Sudan University of Science and Technology

College of Graduate Studies

Assessment of Quality Control Procedures in SPECT Gamma-Camera in Nuclear Medicine Department at Al-Nilen Diagnostic Center

تقييم إجراءات ضبط الجودة للأشعة المقطعية المحوسبة أحادية الفوتون لجهاز غاما كاميرا في قسم الطب النووي بمركز النيلين التشخيصي

A Thesis Submitted for Partial Fulfillment for the Requirements of Master degree in Medical Physics

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الآيـــــــة

قال تعالى :

قُلْ يَا عِبَادِيَ الَّذِينَ أَسْرَفُوا عَلَى أَنْفُسِهِمْ لا تَقْنَطُوا مِنْ رَحْمَةِ اللَّهِ إِنَّ اللَّهَ يَغْفِرُ الذُّنُوبَ جَمِيعًا إِنَّهُ هُوَ الْغَفُورُ الرَّحِيمُ

صدق الله العظيم

(سورة الزمر : الآية 53)

Dedication

I dedicate this thesis to my family

And all my beloved friends but above all I thank Allah. The almighty, for guidance and support that He has given me

Acknowledgement

I would like to express my deepest thanks and gratitude to my supervisor;

Dr. salah ali fadlalla for guidance, useful discussion & giving nessecery advices.

Also I would like to thank technical specialist of bio-line medical company Ms. sarah abd-elsalam for her support and careful monitoring . And special thanks to all staff in Al Nielain Nuclear Medicine Department. Thank again to all who helped me in this thesis.

Abbreviations

abbreviation	meaning
NM	Nuclear medicine
QC	Quality control
NEMA	National Electrical Manufacturer Association
Kev	Kilo electron volt
FWHM	Full Width at Half Maximum
PMT	Photo Multiplier Tube
SPECT	Single photon emission computerized tomography
IC	internal conversion
Min	Minimum
Max	Maximum
FOV	Field of View
UFOV	Useful field of view
PET	Positron Emission T tomography
γ	Gamma radiation
Tc	technetium

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Abstract

The SPECT gamma camera is one of the most important techniques of medical imaging, which provides functional anatomical information that help diagnose many diseases with high accuracy so it widely used in the world. On the other hand, the quality control tests are very important to ensure the performance of a Gamma camera correctly.

The main objective of this research was to evaluate the quality control tests of a Gamma Camera in the Nuclear Medicine Department at Al Neilain Diagnostic Center in Khartoum. The tests that were conducted during this research included the following: The results showed that the central energy photopeak was 140 kV, the energy resolution value was 8.63%, integral uniformity value was 3.34%, the differential uniformity value was 2.74% and the sensitivity was 88.1 Cpm \ Mbq ,and in the center of rotation test the number of images was 64 and start position at 45 degree ,the rotation motion was a clockwise direction and the mean value was -1.2. In conclusion the obtained results lie within the standards of the National Association of Electrical Equipment Manufacturers NU-1 2001.

الملخص

التصوير الطبي باشعة غاما او التصوير المقطعي المحوسب باصدار فوتون واحد يعتبر احد أهم تقنيات التصوير الطبي والتي تمتاز بتوفير معلومات تشريحية وظيفية تساعد في تشخيص العديد من الامراض بدقة عالية ولذلك تستخدم على نطاق واسع , من جانب اخر تعتبراختبارات ضبط الجودة شديدة الاهمية لضمان اداء جهاز غاما كاميرا بصورة صحيحة .

الهدف الاساسي من هذا البحث هو تقييم اختبارات ضبط الجودة لجهاز غاما كاميرا بقسم الطب النووي بمركز النيلين التشخيصي بالخرطوم. كل النتائج المتحصل عليها من الدارسة تمت مقارنتها مع معايير حدود الأمن والسلامة الموضوعة من قبل الجمعية الوطنية لمصنعي الاجهزة الكهربائية. تتضمن الإختبارت التي تم إجاراؤها خلال هذا البحث الآتي:- اختبار قمة مركزية الطاقة ، واختبار دقة الطاقة، الحساسية ،اختبار الاتساق واختبار مركز الدوران أوضحت النتائج أن القيمة المركزية للطاقة كانت عند140 كيلو فولت وقيمة دقة الطاقة تساوي8,63% و قيمة الاتساق التكاملي تساوي3,34% وقيمة الاتساق التبايني تساوي 2,74% والحساسية كانت Cpm\Mbq 88.1. وفي اختبار مركز الدوران وجد ان عدد الصور 64 ونقطة البداية -45 وان اتجاه الدوران كان مع عقارب الساعة والمتوسط كان -1,2 . والقيمة القصوى كانت 2,1. خلص هذا البحث الى ان معظم هذه النتائج تتوافق مع معايير الجمعية الوطنية لمصنعي الاجهزة الكهربائية للعام 2001.

Chapter One

Introduction

Chapter One

Introduction

Nuclear medicine is a medical specialty involving the application of radioactive substances (called Radiopharmaceuticals) in the diagnosis and treatment of disease ·Radiopharmaceuticals are introduced in the patient's body by injection, swallowing, or inhalation. The pharmaceutical part is designed to go to specific place in the body where there could be disease or abnormality, the radioactive part of the radiopharmaceutical that emits radiation known as gamma rays is then detected used a special camera called gamma camera ·Imaging technique called Scintigraphy ("scint") is the use of gamma cameras to capture emitted radiation from internal radioisotopes to create two-dimensional images. The highly efficient capture method of this combination for detecting gamma rays was discovered in 1944 by Sir Samuel Curran· Single Photon Emission Computed Tomography or SPECT and Positron Emission Tomography or PET scans are the two most common imaging modalities in nuclear medicine. The major advantage of PET and SPECT techniques is that the small probe mass and the radiolabeling strategies do not significantly perturb the biological process under study , further PET has high molecular sensitivity and strong quantitative potential (Vallabhajosula, 2009) .

Nuclear medicine scans differ from radiology as the emphasis is not on imaging anatomy but the function and for such reason, it is called a physiological imaging modality and the Localization of Radiopharmaceuticals is based solely upon physiological function of the target organ. The mechanism of localization of a radiopharmaceutical in a particular target organ depends upon processes as varied as antigen-antibody reactions, receptors site binding,…etc. .The Radiopharmaceutical substance is a composed of a radioisotope bond to an organic molecule. The organic molecule conveys the radioisotope to specific organs, tissues or cells. The radioisotope is selected for its properties. The common methods of radionuclide production for nuclear medicine include: fission, neutron activation, cyclotron and generator. Common nuclear medicine applications include; cardiac stress tests to analyze heart function, bone scan for metastatic growths ,lung scans for blood clots, kidney, liver, gall bladder procedures for diagnose abnormal function or blockages. Nuclear medicine also offers therapeutic procedures, such as radioactive iodine (I-131) therapy that use small amounts of radioactive material to treat cancer and other medical conditions affecting the thyroid gland, as well as treatments for other cancers and medical conditions.

1.2 Problem of the study

Inspite of the importance of quality control procedures of nuclear medicine devices and their effects on image quality, no adequate QC studies have been done so far in Sudan , to the best of the researchers knowledge .

