of the camera. It is defined as the counting rate obtained per unit activity in a standard source geometry. It is affected primarily by the choice of the collimator and deteriorates as resolution improves for a given camera (Peter, 2005).

2.1.4.3 Linearity

Linearity of the gamma camera image is tested by examining the image of the bar phantom obtained with a high resolution collimator in place. The lines in the image should be straight and unbroken, note that linearity here refers to the appearance of the bars as lines. Integral linearity is assessed by calculating the variation in distances between adjacent pairs of line source images, while differential linearity measures the maximum in adjacent segments of any one line image [(Peter, 2005), (Hans, 2007)].

2.1.4.4 Energy Resolution

Energy resolution it is defined as the ability of gamma camera to distinguish between photons of different energies. The ability of the analyzer to rejected scatter photons is dependent upon the width of the photopeak in the energy spectrum, usually expressed in term of the FWHM. The pulse height analyzer require adjustment to properly center the window of photon energies accepted, the procedure for checking the location of the energy window is to place a vial or syringe containing a small quantity of isotope without collimator and the computer displayed a plot of counts veers energy. The user can then adjust the location and width of the window [(Peter, 2005), (Hans, 2007)].

2.1.4.5 Count Rate Characteristic

A gamma camera has a pulse processing time associated with each event. The region is reached in which the response of the camera (observed count rate) is no longer linear with increasing source radioactivity (true count rate). The theoretical linear response is obtained by extrapolation of the data points corresponding to count rates below 10^4 counts per second, it being assumed that no data loss occurs below this rate (Peter, 2005).

2.1.4.6 Uniformity

Ideally, a scintillation camera should produce a uniform image of a uniform source, this ideal is not met due to imperfections in the collimators, variations in crystal response, difference among PMT response and minor fluctuations in the electrical circuitry.

The uniformity of the camera's response can be checked by imaging a flood source. A solid plastic disk manufactured with 5 to 20 mCi of ^{57}Co uniformly distributed throughout its extend or a fluid filled sheet source containing a dilute solution of radioactivity is placed directly on the collimator (extrinsic flood field), and other used a point source suspended several feet at a distance three to four times the diameter of the crystal directly above the surface of the crystal (without collimator or intrinsic flood field), 5 to 30 million count image of the flood is then collected according to the manufacturer's directions (Rachel, 2006).

It is usual to carry out the calculations for both the useful field of view (UFOV) it is whole usable field of view and the central field of view (CFOV) is defined as an area centered on the UFOV (Peter, 2005).

2.1.4.7 Center of Rotation

It is assumed that the camera heads will rotate in a near perfect circle and that heads will remain almost precisely aligned in their opposing positions. It is also assumed that the predicted or electronic center of the path of rotation will match the mechanical or actual center of the camera head rotation. Deviation from either expectation will degrade image resolution and can be seen as a displacement of the center of rotation (COR). Probably the most common cause of apparent displacement of COR is a result of errors not leveling the camera head or bumping the table during data collection. The most common cause of true shift of the COR is electronic malfunction (Rachel, 2006).

2.1.5 National Electrical Manufactures Association (NEMA)

The National Electrical Manufactures Association is the trade body of gamma camera manufactures in the USA. They have defined arrange of standard tests for gamma camera performance in their publication (performance measurements of scintillation camera NEMA 2001). The purpose of that publication is to define a common set of criteria for measuring camera performance that can be used by all manufactures defines two types of standard, performance standards and class standards (NEMA 2001).

Table 2.2. Quality control procedures according to IAEA (International Atomic Energy Agency, 1991)

Test	Acceptance	Daily	Weekly	Half year	Monthly	Quarterly
Energy Spectrum	√	√				
Intrinsic uniformity	√	√				
Extrinsic uniformity	√	√		√		
Intrinsic energy resolution	√					√
Extrinsic energy resolution	√					
Intrinsic spatial resolution	√		√			
Sensitivity	√			√		
Center of rotation	√		√			

2.2 Previous Studies

Mark, 2001, Single photon emission computed tomography in the year 2001, titled as: instrumentation quality control, SPECT instrumentation is more complex than that used for whole body planner imaging and requires careful quality control to ensure optimum performance.

Goran, 2007, clinical center Banjaluka, RS, Bosnia and herzogovina, quality control in department of nuclear medicine, the aim of this work was to give a review of situation in the department of nuclear medicine in BanjaLuka related to quality control (perform daily, weekly, and monthly) control of equipment.

Helena Kopera and jarkkniemela 2006, Survey on quality control measurements for nuclear medicine imaging equipment in Finland in 2006, stated that: Routine quality control is an essential requirement in nuclear medicine in order to ensure optimal functioning of equipment, to harmomise the routine quality control of hospitals (planner gamma camera, SPECT, coincidence gamma cameras, PET). The radiation and nuclear safety authority will publish guidelines on quality control in collaboration with several hospital physicists. Recommendations will be provided on routine quality control measurements and on the frequency of testing. It is also planned to provide recommendations for the acceptance criteria when assessing different performance parameter for NM imaging equipment, in order to determine what performance parameters for NM imaging equipment are currently measured in hospitals, how frequently they are measured and what acceptance criteria are used, a survey was carried out on the quality control of NM equipment in Finland during 2006.

