بسم الله الرحمن الرحيم

Sudan University of science and technology

College of Graduate Studies

Evaluation of Performance of the SPECT Camera in Elnilien Medical Diagnostic Centre in Khartoum

تقويم أداء جهاز قاما كاميرا للأشعة المقطعية المحوسب بمركز النيلين التشخيصي بالخرطوم

This research was submitted for partial fulfillment of MSc Degree in medical physics

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جامعة السودان للعلوم والتكنولوجيا

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Approval Page

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قال تعالى:

{وَقُلِ اعْمَلُواْ فَسَيَرَى اللّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُون}

صدق الله العظيم

[التوبة:105

]

Dedication

I dedicate this work

To those who learned me always to go ahead towards success

To My mother

The source of smile of my life who does a lot of things for me to be a good person

To My father

.To my brothers and sisters who supported me

Acknowledgment

First of all, I would like to thank Allah for giving me the power to complete this work. Then I would like to express my special :thanks to my supervisor

Uz / Awadh AbdAllah Adlan

.For his fruitful help

Also I would like to thank the staff in the nuclear medicine department in Elnelien medical Centre in which this work was .done

List of Figures

List of Tables

List of abbreviations

NM	Nuclear Medicine
QC	Quality Control
QA	Quality Assurance
PMT	Photo Multiplier Tube
(NaI (TI	a thallium-activated sodium iodide crystal
PH A	pulse High Analyzer
SPECT	Single Photon Emission Computed Tomography
UFOV	Useful Field Of View
CFOV	Central Field Of View
FWHM	Full Width at Half Maximum
COR	Centre of Rotation
AOR	Axis of Rotation
NEMA	National Electrical Manufactures Association
RS	Relative Sensitivity
NMDC	Nilein Medical Diagnostic Centre
IAEA	International Atomic Energy Agency
Kev	Kilo electron volt
FOV	Field of View
KVp	kilo volt peak
SCA	Single Channel Analyzer
MCA	Multi-Channel Analyzer

Listof contents

Abstract

The objective of this study is to evaluate the performance of the SPECT gamma .camera at Alnilien Medical Diagnostic Centre of Khartoum

This study was carried out in Nuclear Medicine Department in Alnelein Medical Diagnostic Centre (NMDC) and the results were compared with the international guidelines. 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

The results reveal that the energy resolution showed a central peak of the energy at 140KVp and the value of the energy resolution was 7.6%. Also results showed that the average of differential uniformity was 3.4% and it was within the acceptable value, and the integral uniformity was 1.94%. Also the results showed that the average of sensitivity was 83.4cpm/MBq , and the results reveal the average linearity value of 1.3mm that detect distortion of linearity due to X and Y positions do not change linearly with displacement distance of radiation source .across the face of the detector

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

ملخص البحث

تهدف هذه الدراسة إلى تقويم أداء جهاز قاما كاميرا للأشعه المقطعية المحوسب بقسم الطب النووي في مركز النيلين التشخيصي بالخرطوم.

أجريت هذه الدراسة لتقويم آداء جهاز قاما كاميرا المقطعي في قسم الطب النووي بمركز النيلين التشخيصي في الخرطوم وتمت مقارنة هذه النتائج مع موجهات الإرشادات الدولية.

تتضمن هذه الإختبارات المتغيرات الآتية: إختبار حدية الطاقه، الإتساق، الخطية والحساسية.كل النتائج المتحصل عليها من الدراسة تمت مقارنتها مع حدود الأمان التي وضعتها الوكاله الدولية للطاقة الذرية والنيما 2001.أظهرت النتائج أن قرار الطاقه عند القمة المركزية من الطاقة (140كيلوفولت) وحد الطاقة حوالي (7.6%).وأظهرت النتائج معدل الاتساق الخطي حوالي (3.4%) الذي كان ضمن الحدود المقبولة ،بالاضافة الى الإتساق التكاملي الذي وجد حوالي (1.94%) ، وأيضاً أظهرت النتائج متوسط الحساسية حوالي 83.4 cpm/MBq.

وتكشف النتائج أيضاً متوسط الخطية الذي وجد حوالي 1.3مم التي تكتشف تشويه الخطية بسبب مواقع (y, x)لاتتغير بشكل خطي مع إزاحة مصدر الإشعاع عبر وجه الكاشف، ينبغي ان تكون الصورة عالية الجودة لضمان العناية الكاملة للمرضى.إنتظام ضبط الجودة بواسطة مراقب مستقل يعد واحد من مبادئ تطبيق إدارة الجودة الكلية للطب النووي.

Chapter One: General introduction

-:1-1Introduction

Single photon emission computed tomography (SPECT) is dependent on photon detection, localization and multi-plane image acquisition and reconstruction. Dr. Harold Anger paved the way for SPECT imaging through the introduction of scintillation or Anger camera in the 1950s. The basic physics of the Anger camera allows for photon detection and estimation of the photon origination for planar imaging. The essential components of photon detection and localization for Imaging include the crystal, photomultiplier tube (PMT), electronics, and collimator. The use of single-photon emission tomography has become widespread since its .(introduction in the late 1970s. (Hans, etal, 2007