1.3 Objectives of the study

1.3.1 General objective

- To assess the quality control program at Al Nilein Nuclear Medicine department

1.3.2 Specific objectives

To:-

- check the photopeak spectrum of the Tc^{99m} source
- measure uniformity of gamma camera
- measure energy resolution of the source

- calibrate gamma camera center-of-rotation
- measure the sensitivity of gamma camera

Chapter Two

Literature review

Chapter Two

Literature review

2.1 Theoretical background

2.1.1 NM historical and early technical development

As with the development of any field of science or medicine, the history of nuclear medicine is a complex topic, involving contributions from a large number of scientists, engineers, and physicians. The origins of nuclear medicine can be traced back to the last years of the 19^{th} century and the discovery of radioactivity by Henri Becquerel (1896) ,radium by Marie curie (1898) and of the discovery of x-rays in 1895 by Wilhelm Roentgen. Both x-rays and radium sources were quickly adopted for medical applications and were used to make shadow images in which the radiation was transmitted through the body and onto photographic plates.

Although the field of diagnostic x-ray imaging rapidly gained acceptance, nuclear medicine had to wait further. The biologic foundations for nuclear medicine were laid down between 1910 and 1945. In 1913,george de hevesy developed the principles of the tracer approach2 and was the first to apply them to a biologic system in 1923, studying the absorption and translocation of radioactive lead nitrate in plants.3 The first human study employing radioactive tracers was probably that of Blumgart and Weiss (1927),4 who injected an aqueous solution of radon intravenously and measured the transit time of the blood from one arm to the other using a cloud chamber as the radiation detector. 1930s, with the invention of the cyclotron by Lawrence (Fig.1-1),5 it became possible to artificially produce new radionuclides, thereby extending the range of biologic processes that could be studied. Once again, de Hevesy was at the forefront of using these new radionuclides to study biologic processes in plants and in red blood cells. Finally, at the end of the Second World War, the nuclear reactor facilities that were developed as part of the Manhattan Project started to be used for the production of radioactive isotopes in quantities sufficient for medical applications.

The 1950s saw the development of technology that allowed one to obtain images of the distribution of radionuclides in the human body rather than just counting at a few measurement points. Major milestones included the development of the rectilinear scanner in 1951 by Benedict Cassen6 (Fig.1-2) and the Anger camera, the forerunner of all modern nuclear medicine single-photon imaging systems, developed in 1958 by Hal Anger (Fig. 1-3).7 In 1951, the use of positron emitters and the advantageous imaging properties of these radionuclides also were described by Wrenn and coworkers.8 Until the early 1960s, the fledgling field of nuclear medicine primarily used 131I in the study and diagnosis of thyroid disorders and an assortment of other radionuclides that were individually suitable for specific organs The use of 99mTc for imaging in 1964 by Paul Harper and colleagues and was a major turning point for the development of nuclear medicine.

The final important development was the mathematics to reconstruct tomographic images from a set of angular views around the patient. This allowed the development of PET by Phelps and colleagues10 and SPECT by Kuhl and colleagues11 during the 1970s and marked the start of the modern nuclear medicine (Cherry et al., 2012)

2.1.2. NM scanning dangers

Nuclear medicine involves the administration of small amounts of radiopharmaceuticals (larger amount are used for therapy) that emit radiations such as g-rays, x-rays, b-particles, or positrons. This emission exposes the patient to low levels of ionizing radiation that might lead to detrimental health effects, of which carcinogenesis is the primary concern. In the dose range associated with most nuclear medicine procedures, there are limited human epidemiologic data, and mechanistic biologic observations can be contradictory .There is no direct evidence that the ionizing radiation routinely used in nuclear medicine and radiology leads to such effects . Nevertheless, the consensus is that it is prudent to assume that the risk at these lower doses can best be estimated by a linear extrapolation from higher doses for radiation protection purposes (Fahey et al., 2011) that means every exposure to ionizing radiation, no matter how small, carries some small risk of unwanted health effects, including cancer. In NM Therapy Patients receive higher amounts of radiopharmaceuticals of nuclear medicine therapy. These patients might have to stay in the hospital overnight or otherwise take precautions in order to keep the radiation dose to family members at a reasonable level. Many medicines and medical procedures can have side effects, particularly if one uses too much the same is true for nuclear medicine, When recommended, a nuclear medicine test gives your doctor important information that is well worth the very small possible risk But Used in the right way for the right patient at the right time, nuclear medicine is very safe. (Fahey, 2012)

2.1.3 Gamma rays production and decay

Radioactive decay is a process in which an unstable nucleus transforms into a more stable one by emitting particles, photons, or both, releasing energy in the process. There are four main modes of decay include Alfa particle (2 protons , 2 neutrons) , Beta particle(electrons) , Positrons (anti-matter electrons) ,and Isometric transition (gamma rays produced) .Medical imaging is only concerned with Positrons (PET) and Gamma rays (SPECT , Scintigraphy) .

In Isometric transition a nucleus which is unstable changes from a higher energy state to a lower energy state through the emission of electromagnetic radiation photons (called gamma rays). The daughter and parent atoms are isomers. The gamma photon is used in Single photon emission computed tomography (SPECT) .Gamma rays have the same property as X-rays, but are generated different ,X-ray through energetic electron interactions but Gamma-ray through isometric transition in nucleus(Prince and Links, 2006)

$$Tc^{99m} \rightarrow Tc^{99g} + \gamma \ (141 \text{ keV}) \quad \textbf{\{2.1\}} \quad T1/2 = 6.0 \text{ h}$$

An alternative to γ-ray emission is internal conversion. This can occur for any excited state, but is especially common for metastable states. In this process, the nucleus decays by transferring energy to an orbital electron, which is ejected instead of the γ ray. It is as if the γ ray were “internally absorbed” by collision with an orbital electron. The ejected electron is called a conversion electron .These electrons usually originate from one of the inner shells (K or L) . The orbital vacancy created by internal conversion subsequently is filled by an outershell electron, accompanied by emission of characteristic x-rays or Auger electrons.(Stabin, 2008)

$$Tc^{99m} \rightarrow Tc^{99g} + IC\ e^{-} \ (119 \text{ keV}) \quad \textbf{\{2.2\}}$$

2.1.4 Gamma camera components

Gamma camera imaging system is made up of four primary systems, include, the SPECT scanning unit, the patient table, the image processor for image reconstruction and console.

The SPECT scanning unit consists of

1- Detector

Radiation detectors Also known as particle detectors are devices that are designed to identify the presence of some type of radiation within a given area also measure the amount of radiation within the immediate area. Radiation detectors in common use today many facilities make use of larger models of the radiation detector to ensure that radiation levels within the operation remain under acceptable levels