Mohammed 2009, evaluation of intrinsic uniformity and relative sensitivity of quality control tests for a single photon emission computed tomography (SPECT), the aim of study was to evaluate the optimum parameters (source activity, source volume, source distance, matrix size, number of counts required and count rates) affecting the intrinsic uniformity (IU) as quality control tests for the performance of a single photon emission computed tomography (SPECT). The relative sensitivity (RS) was determined also. The study was carried out at the Nelein medical diagnostic center in Khartoum NMDC, department of nuclear medicine. The tests were usually performed by exposure the gamma's crystal to a uniform flux of gamma radiation from a Tc^{99m} point source.

Jabari, 2004, the appropriate energy window width for gamma camera, the different methods of scatter correction have been introduced in order to improve the quality of data, However, the best method is to avoid recording of scatter photons in acquision. The only difference between scattered and non- scattered photons is the energy. Pulse high analyzer is the only option available to discriminate primary photons from scattered ones. Energy resolution of the gamma camera is gradually improving consequently the energy window width has to be decreased accordingly.

Alighieri,1999, A Comparative study between collimators commonly used in SPECT, the purpose of the current study is comparative evaluation of tomographic spatial resolution of two collimators (parallel hole high resolution collimators (LEHR), parallel hole general purpose collimator (LEGP)) commonly used in SPECT systems.

Kera, al. kakulgaku, 1992, Effect of scattering and spatial resolution on SPECT quantification values, the relative SPECT values are often inaccurate by the scattering and limited spatial resolution of single photon emission computed tomography (SPECT). These effects were studied using cylindrical phantom divided into six compartments filled with various radio activities, the linear correlation between SPECT value and radioactivity, and also correlation with partial reduction of radioactivity were identified. But the SPECT value was relatively increased in proportion to the reduction of radioactivity due to the increase of scattering contribution. The SPECT value represented lower radioactivity when the cortical thickness was smaller than two times of FWHM and represented half radioactivity when the cortical thickness was equal to FWHM.

Ghanim 2012, evaluation of quality control program in nuclear medicine departments in Sudan, the aim of that study is to evaluate routine quality control tests in nuclear medicine departments procedures in Sudan and to compare the results with international guidelines, it includes three gamma cameras machines and three dose calibrators.

Salma 2013, Assessment of Gamma Camera Performance in Nuclear Medicine Departments- Khartoum, this study was performed to evaluate the gamma camera machine performance in nuclear medicine at Alneelain Medical Center (NMDC) for the following parameters: Energy Resolution, Uniformity, center of rotation and sensitivity by using ^{99m}TC.

Tagwa 2016, Evaluation of Performance of the SPECT Camera in El-Nilien Medical Diagnostic Centre in Khartoum, the objective of this study is to evaluate the performance of the SPECT gamma camera at El-Nilien Medical Diagnostic Centre of Khartoum. The study evaluates the following parameters: energy resolution, uniformity, sensitivity and linearity. All results that obtained from the study have been compared with the acceptance limits with IAEA and NEMA -2001 standards.

CHAPTER THREE

MATERIALS & METHODS

3.1 Materials

This study was carried out in two departments of nuclear medicine performing diagnostic procedures in Khartoum State, (RCIH) and (NMDC) these hospitals chosen because they have considerable number of patients for nuclear medicine examinations performed on daily basis.

The equipment used in this study include;

- Two Gamma camera machines,
- Dose calibrator **(manufacture:** BIODEX, **model:** 086-336, **serial no**. 62110008)
- Syringes **volume** (1-5), (1-3) ml
- Point source (Tc^{99m}) **activity** (0.4 - 1) ml Ci
- Source holder
- Resolution phantom (Four quadrant bar pattern) bar widths range (2 ~ 3.5) mm.

3.1.1 Gamma cameras

Tow Gamma cameras were used in this study. The specifications of these machines are listed in table (3.1).

Table 3.1. the specifications of gamma camera machines

Centre & Hospital	**Manufacture**	**Model**	**Serial number**	**Date of installation**
RCIH	Nucline Spirit	Double head	DH-004167-V0	2010
NMDC	Orbiter Digi37 WB	Single head	2008 ⁄43	2009

3.2 Methods of data collection

Measurements were performed for evaluation of image resolution including energy spectrum, energy resolution, spatial resolution and uniformity in gamma camera at nuclear medicine department in RCIH and NMDC.

Data concerning the status of quality control tests and their frequency were collected using data sheets from the two departments of nuclear medicine and the data collected covered energy spectrum, uniformity energy resolution, spatial resolution, linearity, sensitivity, center of rotation and counting rate performance.

3.2.1 Spectrum or photopeaking

This procedure apparent as curve to show the relationship between the detected and the measured energy of gamma photon.

Procedure

- Place (Tc^{99m}) point source at distance 5*UFOV from the collimator.
- Make the two head of collimator perpendicular to each other dual head.
- From main menu select and acquire patient study and press computer will calculate and then show the spectrum as figure 4.1

3.2.2 Energy resolution

The cameras ability to distinguish between photons of different energies, in particular between primary and scattered radiation. Usually expressed in terms of the FWHM.

Procedure

- Peak the camera for the isotope used (Tc^{99m}); select a window width of 20%, use matrix size (256*256*16).
- Sure the point source in the central of the detector.
- Place (Tc^{99m}) point source at distance 5*UFOV from the camera head.
- Acquire a digital energy spectrum.
- Calculate FWHM (keV) as % of peak energy.

The ER is given by (Hans, 2007):

$$ER\% = (FWHM/\text{photopeak center}) \times 100$$

3.2.3 Spatial Resolution

Spatial Resolution is a measure of the sharpness and detail of gamma camera image. To test the intrinsic spatial resolution of a scintillation camera in terms of the full width at half maximum (FWHM) of its line spread function.