SPECT has been especially useful in providing tomographic images of myocardial perfusion, the lumbar spine and cerebral perfusion. Much of the research involving radio labeled antibodies has been performed on SPECT instrumentation. SPECT provide high-contrast images of the three-dimensional distribution of internally distributed radiopharmaceuticals. These images not only allow accurate anatomic localization of abnormalities , but also have the potential for providing quantitative information about both the regional concentration of radio activity and it is volume of distribution .However. The acquisition of High-quality SPECT images requires careful attention to detail and the routine performance of quality procedures to avoid the production of .(artifacts. (Graham, 1995

Nuclear medicine is a medical specialty involving the application of radioactive substances in the diagnosis and treatment of disease. In nuclear medicine procedures, radionuclides are combined with other elements to form chemical compound or else combined with existing pharmaceuticals. The radiopharmaceuticals once administered to the patient, can localize to specific organs or cellular receptors. This property of radio pharmaceuticals allows nuclear medicine the ability to image the extent of a disease process in the body, based on the cellular function and physiology. In some diseases nuclear medicine studies can identify medical problems at an earlier stage than other diagnostic tests. Nuclear medicine, in a sense, is radiology done inside out or "end radiology" because it records radiation emitting from within the body rather than radiation that is generated by external sources like x-rays. The performance of machines may decrease and fluctuate and accordingly the results of medical investigations could vary. (Peter, .(2005

The primary purpose of a quality control program in a nuclear medicine department is to verify that the images obtained accurately reflect the distribution of radiopharmaceuticals within a patient. Quality control tests have an important, sensitive role in monitoring changes in performance so that service can be scheduled and performed before the need becomes critical and requires cancellation of patient studies. .((Graham, 1995

:Problem of the study 1-2

Changing one parameter in the SPECT performance will affect all other, and produce artifacts in reconstructed image; these artifacts may not be visible in regular quality control flood image which leads to in- .diagnosable image

:Objectives 1-3

:General objective 1-3-1

- To evaluate the performance of the SPECT Camera in Nuclear Medicine Department in Elnelien Medical Diagnostic Centre in .Khartoum

Specific objective 1-3-2

- .To determine the uniformity of the SPECT
- .To measure energy resolution of the SPECT
- .To determine the linearity of the SPECT
- .To measure the sensitivity of the SPECT
- To compare the results with the standards set by the IAEA and . NEMA

:Study overview 1-4

This research consists of five chapters. Chapter one deals with introduction, problem of study, and objectives. Chapter two deals with literature review related to the current study. Chapter three shows the methodology upon which the study carried out. Chapter four shows the results, and chapter five shows the discussion, conclusion, .recommendation and references

Chapter two: Theoretical Background

:Main Components of SPECT camera 2-1

The most common SPECT systems consist of typical gamma camera with one to three a thallium-activated sodium iodide crystalNaI (TI) detector heads mounted on a gantry and on-line computer for acquisition and processing of data and a display system. The basic components of a gamma camera system are the collimator, the scintillation crystal, an array of photomultiplier tubes (PMTs), preamplifiers, a pulse-height analyzer (PHA) ,X,Y Position circuit and Display or Storage.(Fred etal , .(2006) (Gopal , saha ,2010

:2-1-1collimator

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 ㅎ -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, Saha, 2010

:2-1-2Types of collimator

:Pinhole collimator 2-1-2-1

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

:Parallel-hole collimator 2-1-2-2

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, etal, 2005

Table (2-1): factors affecting the performance of a parallel-hole .(collimator (peter etal, 2005

Parameter that is increased	resolution	Sensitivity
Number of holes	No change	Increases
Hole diameter	worsens	Increases
Hole length	improves	Decreases
Spatial thickness	No change	Decreases
Distance of object from collimator	worsens	No change

:Diverging collimator 2-1-2-3

Diverging collimator achieve a wider field of view by angling the opposite way, out ward toward 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