The detector system plays a special role in the interaction of the gamma camera components. This detects the gamma ray and determines its location and its energy. This is further processed by electronics in the console before displayed on a CRT screen for exposing or collecting into computer memory (eberl, 1993). There are many different types of detectors can be characterized by the nature of radiation interaction with matter. The radiation detectors are main two types according to their physics properties of detection material can be either gas-filled or solid state detectors. Gas filled detectors the principle of detection. In ionization Methods for Measurement of radiation. The interaction between radiation and matter is accompanied by a number of effects such as the emission of photons, charged particles and liberation of heat. All these effects can be used to detect radiation, measure particle flux density or intensity and the radiation spectra. The operation of many measuring devices is based on the ability of radiation to ionize molecules. (Tsoulfanidis, 1983) . Radiation passing through the gas leaves a trail of ionized atoms and free electrons. Those charged particles can be made to move in electric fields. The electric fields draw the ions and electrons to electrodes where their arrival causes an electric current to flow in the signal processing system. Solid state detectors this type consists of the solid materials with fluorescence, phosphorescence and semiconducting properties. There are various types of detectors available for solid state radiation detection system and each type is suitable for a particular use they include scintillation, thermo luminescent and semiconductor detectors (Lutz.1999). The detector type of interest in NM is scintillation detector .Scintillators are materials- solids, liquids, gases- that produce sparks or scintillations of light when ionizing radiation passes through them .The amount of light produced in the scintillate is very small. It must be amplified before it can be recorded When an energetic particle enters the scintillator a large number of atoms are raised to excited states with higher energy levels). When an energetic particle enters the scintillator a large number of atoms are raised to excited states with higher energy levels. The excited atoms return to lower energy states by emitting photons in the visible or near ultraviolet regions of the spectrum. This process is called fluorescence. Recent SPECT SCANNER use (NaI(Tl)) scintillator detector ((Gerber and Miller, 1977) which the most commonly used scintillator for detectors in nuclear medicine is NaI(Tl) with (typically 30-50 cm in diameter by 1-cm thick These) . Pure NaI crystals are scintillators only at liquid nitrogen temperatures. They become efficient scintillators at room temperatures with the addition of thallium a small amount (0.1-0.4 mole percent) must been added. Crystals containing small amounts of “impurity” atoms of other elements. Impurity atoms in the crystal matrix cause disturbances in its normal structure. Because they are responsible for the scintillation effect, the impurity atoms in the crystal matrix are sometimes called activator centers. (Cherry et al., 2012)

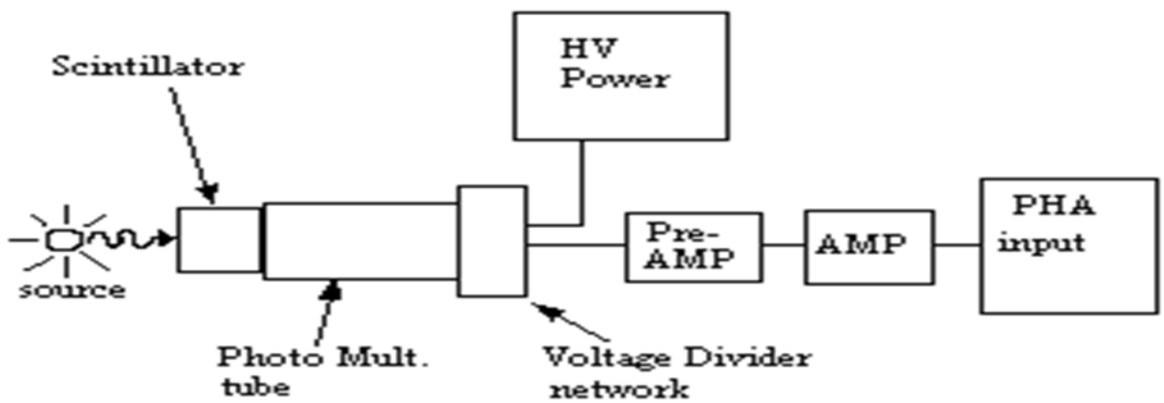

Fig 2.4.1: Simple scintillation detector scheme

2- Collimator

The collimation system is the heart of the SPECT instrument – it's the front-end and has the biggest impact on SNR . An absorptive collimator projects an image of the source distribution onto the detector by allowing only those γ rays traveling along certain directions to reach the detector. Gamma rays not traveling in the proper direction are absorbed by the collimator before they reach the detector .there for the right choice of collimator is essential for optimum image quality. Four basic collimator types are used with the gamma camera: pinhole, parallel-hole, diverging, and converging.(Cherry et al., 2012)

a. Parallel hole collimator

The most commonly used collimator it consists of large number of small holes separated by thin lead septa, which are parallel to each other and usually perpendicular to the face of the crystal the design of the collimator is always trade of between resolution, sensitivity, and maximum energy

b. Pin hole collimator

The pin hole collimator is very important for small organs such as the thyroid. It can provide magnification of the organ as well as much improved resolution foe small organs a typical hole collimator is shown in figure. The pin hole collimator is usually at a distance L of 20-30cm from the crystal and its diameter ranges from 2mm to 8mm. the larger the hole diameter the better the sensitivity but also the worse the resolution so there is a compromise between resolution and the sensitivity. In practice a hole diameter of 3-4 mm is usually used .

c. Converging and diverging collimator

Those types of collimators are similar to parallel hole collimators (have many thousands of holes), these holes not parallel but are angled to converge to focal points. For the diverging collimators, the holes are angled in the opposite direction to the converging collimators which makes the image of the organ projected smaller diverging collimators were mainly introduced to overcome the limited field of view of early gamma cameras, but now rarely used .

d. Fan beam collimators

Fan beam collimators a type of converging collimator which converges only in one direction , are now used extensively for brain SPECT and a lesser extend for cardiac SPECT due to the higher resolution and sensitivity achieved compared with standard parallel collimators .(eberl, 1993)

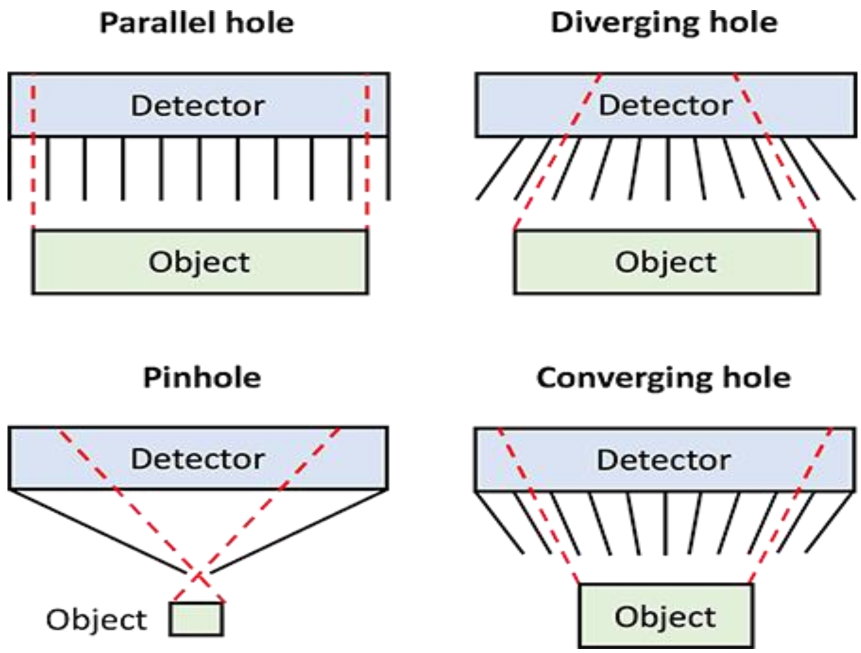

Figure 2.4.2 types of SPECT collimators

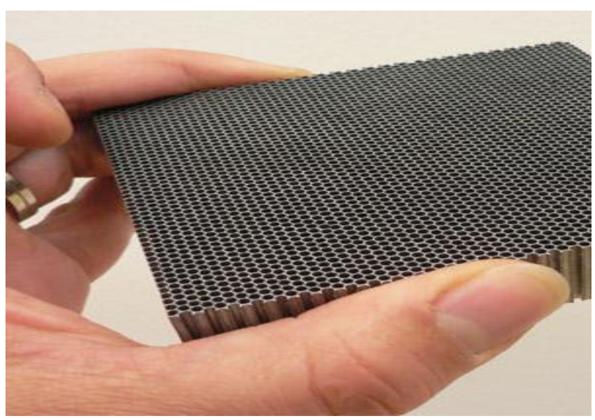

Figure 2.4.3 show parallel collimator cross sectional view

3-. Photomultiplier tubes

PM tubes (also called phototubes and sometimes abbreviated PMT) are electronic tubes that produce a pulse of electrical signals when stimulated by very weak light signals, such as the scintillation produced by a γ ray or β particle in a scintillation detector ultrasensitive electronic light detectors called photomultiplier (PM) (Cherry et al., 2012) These analog signals are amplified by downstream electronic components and converted to digital pulses (1), usually are 30-100PMTs.