Procedure

- Remove the collimator from the detector head.
- Position the lead mask centrally on the crystal housing.
- Mount the source in the source mounting.
- Centre a 20% PHA window on the photopeak.
- Position the quadrant bar phantom so that it is supported on the detector head housing and as close to the crystal housing as possible. The bars should be carefully aligned with the X- and Y-axes of the detector face.
- Acquire an image on the display at a preset count of 6×106.
- Rotate the quadrant bar phantom through 90^0 and repeat last step.
- Repeat this process two additional times. Invert the phantom, and acquire a similar set of four images so that the smallest bars are imaged in each quadrant in each direction.
- Accurately measure the widths, B, of the bars in the quadrant bar phantom.
- Determine the widths of the smallest bars that the scintillation camera can resolve in the X and Y directions. This can be done by visual inspection of the images.
- Estimate the intrinsic spatial resolutions in the X and Y directions in terms of the full width at half maximum FWHM, of the line-spread function, using the relationship

$$FWHM = 1.75B$$

where **B** is the width of the smallest bars that the camera can resolve.

3.2.4 Uniformity

The camera ability to detect a uniform source of radioactivity distribution.

Integral uniformity:

the difference between the maximum and minimum pixel count.

$$IU\ (\%) = (max - min)/\ (max + min) \times 100$$

Differential uniformity:

the difference between two adjacent pixels.

$$DU\ (\%) = (max - min)/\ (max + min) \times 100$$

Procedure

- peak the camera for the isotope used (Tc^{99m}); select a window width 20%, use matrix size (256*256*16).
- sure the point source in the central axis of the detector.
- Place the (Tc^{99m}) point source at the 5*FOV from the camera head.
- Adjust the activity isotope used such that the count rate does not exceed 30,000 cps.
- Calculate Integral and differential uniformity from the computer.

CHAPTER FOUR

RESULTS

The result of thesis was presented in this chapter which includes results of resolution and frequency of quality control tests for gamma camera in tow departments of nuclear medicine performing diagnostic nuclear medicine procedures in Khartoum at a period from January-2017 to September-2017.

4.1 Results for resolution tests

4.1.1 Spectrum and energy resolution test

Table 4.1 shows results of energy spectrum testing

Hospital & center		**Result**
NMDC		139 keV
RCIH	**Head 1**	139.86 keV
	Head 2	140.58 keV

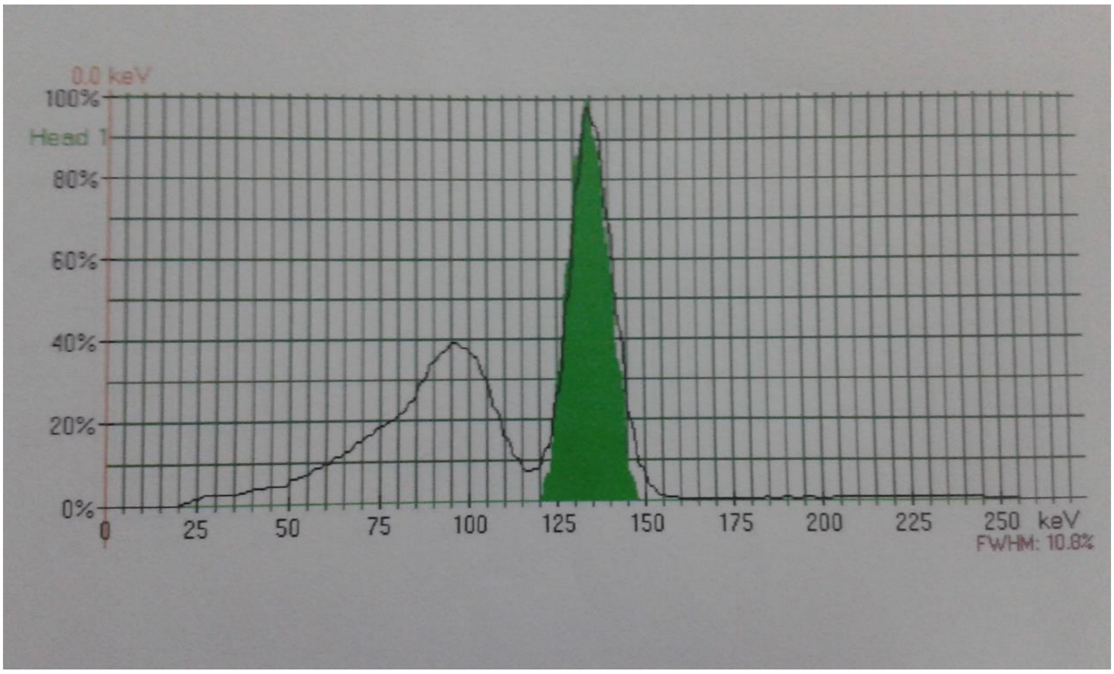


Figure 4.1 Spectrum for gamma camera machine in NMDC

Table 4.2 shows results of energy resolution

Hospital & center		Result	ER%
NMDC		10.8 % at FWHM	7.77
RCIH	**Head 1**	10.1 % at FWHM	7.22
	Head 2	10.54 % at FWHM	7.5