:Converging collimator 2-1-2-4

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

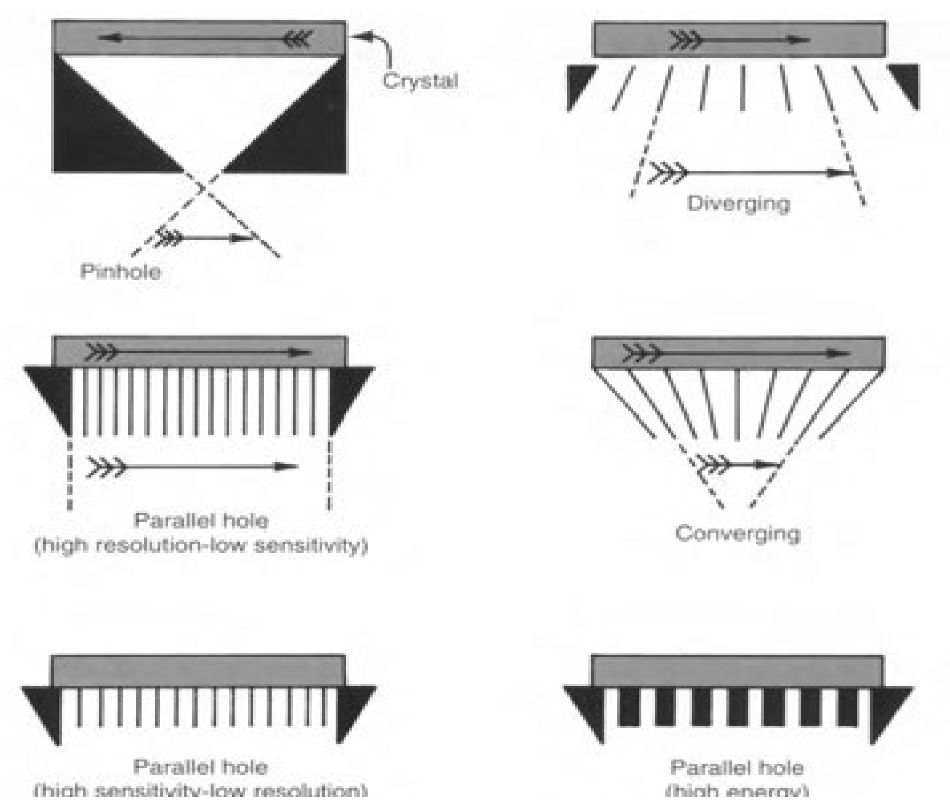

Fig (2-1) Types of collimators

:2-1-3Detector

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 γ-ray detection. The choice of NaI (TI) crystals for γ-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 γ-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 γ-rays and the .(sensitivity of the detector. (Gopal,Saha, 2010

:(2-1-4Photo 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 10^5-10^8 electrons is produced, and the pulse is then attracted to the anode and finally delivered to .(the preamplifier. (Gopal ,Saha, 2010

:preamplifier 2-1-5

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,Saha, 2010

:linear amplifier 2-1-6

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, .(saha,2010

:X, Y Positioning Circuit 2-1-7

When a gamma- ray interacts in the crystal, its exact location is determined by the X, Y positioning circuit in conjunction with an array of PM tubes. Many PM tubes (19–94) are mounted on the NaI (Tl) crystal in scintillation cameras. After gamma-ray interaction in the crystal, a maximum amount of light will be received by the PM tube nearest to the point of interaction, whereas other PM tubes will receive an amount of light directly proportional to the solid angle subtended by the PM tube at the point of interaction. The X, Y positioning circuit sums up the output of different PM tubes and produces X and Y pulses in direct proportion to the X, Y coordinates of the point of interaction of gamma- rays and thus gives an image of the distribution of activity in a source. The pulses are stored in a computer, for further processing. .((Gopal,Saha, 2010

:(2-1-8Pulse high Analyzer (PHA

The pulse coming out of the amplifier may then be different in amplitude due to differing ઠ -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, Saha, 2010

:2-1-9Display 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 ,Saha, 2010

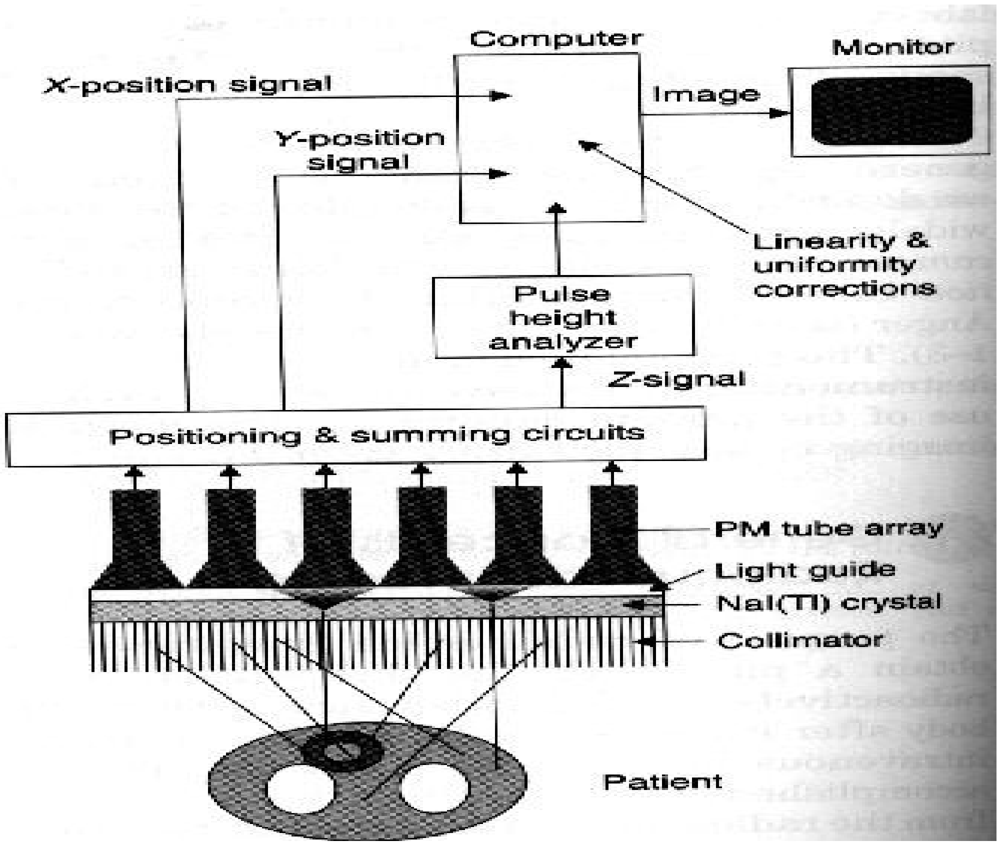

Fig (2-2) basic principles and components of the gamma camera (cherry, .(etal , 2003

:SPECT performance and quality control 2-2

A comprehensive performance testing program is an essential ingredient of high-quality single photon emission computed tomography (SPECT). Many of the procedures previously published are complicated, time consuming, or require a special testing environment. The acquisition of high-quality SPECT images requires careful Attention to detail and the routine performance of quality Control procedures to .(avoid the production of artifacts.(Nucl med, 2010