Other electronic circuits respectively pre-amplifier, amplifier , high pulse analyzer, y-x position circuit. The gamma camera is made up of many parts, each part performs as a specific function in converting gamma rays into light images and finally we get appropriate viewing image.

4. Data acquisition system (detecting system):

The most common device used for imaging in nuclear medicine is the gamma camera. Here, a collimator being a sheet of lead with holes, is used to select photons arriving from a particular (set of) directions, and then the gamma events are detected from a scintillation occurring most commonly in a sheet of a material such as NaI(Tl) producing light which is then converted to electrical signals by an array of photomultipliers. Data are acquired on an event by event basis. The position (and energy) of each individual detected gamma event is recorded or used to create images. Thus two basic detection modes are used, frame mode and list mode. Frame mode acquisition is the most commonly used. The form of the data coming from the detector is as a sequence of x,y coordinates. At some point we must form images. If we form images directly as part of the acquisition, this is called frame mode, whereas if we store the list of x,y coordinates, this is called list mode.(Todd-Pokropek)

a. Frame Mode

Frame mode is the most common mode of image acquisition for nuclear medicine studies. Static, dynamic, gated, whole-body, and single-photon emission computed tomography (SPECT) studies are acquired in frame mode. With frame mode, a matrix of computer locations is cleared in memory prior to the start of acquisition. For each detected event, the appropriate matrix element is incremented. This continues until a preselected time interval or total count value is reached. The memory or storage space required for a frame mode acquisition is determined solely by the matrix size and the number of frames acquired.(Madsen, 1994)

b. List Mode

List mode acquisition is less commonly used and some nuclear medicine computer systems no longer offer it as an option. Since information collected in list mode is a series of x and y locations, it cannot be viewed directly It must be reconstructed into image matrices ,the computer goes through the list of locations and increments a matrix element corresponding to that set of coordinates. (Madsen, 1994)

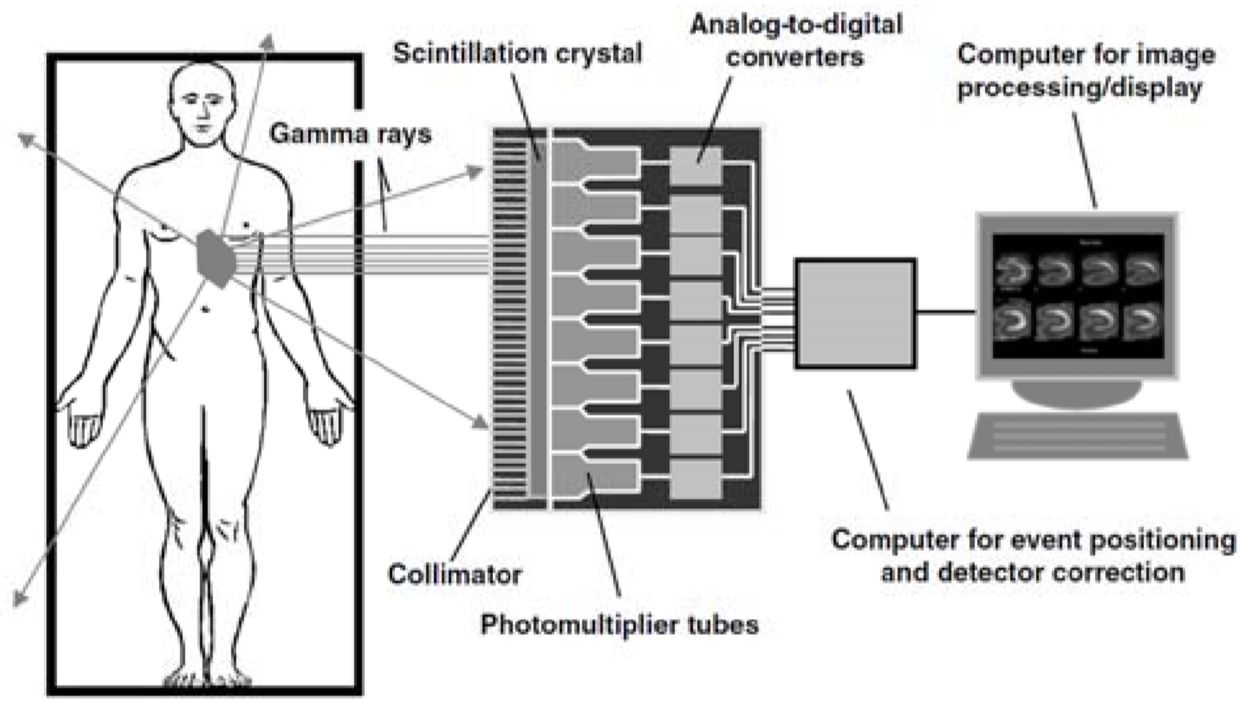

Figure 2.4.4 Schematic diagram of a conventional gamma camera used in SPECT. (Miles N. Wenick and John N. Aarsvdld, 2004)

2.1.5 The quality control program

Nuclear medicine is critically dependent on the accurate, reproducible performance of clinical radionuclide counting and imaging instrumentation. Quality control (QC), which may be defined as an established set of ongoing measurements and analyses designed to ensure that the performance of a procedure or instrument is within a predefined acceptable range, is thus a critical component of routine nuclear medicine practice. An extensive series of parameters has been developed over the years for acceptance testing and performance characterization of γ-cameras, SPECT and PET scanners, and other nuclear medicine instrumentation. And detailed data acquisition and analysis protocols for this purpose have been promulgated by the National Electrical Manufacturers Association (NEMA), the American Association of Physicists in Medicine (AAPM), and other regulatory, advisory, and professional organizations. The γ-camera has long been, and remains, the most widely used imaging device in nuclear medicine. The performance parameters most commonly evaluated as part of a routine γ-camera QC program include uniformity, spatial resolution, spatial linearity, and energy resolution and peaking. (Zanzonico, 2008) . Quality control of nuclear medicine equipment includes both safety and performance tests during the use of equipment. Safety tests include checks of condition and operation of radiation detectors, warning lights, radiation protection meters and the condition of radiation shielding as well as testing the mechanical operational safety