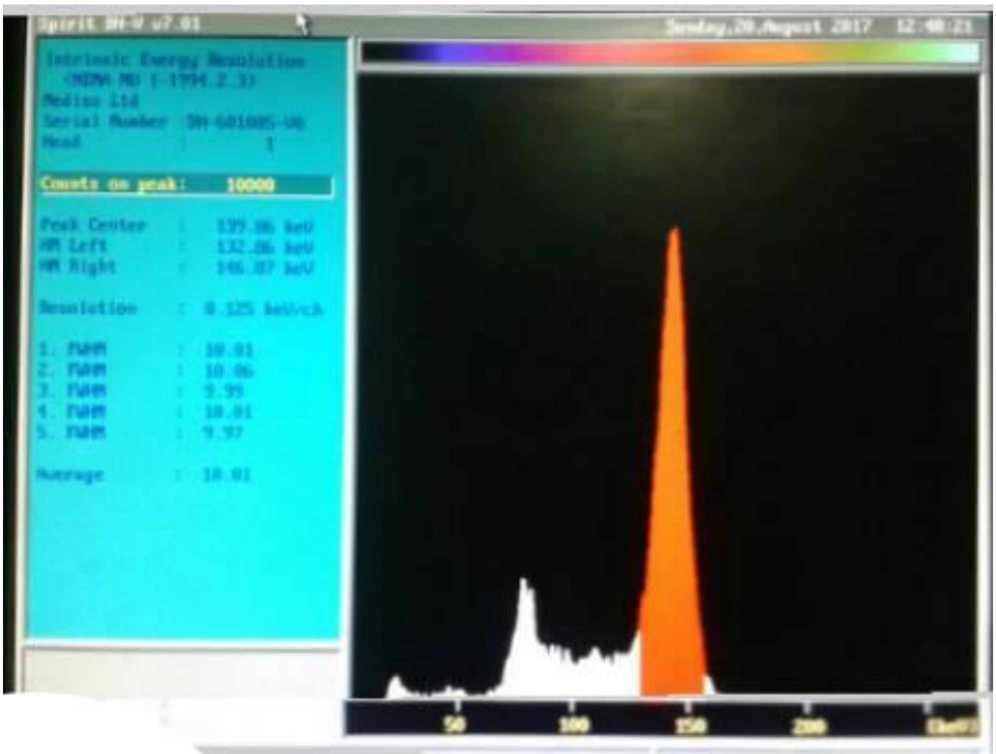


Figure 4.2 energy resolution test for gamma camera machine in RCIH

4.1.2 Spatial resolution test

Table 4.3 Results of spatial resolution

Hospital & center		Result		
		X	**Y**	**FWHM**
RCIH	**Head 1**	B = 2.5 mm	B = 2.5 mm	(X) = 4.38 mm (Y) = 4.38 mm
	Head 2	B = 2.5 mm	B = 2.5 mm	(X) = 4.38 mm (Y) = 4.38 mm