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. Clearly, there are a large number of factors that contribute to the final image quality, including uniformity, resolution (both spatial and energy), collimation and the hard copy device. In addition, for certain types of studies, other factors such as count rate capability come into play. With the addition of tomographic imaging, comes an additional suite of parameters that can influence the clinical images - these include system center of rotation, gantry and collimator hole alignment, rotational stability of the detector head and the integrity of the reconstruction algorithms. A great deal of attention has been given in the past few years to quality control protocols for SPECT. The substantial increases in the number of publications on artifact formation and quality control procedures for SPECT are not without justification. It is now well known that there are significant problems with respect to accurate presentation of the spatial distribution of radioactivity in transverse sections. Data acquisition or processing can have substantial adverse effects on the results. In fact, poorly performed .SPECT can be more detrimental to patient care than no SPECT at all

The potential advantages of tomography over planar imaging can be achieved only by emphasizing the strict adherence to proven acquisition protocols and by understanding what the processing protocols are doing to the data. This means that the physician and technologist must be familiar with options of data acquisition, available filters, and attenuation correction techniques. They must know where each is most appropriate, "different filters may be indicated for different clinical studies". The performance parameters most commonly evaluated of a routine SPECT quality control program include energy resolution, spatial resolution, uniformity, center of rotation and sensitivity. Some of this check should be made daily, while others need be only on a weekly .(or three monthly bases (Hans etal, 2007

:Spatial Resolution 2-2-1

Spatial resolution is a measure of an imaging system's ability to detect two closely spaced objects as two Separate entities. The resolving limit of an instrument is the minimum distance that two objects can be .(separated and still be distinguished as two objects.(Nucl med, 1987

Spatial resolution is commonly quantified from the full-width-at-half-maximum (FWHM) of the line spread response function. In planar imaging it depends on the intrinsic capabilities of the scintillation camera, the geometrical properties of the collimator, and the presence of scatter. In SPECT, additional factors affect resolution because the information is gathered over multiple angles. Precise positioning of the gantry, detector, and table and calibration of the center of rotation (COR) is required. In addition, the reconstruction matrix size, filter, and use of preand post-processing procedures can affect the measured spatial .(resolution.(Graham, 1995

The spatial resolution should be measured intrinsically and extrinsically. Spatial resolution can be assessed qualitatively by using test patterns such as bar phantom and Anger phantom, and assessed quantitatively by using point source (PSF) or line source (LSF).The FWHM of PSF and LSF used to determine the spatial resolution

:Types of spatial resolution 2-2-1-1

Collimator resolution: Ability to transfer detailed information on the**-1** .distribution of the radiation material from the object to the image

.**Intrinsicresolution:** Resolution measured in absence of collimator **-2**

.**Systemresolution**: Resolution measured in present of collimator **-3**

Equation: $[R_S]^2 = [R_I]^2 + [R_C]^2$

:2-2-2Intrinsic Uniformity

The intrinsic uniformity of a scintillation camera is the ability of the camera to produce a uniform image when exposed to a homogeneous spatial distribution of gamma rays. Most modern cameras are not designed to be intrinsically uniform because gains in spatial resolution can be obtained by sacrificing intrinsic uniformity. Therefore, these .systems require some mechanism of uniformity correction

The intrinsic uniformity of the system shall be measured for the central field of view (CFOV) and useful field of view (UFOV). The intrinsic uniformity is the response of the system without a collimator to a uniform flux of radiation from a point source. Two different uniformity parameters shall be determined: integral uniformity and differential .(uniformity.(Stephen etal, 1995

- **Field of view:** The area of the camera that can be imaged at any one time and the shape of FOV may be circular, hexagonal or .rectangular
- **Useful field of view:** The area of the detector that is actually used for image and the shape of UFOV can be defined by the .manufacture in an x way that he likes
- **Central field of view:** Defined in order to exclude edge effects of .the crystal. CFOV is always the same shape as the UFOV

:2-2-2-1Integral uniformity

Is measure of how bad the uniformity is in the worst areas of the field of view? It is assessed by looking at the counts in the hottest (C_{max}) and .coldest (C_{min}) pixels anywhere within the FOV

$$\text{Integral uniformity} = (C_{max} - C_{min}) / (C_{max} + C_{min}) \times 100$$

:Differential uniformity 2-2-2-2

Is measure of how rapidly uniformity changes over a small distance in worst part of the FOV? It is assessed by looking at the difference in counts between two pixels that are close together. To measure DU group of adjacent 5 pixels should be selected and if (H) is highest count. In this :group of pixels and L is the lowest count. Then

.Differential uniformity = (H – L)/ (H+L) x 100

:2-2-3Linearity

Is a measure of spatial distortion of image (the image of line source should appears straight and not bent). Spatial linearity should be measured intrinsically and extrinsically, assessed qualitatively by using linearity phantom and quantitatively in terms called absolute non-linearity .and differential linearity

Spatial linearity is one of the parameters that influence flood field uniformity. In the ideal system, a straight line source of gamma rays should yield a straight line in the image. Any deviation from a straight line represents distortion. Because of the finite number of PM tubes in scintillation cameras there is a wavelike distortion in the image ofa line .(source. (Peter, 2005