2.1.5.1 Safety and Electromechanical Inspection

For those nuclear medicine instruments that “interface” directly with patients—the intraoperative probe, organ uptake probe, γ-camera, SPECT and SPECT/CT scanner, and PET and PET/CT scanner—safety features should be regularly inspected. Such features include manual emergency-off switches (“panic buttons”), collision-detection switches that immediately stop all motion if a collision occurs (e.g., between the rotating γ-camera detector and the patient during a SPECT acquisition), and interlocks that immediately turn off the x-ray tube of a SPECT/CT or PET/CT scanner if a primary-barrier door is opened during a SPECT scan. All position displays on the gantry and computer console and all alignment lasers should likewise be visually inspected. All manual motion-control functions (e.g., gantry rotation, detector radial motion, and table translation) should be checked as well. Finally, as with all electromechanical devices, intraoperative probes, organ uptake probes, γ-cameras, SPECT and SPECT/CT scanners, and PET and PET/CT scanners should be inspected regularly for frayed wires and broken or otherwise damaged electrical insulation, loose electrical or mechanical connections (including missing or visibly loose screws, nuts, or bolts), and dents, sharp edges, or other physical damage.(Zanzonico, 2008) . The fundamental design of scintillation camera-based SPECT systems results in multiple performance parameters being coupled or linked. Thus, it is likely that an electrical or mechanical change in the system will result in changes in several measured parameters (Hines et al., 1999)

2.1.5.2 Performance Measurements of Gamma Cameras

Quality control tests during the use of equipment are conducted at periodic intervals according to a written quality control program.

2.1.5.2.1 Check the Photopeak

There is a single peak, corresponding to the energy of the nuclear decay. This peak is referred to as the ‘photopeak.’the photopeak is the peak formed by the case where the gamma ray deposits all of its energy in the detector. This can happen because the gamma interacts once through the photoelectric effect. It can also happen if the gamma initially interacts through Compton scattering or pair production, but the secondary particles then are also completely absorbed in other words A peak which is formed due to the complete absorption of photon energy in the detector is called "photo peak" .

Figure() pulse high

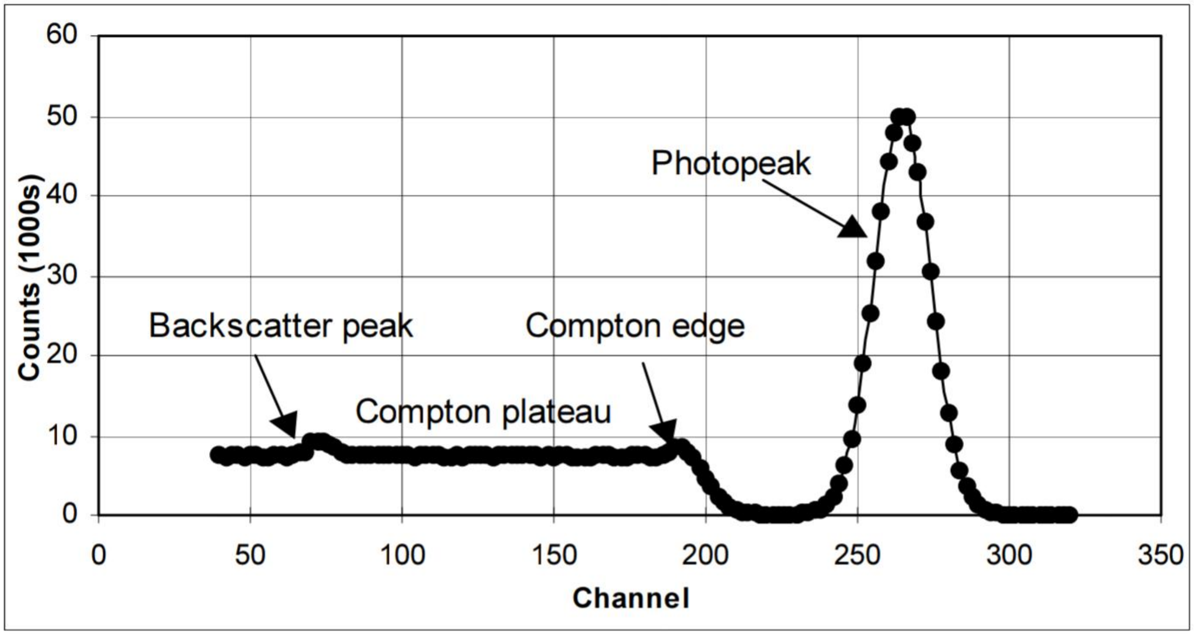

Fig 2.1.5.2.1 spectrum for a monochromatic gamma-ray source

2.1.5.2.2 Energy resolution

Energy Resolution is the ability of the Detector to accurately determine the Energy of the Incoming Radiation. Energy resolution is a very important parameter in determining the overall performance of a gamma camera, because it is the parameter, which allows a camera to differentiate between primary photons and Compton scattered photons. This ultimately determines the spatial resolution of the system. Since no camera system is perfect, no system is capable of determining precisely what energy photon struck the crystal. Instead, the system can only determine within a range of values, what energy radiation it is detecting. The energy resolution is expressed as a percent of the energy of the incoming photons. If the energy resolution of a camera is 10%, and only 140 KeV photons are striking the crystal, the system will "see" photons ranging from 133 KeV to 147 KeV. That is, it can only determine to within 14 KeV, what the actual incoming energy really is. An important measurement to assess the efficiency of the scintillation counting equipment in a Nuclear Medicine department is the Full Width at Half Maximum (FWHM), which should typically be less than 10% .Energy resolution, is expressed as a percent of the FWHM of a specific energy. Most cameras have an energy resolution in the range of 11% to 13% FWHM at 140 KeV.

The formula for determining the percent energy resolution for a particular radionuclide is:-

%Energy resolution = FWHM x 100 /photo peak {**2.3}**

Note; The lower the number of FWHM (smaller the percent), the Better the Energy Resolution.

Image quality is affected by energy resolution. Ideally, images would be comprised of only primary photons emitted by the decay of a radionuclide, not the secondary scattered photons. The better the energy resolution of an imaging device, the more successful the discrimination of primary from scattered photons, and thus, the better the image contrast and the more accurate quantitation of the amount and distribution of the radionuclide in vivo. In the context of myocardial perfusion imaging, systems with better energy resolution have the ability to discriminate areas of hypo perfusion from those of neighboring normal perfusion through enhanced image contrast .(Holly, 2010)

2.1.5.2.3 Spatial resolution

The NEMA definition of spatial resolution outlines the intrinsic ability of the camera to accurately detect the original location of a gamma ray on an x-y plane. The NEMA standard calls for spatial resolution to be measured in both the x and y direction and to be expressed as the full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of a line-spread function measured in millimeters. This measurement as performed by NEMA standards requires a special slit phantom, but extrinsic calculations may be performed for all collimators using a 99mTc point source in a capillary tube. The source is imaged at various locations along the x and y axes and line-spread functions are generated. Manual calculations of FWHM and FWTM can then be performed. Some nuclear medicine computer systems include programs for this testing, but as long as a line-spread function can be generated, the extrinsic spatial resolution for each collimator can be measured and compared to manufacturer specifications. The results are given in millimeters. (Blust. 1994)

2.1.5.2.4 Linearity

Spatial nonlinearities are caused by the mispositioning of individual photon events. This displacement is caused by a counts per sec distance • activity limited number of PM tubes trying to locate an infinite number of events and results in a wave-like distortion over the field of view of the system. The manufacturer uses a correction algorithm to compensate for this inherent Distortion. Resolution/linearity phantom (slite phantom) was used to collect an image for evaluation by placing it directly on the crystal face and point source of $Tc\text{-}^{99m}$ is centered at least 5 UFOV diameter a above the phantom as described by the NEMA protocol. Center 20% window on the photopeak. The phantom is aligned with either the χ or y camera axis. Determination of line-spread function peak positions is then compared to an ideal grid. (F. A. Salah et al,. 2002)

2.1.5.2.5 Uniformity

The uniformity of the gamma camera is normally defined as the difference between the maximum and minimum counts per field element (or count density) expressed as a percentage of the mean number of counts per element or of the average of the maximum and minimum values (Macey, 1972). The system uniformity is the most important and sensitive QC parameter of gamma camera. Intrinsic uniformity is determined from flood field images acquired without a collimator .For convenience, uniformity measurements often are made with the collimator in place (extrinsic uniformity). Extrinsic uniformity measurements also have the advantage that they reveal any defects or problems caused by the collimator itself. Integral and differential uniformity parameters calculated from flood source image are most commonly used method to monitor the gamma camera uniformity daily.