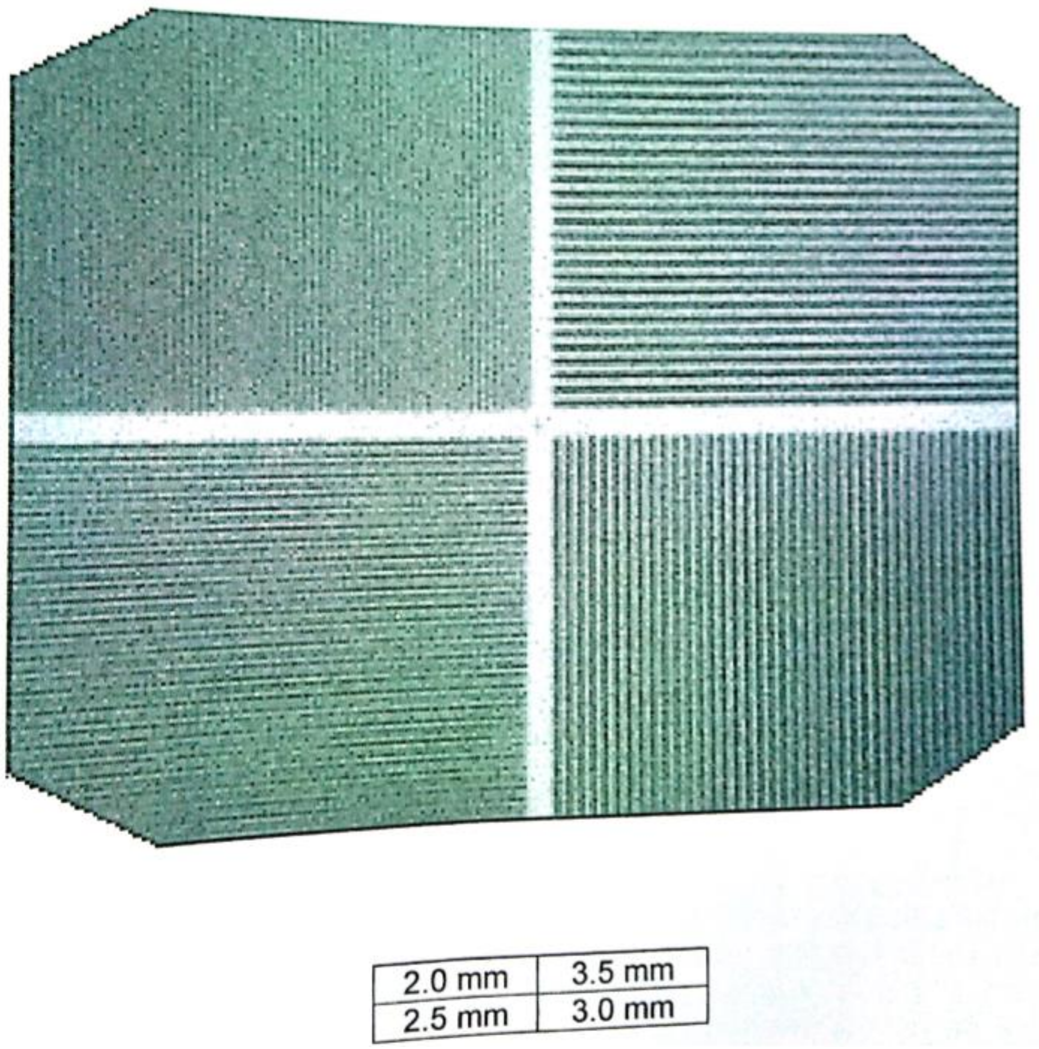


Figure 4.3 Spatial resolution test for gamma camera machine in RCIH

4.1.3 Intrinsic uniformity test

Table 4.4 Results of Intrinsic uniformity

Hospital & center		Result			
		UFOV		CFOV	
		Diff	Int	Diff	Int
NMDC		3.26 %	5. 9 %	2.02 %	3.55 %
RCIH	**Head 1**	2.8 %	3.6 %	2.3 %	2.7 %
	Head 2	1.7 %	2.6 %	1.7 %	2.5 %

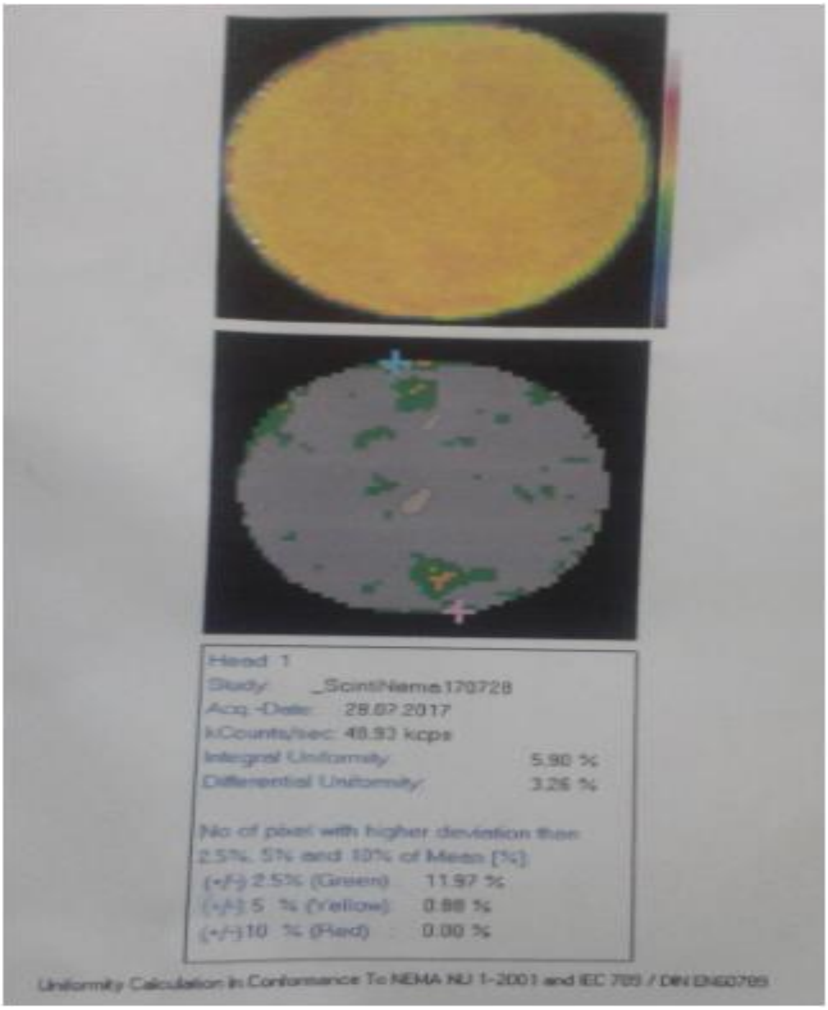
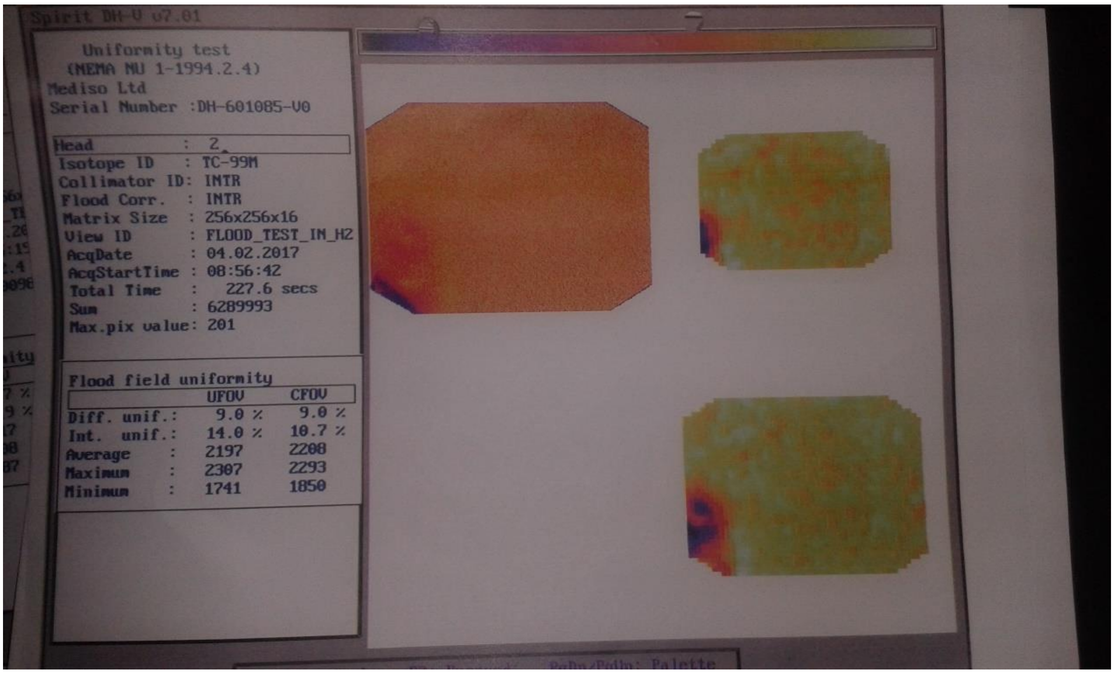