:2-2-4Energy Resolution

The energy resolution of a scintillation camera is a measure of its ability to separately distinguish the energies of two gamma rays that differ only slightly in energy. The parameter that is measuredisthe full width at half maximum of the photo peak expressed as a percentage of the photo peak value. Energy resolution is a function of gamma ray energy and .(therefore the energy at which it is measured must specified.(Peter,2005

:Sensitivity 2-2-5

The sensitivity of a scintillation camera is measured as the number of detected counts per unit time per unit source activity for a specified energy window and geometry of measurement. The factors that affect the sensitivity of gamma camera are detector configuration,Source configuration,collimator type, energy of radionuclide ,window width.The system sensitivity divided into planner sensitivity and volume .(sensitivity. (Jerrold etal, 2002

Planar sensitvity :Is the senstivity in one acquisition plane to a **2-2-5-1** spesific planer source placed parallel to that plane . It should be measured for all collimators type . Units count/min/MBq or .Count/sec/µCi

2-2-5-2Volume senstivity: Is the total system senstivity to uniform concentration of activity in a spesific cylinderrical phantom . It should be measured for all collimator types and Average volume senstivity per axial centimeter of phamtom used should be determined from this .measurment

:2-2-6COR Calibration

The SPECT process comprises the acquisition of series of projection images collected from specific location around the patient, usually based upon the mechanical rotation of the detectors. The subsequent reconstruction of the projection data into Tran's axial images has to mirror the acquisition process by re-projection the data from equivalent angles and relative alignment, as was set in the mechanical rotation. The mechanical rotation defines a line in space called the axis of rotation, about which the detectors rotate. The axis of rotation (AOR) is an imaginary reference line about which the head or heads of a SPECT camera rotates. If a radioactive line source were placed on the AOR, each projection image would depict a vertical straight line near the center of the image; this projection of the AOR into the image is called the center of rotation (COR). The COR alignment is assessed by placing a point source or line source in the camera field of view, acquiring a set of projection images, and analyzing these images using .the SPECT system's computer

Accurate center of rotation (COR) correction is important for high quality tomography. Errors in COR of as little as 0.5 pixel in a 128 x 128 matrix can lead to degradation in image quality . COR is measured by performing a 360 degree acquisition around a point source of Tc-99m. Most manufacturers have software designed to analyze the acquisition .and determine if the COR is within acceptable limits

Not only is it important to use the correct value of COR, it is also essential that this value remain constant as a function of angle. When measured on a gamma camera system, at a radius of rotation of 20 cm, both the X and Y values for the COR should show less than a 2 mm variation over a 360o orbit. COR is normally a very stable parameter of modern gamma camera systems and a weekly check is adequate to .(ensure proper correction. (Cerquira,Ritchieetal, 1989

:Count Rate and Dead Time 2-2-7

As with any detection system, it is important that scintillation events do not occur so fast that the electronic system is unable to count each as a separate event. If two equal light pulses occur too close together in time, the system may perceive this as one event with twice the energy actually present. Such an occurrence of primary photons would be eliminated by the energy window of the PHA, and none of the information from the two events would be imaged; thus, the sensitivity of the system would be diminished. A more significant problem is loss of spatial resolution when several scattered (low- energy) photons strike the crystal at the same time, so that their light production is summed and appears as a photon of interest. The time after an event during which the system is unable to respond to another event is referred to as dead time. **Dead time** can be important in high count rate dynamic studies (in the range of 50,000 counts/second), particularly with single-crystal cameras. (Fred, mettler, .(2006

:2-2-8Sources of errors in SPECT performance

: The common sources could be synopsis in some parameters

damaging of the crystal(crake , loss of obesity due to absorption of-1 .(moisture

.(different setting of PHA (effect of uniformity-2

.(thick crystal (bad resolution-3

collimator damage (non uniformity due to crushed lead septa or lead-4 .(foil seperation

collimator structure artifacts (non uniformity due to large diameter-5 .(hole , irregular lead foil construction

National Electrical Manufactures Association 2-2-9 :((NEMA

The national electrical manufactures association is the trade body of gamma camera manufactures in the USA. They have define 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	√		√			

:2-3Previous 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. However, According to National Electrical Manufactures Association NEMA protocols, the collimator must be removal before the IU test is carried out. The IU test is performed for correction of many gamma camera problems as soon as the appear, whereas the RS characterizes the stability of response to gamma radiation. RS and IU tests were performed simultaneously in order to determine the elapsed time required acquire the image. A set of a parameters for rapid performance of daily gamma camera IU and RS was determined. The .dead time of our camera system found to be 5±0.1µs

jabari ,etal ,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. In this study we tried to determine the most appropriate energy window width for present gamma camera systems. Since it was not possible to retrieve the data spectrum from the most of the gamma camera systems, a simple method was developed to extract the data from the image of the energy spectrum. Using a scatter phantom different level of scatter and count rate were generated and correspondingly analyzed, it was assumed that around the peak of the spectrum, the primary photons obey a Gaussian distribution. The data were analyzed using three different methods. All methods prove that the optimum window width regarding the present gamma camera energy resolution is 15% at this level, the scattered radiation is decreased to 5%

in comparison to conventional window width of 20%, and the sensitivity does not change dramatically. At the present, for most gamma camera, the energy window width of 20% is recommended. However, occasionally energy window width of 15% and 25% are also used. In this study the energy spectrum at different levels of scatter were analyzed and the most suitable energy window width was found to be 15% for the gamma camera having approximate energy resolution of 11% at this window setting the scatter decreases to 5% of the total counts recorded . Visually the quality of the images does not improve significantly; however, accuracy of data quantification improves .significantly