- Differential uniformity

For pixels within each area (CFOV and UFOV), is based on the change in counts of five consecutive pixels across all rows and columns of the image. It is defined as

Differential Uniformity = 100% ((high – low)/ (high + low)

Where “high” refers to the maximum count difference for any five consecutive pixels (row or column) in the image and “low” refers to the minimum count different for any five consecutive pixels.(Cherry et al., 2012) .

- Integral uniformity

For pixels within each area (CFOV and UFOV), the maximum and the minimum values are to be found from the smoothed data. The difference between the maximum and the minimum is divided by the sum of these two values and multiplied by 100.

Integral Uniformity = ± 100 ((Max - Min) /(Max + Min))*

Integral uniformity values are typically 2% to 4%.

2.1.5.2.4 Detector Sensitivity

The sensitivity of a scintillation camera is measured as the number of detected counts per unit time per unit source activity Measure as (CPM/μCi) for a specified energy window and geometry of measurement. The NEMA approach to measuring sensitivity is to measure the count rate per micro curie for a small source of known activity in a 10 cm diameter flat dish the activity should be low enough so that data loss because of camera deadtime is negligible. The sensitivity depend on the collimator type , window width, gamma energy, source configuration and system factors. . In general, the sensitivity of low-energy collimators is measured with 99mTc (Eγ= 140 keV), that of medium-energy collimators is measured with 111In (Eγ = 172, 247 keV), and 131I (Eγ = 364 keV) is used for high-energy collimators .

2.1.5.2.5 Center of Rotation

One of the most important quality control procedures for tomography is the center-of-rotation (COR) calibration. It is not a test of performance, but a calibration the COR must be calibrated for each collimator, matrix size, and zoom that is used for tomography.. The principle behind this calibration is that the center of the camera image must exactly match the center of the computer image when the images are reconstructed. 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.

2.1.6 National Electrical Manufacturers Association NEMA

NEMA Provides a uniform criterion for the measurement and reporting of gamma camera performance parameters for single and multiple crystal cameras. the NEMA Standard Publication NU-1 2001 of Performance Measurements of Scintillation Cameras have been applied in this research and all the results of performance tests undergo analysis and compare according to the NEMA international standards Manufacturers specifications

2.2 Previous studies:-

Abdelhamid A. Elkamhawy and et.al (2000)" Intrinsic Uniformity and Relative Sensitivity Quality Control" studied the purpose of the study was to determine the best parameters for rapid performance of daily quality control testing of intrinsic uniformity and relative sensitivity for the single-head gamma- camera system in their nuclear medicine department .They found that The dead time of used gamma-camera system was 4.5 ± 0.2 μs .With the recommended parameters, the intrinsic uniformity and relative sensitivity quality control testing can be performed in 5–6 min and the dead time of each gamma- camera system must be determined experimentally in each nuclear medicine department.

Another study was done by Michael K. O'Connor entitled, "Quality Control of Scintillation Cameras (Planar and SPECT)" This study focused on some of the more critical areas in the quality control of gamma camera systems. Which adversely affect the the image quality and clinical studies and he recommended the importance of both the technologist and physician to be able to recognize the various types of artifacts that can occur in gamma camera systems and their potential impact on clinical studies now in modern systems, may be subtle and difficult to recognize, The failure of a system component can occur at any time. But a thorough evaluation of the system at installation and a comprehensive quality control program will detect the majority of problems that can occur.

Ficken and William McCartney,1994, SPECT Quality Control: A Program Recommended by the American College of Nuclear Physicians and the ACNP Corporate Committee, wrote a paper, whose purpose was to identify basic quality control procedures and frequency of testing, the results of which yield a "use" or "no-use" condition for a single head SPECT camera. Due to variation in SPECT cameras and computer software, the exact type and frequency of the testing procedures cannot be specified exactly so Specific procedures and testing frequency should be approved by each equipment manufacturer or by a qualified physicist.

Nasser Ballani etal, 2015,carried out a study under the title of Simple method to measure gamma camera energy resolution, Energy resolution is one of the major limitations of gamma camera performance, mainly affecting image contrast and resolution. There is a need for a simple method of measuring gamma camera energy resolution, which is practical for technology students as well as for routine quality control.

Mr Hasan, 2017, carried out a study under the title Quality Control of Gamma Camera with SPECT Systems, The study was done using the data from Siemens Symbia S Series gamma camera by using a point source Tc^{99m} at the Institute of Nuclear Medicine & Allied Sciences (INMAS), the integral uniformity for the central field of view (CFOV) has been found in between 4.01% and 2.88% and for the useful field of view (UFOV) has been in between 4.77% and 4.30%. The differential uniformity for the CFOV has been in between 1.53% and 2.04% and for the UFOV has been in between 2.32% and 2.77%. .

In conclusion, these results showed that the intrinsic uniformity of the gamma camera under this condition was within an acceptable range; (do not exceed the Operating Instruction Symbia System S Series Manual value (10% for IU and 4% for DU).) thus the gamma camera working in INMAS is performed well.

Chapter Three

Materials and methods

Chapter Three

Materials and Methods

3.1 Materials

3.1.1 the SPECT machine specifications in the present research

Model Ulie 2008

Manufacture MiE (Medical Imaging Electronics

Serial number 2008/43

Type Orbiter 37

Installation 2009

Fig 3.11Typical SPECT gamma camera (orbital37) installed in Al Nilien Nuclear Medicine Department.

3.1.2 Dose Calibrators

The dose calibrator is a pressurized gas-filled ionization chamber for assaying activities in radiopharmaceutical vials and syringes and in other small sources.

Fig 3.1.2 the dose calibrator used in this research

3.1.3 Syringes

5 ml syringes were used for Tc^{99m} with drawing

3.1.4 Plastic dish

Dish filled with water and Tc99m for uniformity test.

Fig 3.1.4 the plastic dish used for sensitivity test

3.2 Methods

3.2.1 photopeak spectrum check

- The activity of a 5 mCi of Tc^{99m} point source in a syringe was measured in the dose calibrator after replacing the needle.
- 5 Mci of Tc^{m99} point source was prepared and positioned in the center of the detector .
- The camera was set with its face perpendicular to the floor.
- Static images were acquired with the same acquisition time 1-5 min), acquisition window 20%.