Figure 4.4 Uniformity test for gamma camera machine in NMDC



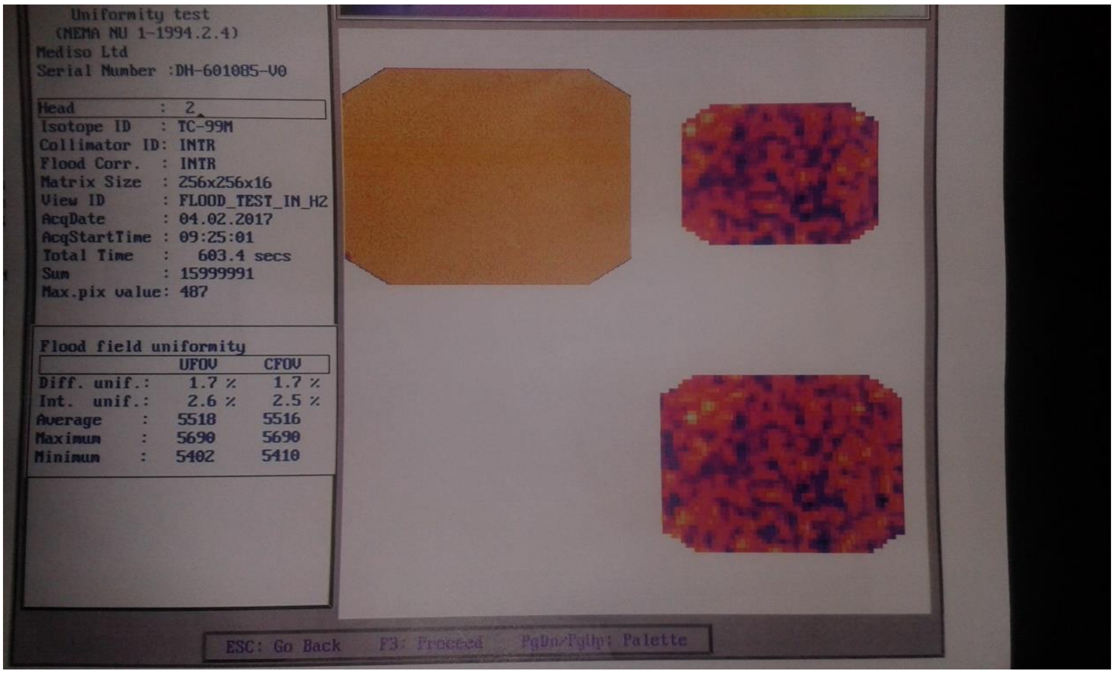


Figure 4.5 Uniformity test for gamma camera machine in RCIH

4.2 Results of Frequency of Quality control tests

In departments of nuclear medicine performing diagnostic nuclear medicine procedures in RCIH and NMDC responded to the questionnaire for frequencies of quality control tests show in figures below