Alighieri , F.C.et al,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. This study was performed using a jaszczak phantom, which is a cylindrical acrylic phantom with inserts of rods and spheres representing (cold) areas, and a region of uniformity, the single photon emission computed tomography (SPECT) regarding special resolution and uniformity. The tomographic resolution is determined through the observation of the cold rods section, the section without inserts; filled with water and 851M Bq of Tc99m (TCO_4^-) is used as a reference only for the visual uniformity analysis. The test with the phantom must be part of a quality control routine program in SPECT systems. Which enables the user to evaluate the performance of the whole system every six months, when take radius of rotation 185 mm the spatial resolution for LEHR collimator 9.5 mm, the spatial tomographic resolution for LEGP collimator 11.1mm, when take radius of rotation 150 mm, the spatial tomographic resolution LEHR collimator 7.9 mm, the spatial tomographic resolution LEGP collimator 9.5 mm. the smallest sphere observed was the 12.7mm in diameter in both collimators. The high resolution collimators increase the ability to visualize small lesions and structure in a lesion provided that count density is satisfactory, the best will be the detection ability of the SPECT system. The results showed that LEHR collimator offers the best resolution when compared with LEGP collimator, with a difference of 1.6mm between them. The best resolution was obtained with the LEHR collimator at the smallest radius of rotation used in this study 150mm. Ring artifacts were not seen at the reconstructed images due to the application of a uniformity correction .(map with a large count (100 million kc

Kera M, et 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

Chapter three: Materials and Methods

Materials and Methods -3

:Materials 3-1

This study was conducted at Elnilein medical diagnostic Centre, .department of nuclear medicine

:The equipment used in this study includes

- .(Gamma camera machine (SPECT
- .Dose calibrator
- .Syringes, point source Tc^{99m}
- .Strips
- .TC^{99m} generator
- .(Resolution phantom (Four quadrant bar pattern
- Source holder

:Gamma camera (SPECT) Specification 3-1-1

Table (3-1) the specification of gamma camera (SPECT) in NMDC .Centre

Centre or hospital	NMDC Centre
Manufacture	Ulie
Model	Single head
Serial number	Orbiter 27
Date of installation	2009

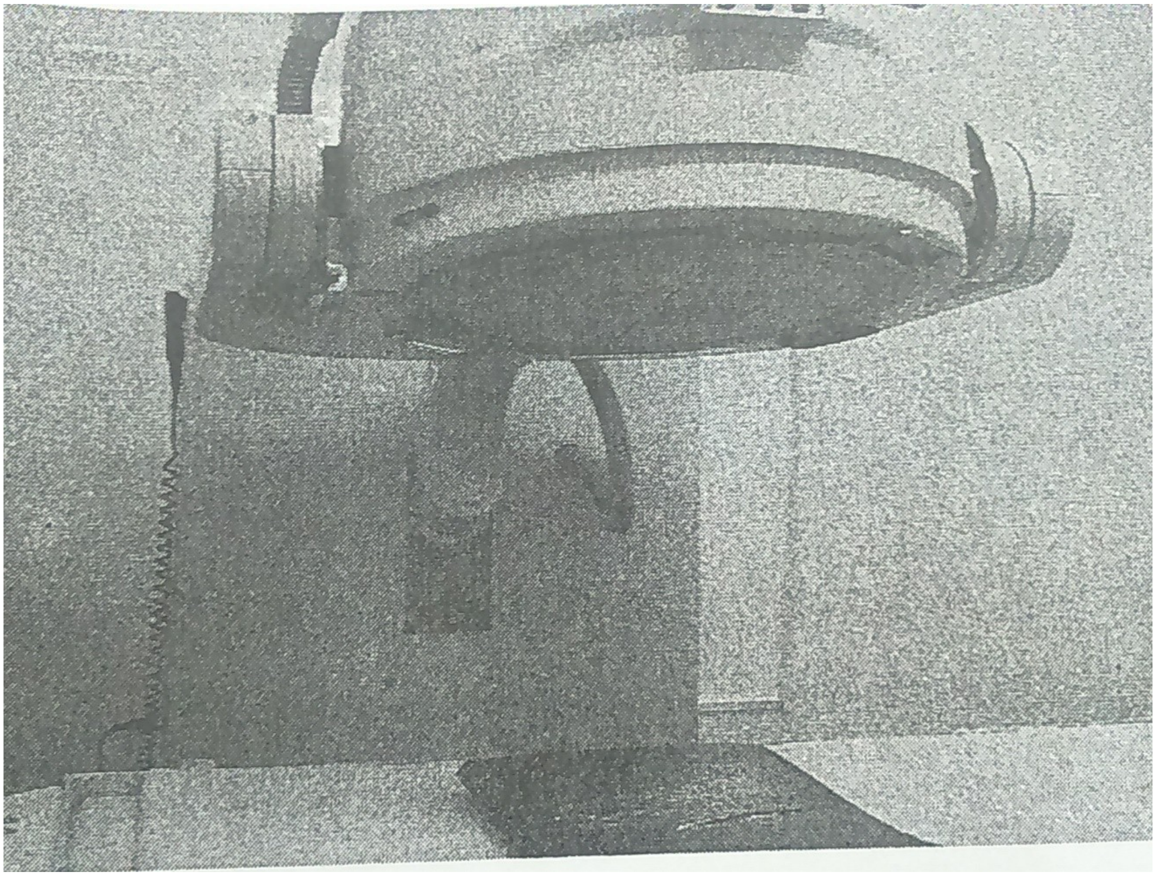

Figure (3-1) shows the gamma camera machine (SPECT) in NMDC .Centre

:Methods 3-2

The data were obtained from nuclear medicine department in NMDC Centre from the records of test results at a period from (4/1/2014) to (25/8/2015), and data analysis by statistical program (Excel), determine the mean and standard deviation between different variables that show in figures and tables, and make comparisons between the results of the study and basic standards of performance of SPECT compare .interpretation and conclusions to the previous studies