3.2.2 Energy resolution measurement

- the energy resolution calculated using the formula

Energy resolution % = (FWHM/ photo peak) x 100

3.2.3 Extrinsic Uniformity measurement

The method used to assess field uniformity effect was similar to that recommended by NEMA **(2001).** The following procedure was used:

- A 5 mCi Tc^{99m} point source in end of the needle cap was measured in dose calibrator with the needle cap changed.
- The detector was turned upside down.
- A 5 mCi Tc^{99m} point source in end of the needle cap was placed at a distance of five times the detector field of view
- The activity was adjusted to collect a 15,000 count 64X64-image ,(FOV 408X408 mm)

Figure 3.2.3: the position of point source during the uniformity test

3.2.4 Sensitivity test;-

To verify that count rate per unit activity per detector is satisfactory the following procedure was used:-

- 1 mCi of Tc^{99m} source inside the plastic syringe, was accurately measured using a dose calibrator with the needle cap changed .The activity should be low enough so that data loss because of camera dead time is negligible.
- This source was then dispersed from the syringe into water in a plastic flat dish as shown in Fig (3.2.4).

- The prepared dish was placed in the center of the field of view
- 4 million counts were acquired with the imaging system

Fig 3.2.4 the position of the plastic dish in the detector center during sensitivity measurement

3.2.5 Center of rotation calibration

- cardiac position scanning was set

- syringe full of 0.5 mCi of Tc^{99m} was put in the peripheral hole of the phantom
- the detector was set to turn 360 from the start position which is 45
- The data were collected and reconstructed in a matrix .20,000 total counts were acquired in each of 120 different projections angle images over 360°' utilizing step and shoot mode.

3.2.6 Linearity test

The test was not applied due to lack of tools.

3.2.7 Spatial resolution test

The test was not applied due to lack of tools.

Chapter Four

Results

Chapter four

Results

4.1 Photopeak test

Table 4.1: the acquisition data and The photopeak test result

Acquisition data	Photopeak result
FWHM = 12.1% window width = 20%	140 Kev

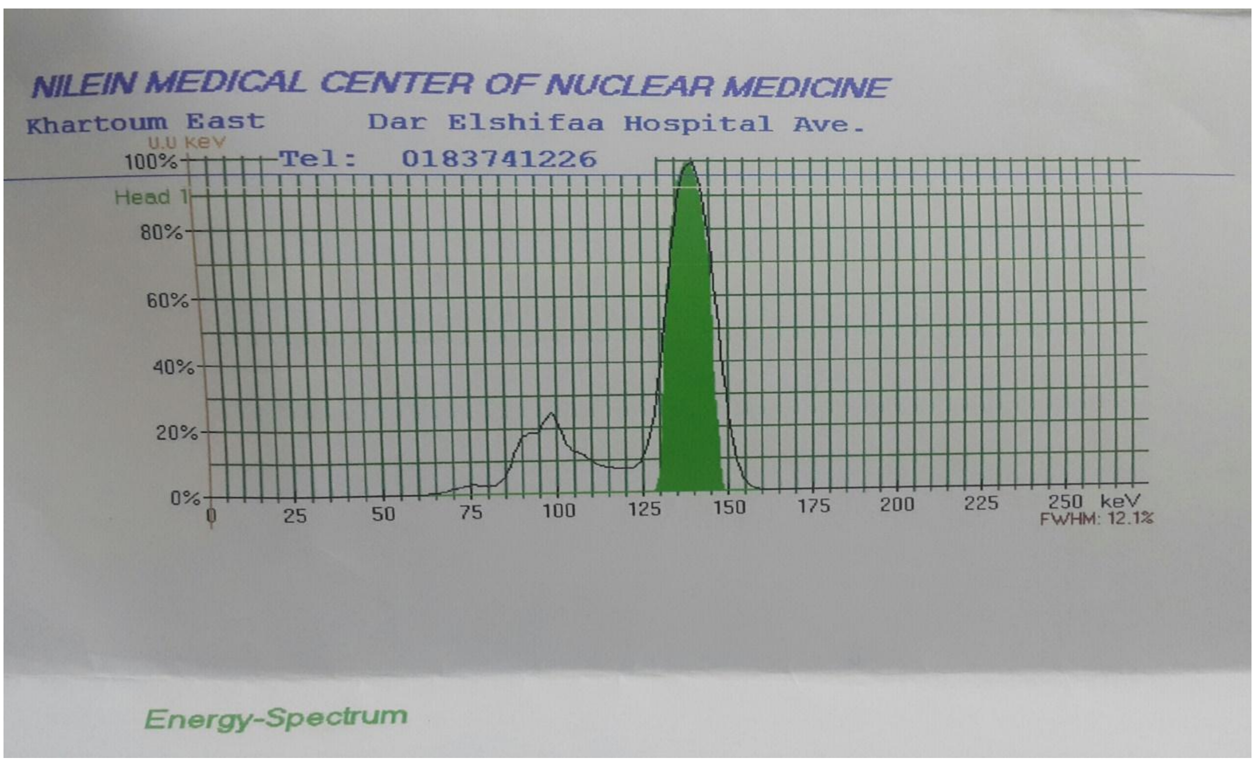

Fig 4.1: Tc^{99m} energy spectrum in the SPECT gamma camera of Al Nilein Nuclear Medicine Department, FWHM = 12.1%, window width = 20%.

4.2 Energy Resolution Test

Table 4.2: the Acquisition data and Energy resolution result

parameter	% / degree
FWHM	12.1
Window width	20
Energy resolution	8.64

4.3 Uniformity Test ;-

Table : The uniformity test results

parameter	%/degree
Integral uniformity	3.34
Differential uniformity	2.74

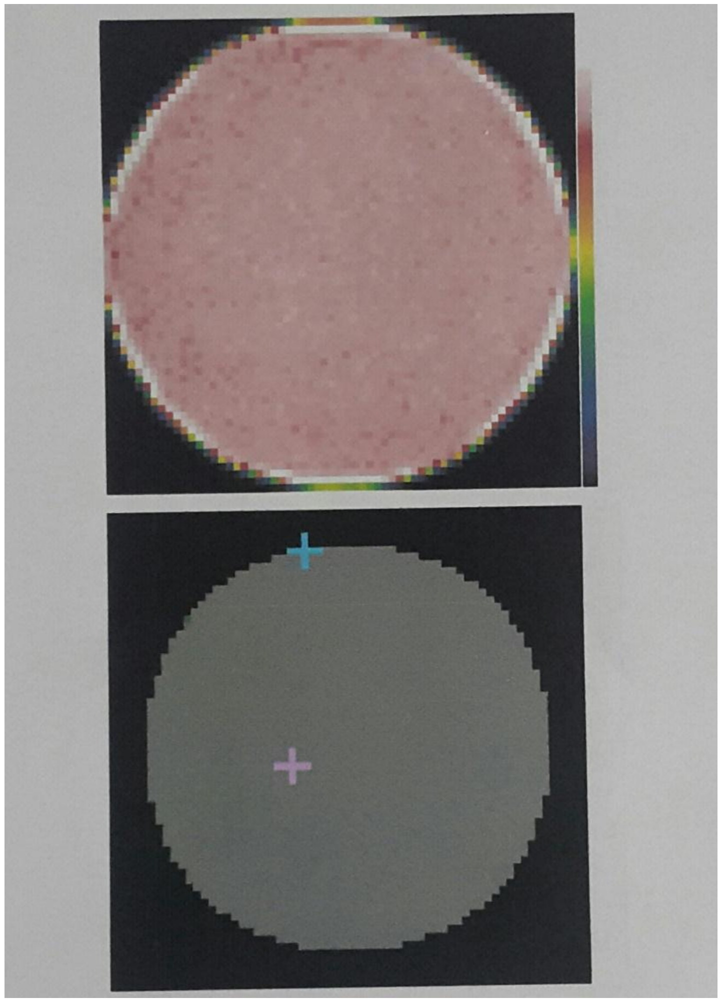

Fig 4.3: Flood field uniformity image

4.4 Sensitivity test ;-

Table 4.4: The sensitivity test result

Sensitivity value	88.1 CPM/µCi

4.5 Center of Rotation Calibration

Table 4.5: the acquisition data and results for COR calibration

	New values	Saved values
Number of image	64	64
Start position	-45	-45
Direction	Clockwise	clockwise
Mean	-1.2	-1.2
Max	2.1	2.1