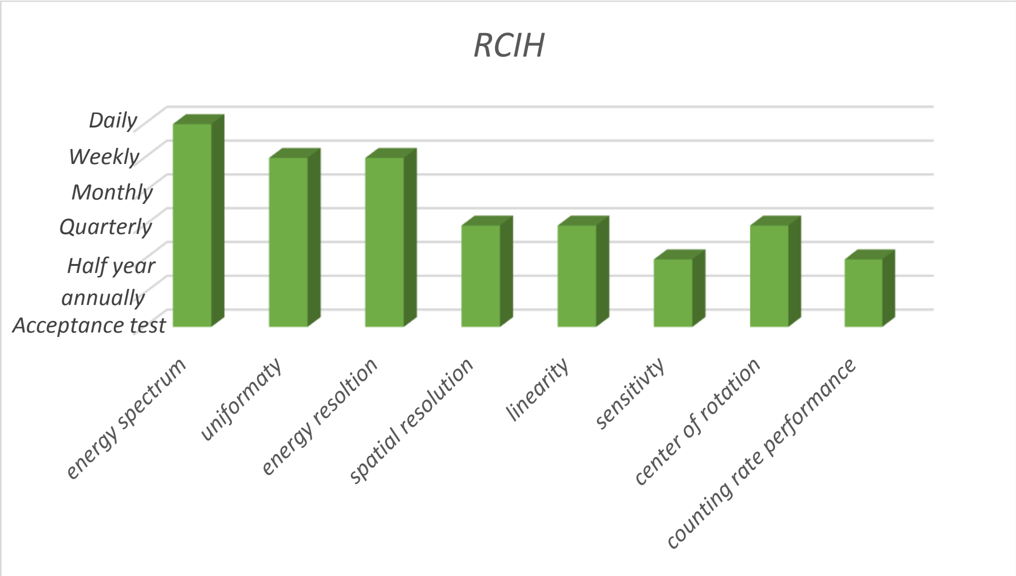


Figure 4.6 Frequency of Quality control tests in RCIH

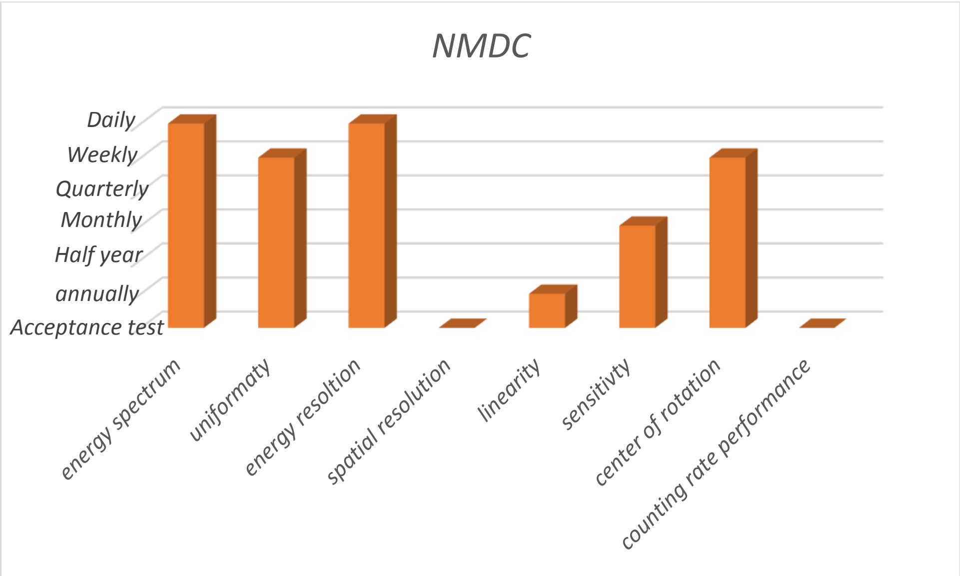


Figure 4.7 Frequency of Quality control tests in NMDC

CHAPTER FIVE

DISCUSSION, CONCLUSION & RECOMMENDATIONS

5.1 Discussion

The data were collected form two departments of nuclear medicine performing diagnostic nuclear medicine procedures in Khartoum. The data collected can be divided into:

- practical direct measurement to evaluate image resolution include energy spectrum, energy resolution, spatial resolution and intrinsic uniformity in gamma camera at nuclear medicine department.
- quality control tests and the frequency of tests for gamma cameras included energy spectrum, uniformity, energy resolution, spatial resolution, linearity, sensitivity, center of rotation and counting rate performance

The first part of results show that measurements:

- The energy spectrum test result for two hospitals were in the acceptable limits (140$\pm$ 10 keV) that established by IAEA organization that illustrated in table 4.1
- Table 4.2 has presented the energy resolution test results for these hospitals in the acceptable limits according to IAEA standards their typical value in the range 9% to 11% at FWHM.
- The spatial resolution test for RCIH was in the accepted limits that established by NEMA-2001 that illustrated in table 4.3, the typical values of intrinsic spatial resolution is 2.5 to 3.5 mm for width of the smallest bars can resolve
- Table 4.4 has presented the intrinsic uniformity test results for differential and integral in two hospitals were in the acceptable limits according to IAEA standards (not more than 5%).
- Figure 4.5 shows artefact image before and after correction during uniformity test

The second part of results presented frequency of quality control tests illustrated in graphs contained from two axis (y) presented frequency of quality control tests and (x) type of tests.

- The frequency of energy spectrum for the two centres were found to be within the acceptance level.
- The frequency of uniformity for tow center the perfume weekly
- The frequency of energy resolution test was performed on a daily basis in NMDC, while RCIH perform the test on weekly basis.
- Spatial resolution test frequency that perform quarterly in RCIH center and not performed in NMDC.
- linearity test frequency that perform half year in RCIH center and was performed annually in NMDC.
- Sensitivity test frequency that perform half year in RCIH centers and quarterly in NMDC.
- The center of rotation test frequency that perform quarterly in RCIH center and weekly in NMDC.
- Counting rate performance test frequency that perform quarterly in RCIH and was not performed in NMDC.

5.2 Conclusion

Quality control is required to ensure that nuclear medicine equipment is functioning properly. This quality control tests are intended to detect problems before they impact on clinical patient studies for gamma camera machine (SPECT), the researcher managed to evaluate the image resolution of the single photon emission computed tomography working in nuclear medicine departments in RCIH hospital and NMDC centre and determent the minimum frequency of quality control tests and compare it with NEMA.

The quality of medical images was high and provides good care of patients. A regular quality assurance tests improve quality management of nuclear medicine imaging.

The results reveal that the energy resolution showed a central peak of the energy at 139 keV, 139.86 and 140.58 keV and the value of the energy resolution was 7.77%, 7.22% and 7.5% at NMDC and two heads for RCIH respectively. Also results showed that the spatial resolution test for RCIH was 4.38 mm 4.38 mm (FWHM in X&Y), and the intrinsic uniformity for differential and integral were in the accepted limits that established by NEMA-2001 for two hospitals.