$$\bar{x} = \sum_{i=1}^{n} x_i \Big/ n$$

= The average

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

= Standard deviation

-:3-2-1Energy 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

ER% = (FWHM/photo peak center) ×100

:Procedures

Peak the camera for the isotope used (Tc^{99m}); select a window width - .(of 15%, use matrix size (128*128

.Sure the point source in the central of the detector -

.Place (Tc^{99m}) point source at distance 5*FOV from the camera head -

.Acquire a digital energy spectrum -

:Calculate FWHM (keV) as % of peak energy. The ER is given by -

ER% = (FWHM/photo peak center) ×100

:Uniformity 3-2-2

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) ×100

Differential uniformity: the difference between two adjacent .pixels

DU (%) = (max - min)/ (max + min) ×100

:Procedure

peak the camera for the isotope used (Tc^{99m}); select a window-
.(width 15 %, use matrix size (64*64

.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 10,000 cps

Calculate Integral and differential uniformity from the -
.(computer will apparent as seen in table (4-1

:Sensitivity 3-2-3

Ability to detect the ionizing events that occur in the NaI (TI) crystal. The events recorded as count /min are calculated and .expressed as counts per minute per µci of activity present

:Procedure

Measure the activity of TC^{99m} source in a syringe in a dose -
.(calibrator (A_{sri}

.Put water in the phantom -

Disperse a syringe activity into a flat plastic and then measure -
.(the activity residual in syringe (A_{res}

Calculate the activity into the phantom by using equation -

$$A_{cal} = A_{sri} – A_{res}$$.

Place the phantom at distance 10cm from the collimator face, -.(use matrix size (128*128

From the computer user sensitivity test calculate the sensitivity -.(will apparent as seen in table (4-2

-:linearity 3-2-4

Is the ability produce a linear image with straight lines .corresponding to the same straight lines of the bar pattern

:**Procedure**

Place the test pattern in the detector (the cent slit is center the -.(detector

.place the center slit perpendicular to the axis of measurement-

.aligned the center slit with in ±1mm at the edge of FOV-

.place the radionuclide point source at 5 times FOV-

.(acquire the linearity test will apparent as seen in table (4-3-

Chapter four: Results

This chapter showed the results of gamma camera performance (SPECT) in nuclear medicine department in NMDC Centre at a period .from 4/1/2014 to 25/8/2015

The QC tests carried out at the hospital include: energy spectrum, energy resolution, uniformity test, sensitivity test and linearity test that would .be highlighted in a form of figures or tables

-:Spectrum and energy resolution test 4-1

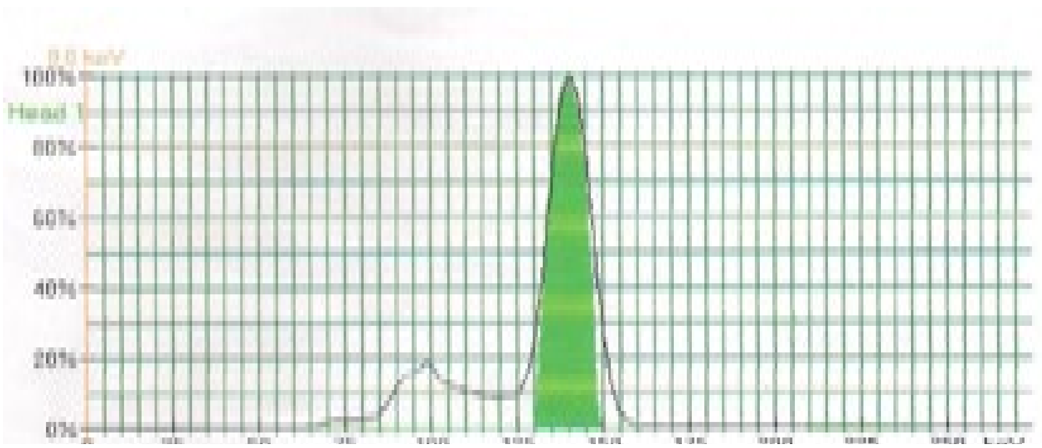

Fig (4 –1): the Energy spectrum of Tc^{99m} For Gamma Camera Machine (SPECT) in NMDC Centre, FWHM (10.7%) and the window of energy spectrum about 15%. .((17/12/2015

:uniformity test 4-2

The table (4-1) the results of integral uniformity and differential .uniformity in NMDC centre from 04/01/2014 to 25/08/2015