- In NMDC there is no resolution test phantom available in center.
- In RCIH they not have enough time to measure QC tests.
- They applied the QC tests procedures like standards set by the IAEA and NEMA.
- The most of tests they measure without collimator (only intrinsic tests).
- There may be some artefacts in the images during the tests they caused by the change in temperature and electricity; the machine is correcting automatically.

5.3 Recommendations

- Applying a quality assurance program (QA) that include quality control tests for gamma camera machines, radionuclide, and dose calibrators, waste management and radiation protection program, is essential to decrease the radiation risks for patients and staff.
- Applying the ALARA (As Low As Reasonably Achievable) principle in nuclear medicine practice reduces the radiation dose to patients.
- Raising the standards of technologists through training the quality of the image and prevent repetitions
- The regular quality control for gamma camera is essential to ensure proper function of the device.
- The surrounding environmental conditions of the test and operation should always be considered and recorded.
- Encouraging the cooperation of the relevant regulatory bodies and nuclear medicine centers in Sudan improves nuclear medicine practice.
- Encouraging the cooperation of the relevant regulatory bodies in Sudan with international atomic energy agency to provide technical support training courses and quality control tools for nuclear medicine centers through regional projects.
- I think must be they nuclear medicine departments need spatialized day for applied quality control tests.

References

Cherry SR, sorensond A and Phelps ME, 2003, physics in nuclear medicine, 3d edition, Elsevier science, USA,211-321.

Gopal B. Saha. Physics and Radiobiology of Nuclear Medicine. Springer: 2012

Hans-Jurgen Biersack, Leonard M. Freeman. Clinical Nuclear Medicine. Spriner: 2007

International Atomic Energy Agency (IAEA), 1991, quality control of nuclea medicine instrumentations, IAEA, TECDOC602. Jerrold J, J.Anthonyseibert,

Michael K. O'Connor, Quality Control of Scintillation Cameras (Planar and SPECT)

National Electrical Manufactures Association (NEMA), 2001, performance measurements of scintillation cameras, NEMA Standard puplication NU-1-2001, Washington, D-C-USA,Global Engineering Documents.

Peter F. S., Howard G. Gemmell, Alison D. Murray. Practical Nuclear Medicine. Springer: 2005

Rachel A. Powsner, Edward R. Powsne. Essential Nuclear Medicine physics. Second edition, Blackweel Publishing, 2006.

Shankar Vallabhajosula, Molecular Imaging Radiopharmaceuticals for PET and SPECT. Spriner: 2009

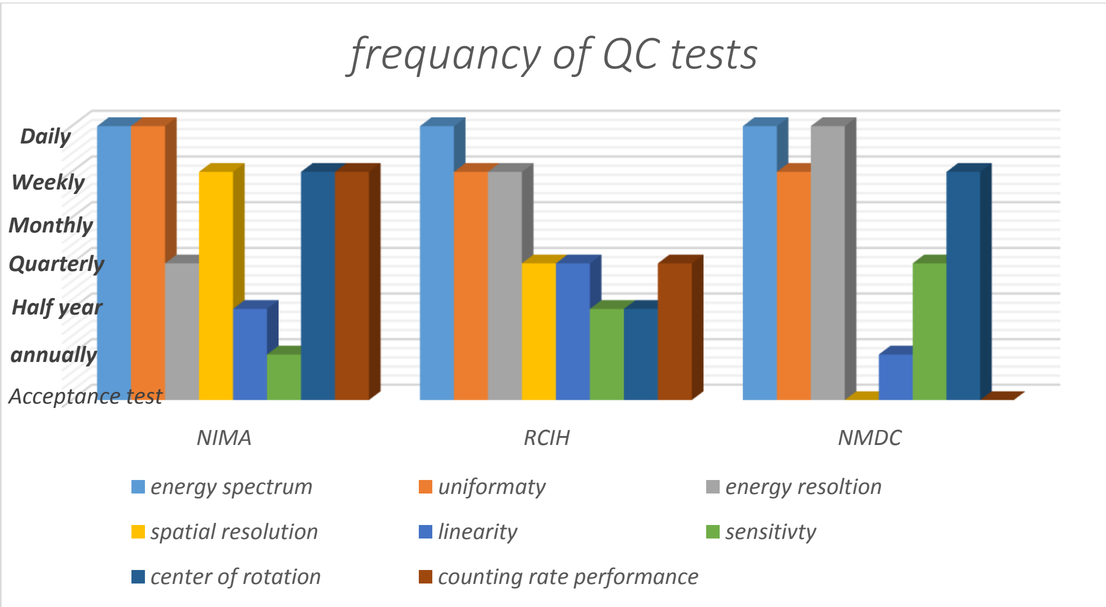
Technical Standards Subcommittee of the Australian and New Zealand Society of Nuclear Medicine (ANZSNM), MINIMUM QUALITY CONTROL REQUIREMENTS FOR NUCLEAR MEDICINE EQUIPMENT, Version 5.7 November 1999.

APPENDICES

Appendix.1. Gamma camera machine (SPECT) in hospital (RCIH)

Appendix.2. Gamma camera machine (SPECT) in hospital (NMDC)

Appendix.3. Resolution phantom (Four quadrant bar pattern) in hospital (RCIH)



Appendix.4. Frequency of Quality control tests in two departments compare with NEMA