Date	INTEGRAL	DIFFERNTIAL
04-01-2014	2.53%	1.81%
12-02-2014	3.45%	1.18%
26-03-2014	4.23%	2.46%
2014-04-23	3.48%	2.26%
2014-05-07	2.74%	1.42%
2014-06-04	5.53%	2.13%
2014-07-20	4.49%	2.00%
2014-08-13	2.71%	1.27%
2015-01-30	2.71%	1.27%
2015-02-27	1.92%	1.30%
2015-03-21	5.78%	4.57%
2015-04-30	2.05%	1.67%
2015-05-21	2.42%	1.72%
2015-06-20	2.53%	1.22%
2015-07-25	4.57%	2.41%
2015-08-25	4.67%	2.37%

-Fig (4-2): shows the integral uniformity test in NMDC Centre from 4-1 to 25-8-2015 2014

Fig (4-3): shows the differential uniformity test in NMDC Centre from .4-1-2014 to 25-8-2015

-:sensitivity test 4-3

The table (4-2) shows the sensitivity of gamma camera (SPECT) in .NMDC center, isotope Tc^{99m}

Date	Isotope	Sensitivity (measurements(cps/MBq
04-01-2014	Tc^{99m}	86.5
12-02-2014	Tc^{99m}	86.4
2014-03-26	Tc^{99m}	87.8
2014-04-23	Tc^{99m}	79.9
2014-05-07	Tc^{99m}	87.0
2014-06-04	Tc^{99m}	92.1
2015-01-22	Tc^{99m}	78.3
2015-02-27	Tc^{99m}	69.1
2015-03-21	Tc^{99m}	83.6
2015-04-30	Tc^{99m}	80.4

2015-05-21	Tc^{99m}	83.6
2015-06-20	Tc^{99m}	80.7
2015-07-25	Tc^{99m}	86.1
2015-08-25	Tc^{99m}	86.8

Fig (4-4) shows the sensitivity measurement's in NMDC Centre from 4-.1-2014 to 25-8-2015

-:4-4linearity test

Table (4-3) shows the results of linearity test for SPECT machine

Date	(Linearity measurement (mm
04-01-2014	1.30
02-05-2014	1.28
22-01-2015	1.20
14-05-2015	1.26
18-08-2015	1.50

Fig (4-5) shows the linearity test for SPECT machine in NMDC Centre

Chapter five: Discussion, Conclusion and Recommendations

:Discussion 5-1

The QC tests carried out at the hospital include: energy spectrum, energy .resolution, uniformity test, sensitivity test and linearity test

Fig (4-1) shows the energy spectrum for gamma camera machine (SPECT), isotope Tc^{99m}, FWHM (10.7%) and the window of energy spectrum about 15% for SPECT machine in NMDC Centre. The central .peak of energy 140 kvp

The calculated energy resolution from the equation (5-1) given by .((Hans, 2007) and was found about (7.6%

(Energy resolution = FWHM/Photo peak ×100 (5-1

.Energy resolution = 10.7/140 ×100 = 7.6%

The table (4-1) shows the results of integral uniformity and differential uniformity. For integral uniformity found the mean and standard deviation was about 3.4% and the standard about 4%, the difference between practical and standard about 0.6. For differential uniformity the mean and standard deviation was about 1.94% and the standard about .3%, the difference between practical and standard about 1.06

The average for integral uniformity = 55.81/16=3.4%

Standard deviation = 1.1

Integral uniformity = 3.4±1.1%

The average of differential uniformity = 31.08/16=1.94%

Standard deviation=0.84

Differential uniformity= 1.94±0.84%

The table (4-2) shows the sensitivity of gamma camera (SPECT) , .isotope Tc^{99m} ,the average sensitivity about 83.4 cpm/MBq

.**The average X_i**= 1168.3/14 = 83.4cpm/MBq

The table (4-3) shows the results of linearity test for SPECT machine .and found the mean and standard deviation was 1.3 mm

Table (5-1): Results of the quality control tests for NMDC compared .with IAEA or NEMA standards

Performance characteristic	**Result**	**IAEA OR NEMA 2001 standard**	**Acceptance**
Energy Resolution	7.5%	at FWHM 10%	accepted
Integral Uniformity	3.27%	4%	accepted
Differential Uniformity	1.94%	3%	accepted
Sensitivity	83.4cpm/MBq	70cpm/MBq>	accepted
Linearity	1.3mm	Linearity deviation >1mm	Not accepted

:5-2conclusion

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 performance of the single photon emission computed tomography working in nuclear medicine departments in NMDC Centre using five quality control tests include: energy spectrum, energy .resolution, uniformity, sensitivity and linearity

The results are shown in tables from table (4-1) to table (4-3) and figures .(from fig (4-1) to fig (4-5

The data reveals that: the energy spectrum for Tc^{99m} and the window of energy spectrum about 15% for SPECT machine in Alnelien Centre. The central peak of energy is 140 kvp, the FWHM about 10.7% and the .energy resolution about 7.6%

The data reveals that: the comparison between the practical and standard integral uniformity and differential uniformity. For integral uniformity found the mean and standard deviation about 3.4% and the standard about 4%, the difference between practical and standard about 0.6%. For differential uniformity found the mean and standard deviation about 1.94% and the standard about 3%, the difference between practical and .standard about 1.06%

The data reveals that: the average sensitivity for gamma camera was .about 83.4 cpm/MBq

The data reveals that: the average linearity test for gamma camera was about 1.3 and the results detect distortion of linearity due to X and Y positions do not change linearity with displacement distance of radiation .sources across the face of the detector

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

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.

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