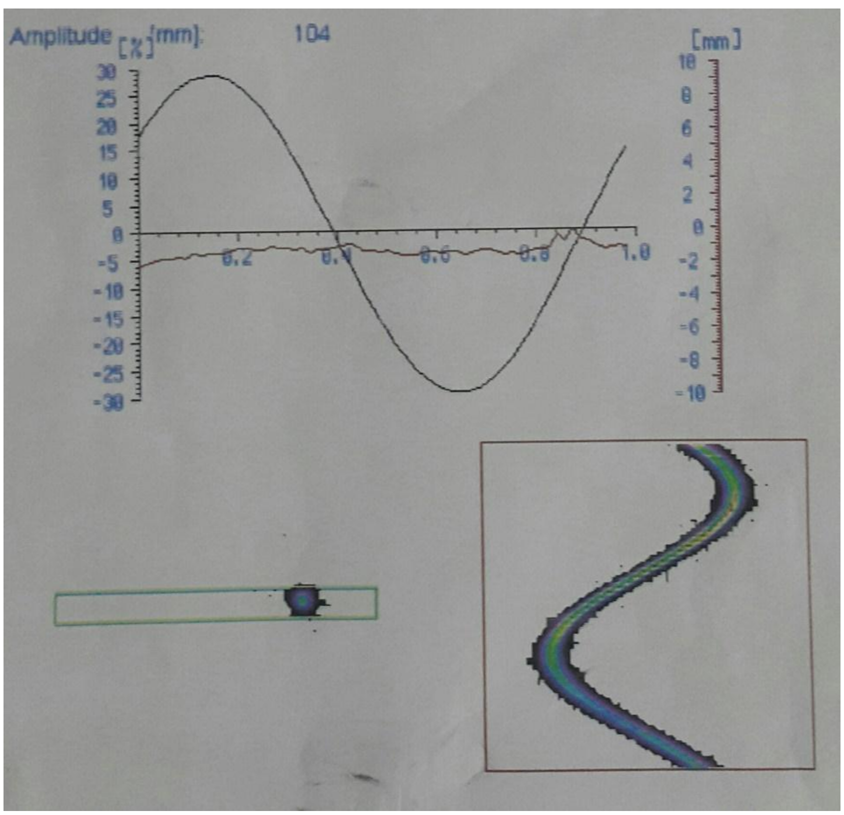

Fig 4.5 center of rotation calculations

NB: Zoom Number: 3, Field Size: 355 (mm), Rotation (deg): 360.

4.6 spatial resolution test

No results were obtained.

Table 4.6 show spatial resolution test of SPECT camera for Al Nilein Medical Center of Nuclear Medicine

X(mm)	Y(mm)
-	-

4.7 Linearity test

No results were obtained.

Table 4.8 NEMA QC performance standards compare to QC results of Al Nilein Medical Center of Nuclear Medicine

Test	result	NEMA standards	evaluation	Frequency
Energy resolution	8.64%	10%	Acceptable	daily
Integral uniformity test	3.34%	4%	Acceptable	daily
Differential uniformity test	2.74%	3%	Acceptable	daily
Spatial resolution	-	1.0 mm	-	quarterly
Sensitivity test	88.1	85	Acceptable	Semi-annually
COR	-1.2	0.5	Not acceptable	weekly

Chapter five

Discussion, Conclusion and Recommendations

Chapter five

Discussion Conclusion and Recommendations

5.1 Discussion

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 . The QC tests carried out at Al Nielien Nuclear Medicine Department included: photopeak test, energy resolution, extrinsic uniformity, sensitivity and center of rotation.

Concerning table 4.1 shows photopeak measurement result. The result obtained lie within NEMA standards typically. In table 4.2 The result obtained by equation**{** 2.3} was 8.64% ,which was in compatibility with international standards that should not exceed 10% . In table 4.3 results concerning the integral and differential uniformity which were 3.34% , 2.74% respectively . The results were considered good according to NEMA performance standards and these result agreed with that published by Mr Hasan (2017) .Table 4 .5 showed the sensitivity test result for the gamma camera that matched NEMA standards .in table 4.6 results were not otained due to the lack of facilities . Note that in Al Nielien Nuclear Medicine Department they don’t have tools to perform the linearity test and spatial resolution test so the tests were not apply .

The COR measurement mean value shown in table 4.5 was too high (-1.2) compared with NEMA reference results (.5) .This may be due to human error during COR calibration or the defect in SPECT machine .Therefore the COR should be measured again for more investigation. Table 4.6 show comparison of our results with NEMA QC performance standards

5.2 Conclusion

In conclusion QC program considered as one of the important quality assurance part in practice of NM imaging technology since it can be used as indicator for machine performance according to the protocol used . Therefore, this study was implemented to assess the SPECT gamma camera QC program carried out at Nilien nuclear medicine department . The obtained results that agreed with the NEMA-2001 standard values were photopeak , energy resolution ,sensitivity ,and uniformity tests .The center of rotation calibration didn’t agree with the reference value .

The (FWHM) can be used for obtaining the energy resolution value The uniformity is the most important and sensitive QC parameter for estmating the image quality of gamma camera due to giving excellent images to diagnose.

5.3 Recommendations

- The Comprehensive application of quality assurance that include quality control for gamma camera machines, radionuclide, dose calibrators, waste management and radiation protection program, is very essential to decrease the radiation risks for patients and staff . These parameters should be applied carefully at all nuclear medicine departments in Sudan.
- Quality control equipment and facilieteis should be available at any NM department in Sudan
- QC procedures should be carried out daily,weakly ,monthly,anually as recommended by the international standards .
- The enviromental condition such as temprature and presure should be measured and recorded before and after the QC test .
- It is very important for NM clinics to use the free commercial or the open NM estimantion software to estimate the patient dose prior to each NM examination.
- QC training courses should be made for NM technologists and Physicists to be updated with QC programs and dose estimation and their useful impact on the hospital performance .
- More cooperation between the NM staff and researchers is hightly recommended to obtained good results for the bebefit of all .
- Future studies should be carried out in QC procedures included more parameters and using more advanced facilities .

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Appendices

Appendix 1 show the hot lab in NM department

Available from (https://www.actx.edu/nuclear_med/classroomhot-lab-images)

Appendix 2 technetium-99m-generator available from (http://www.geebeeinternational.com/india/index.php/products-of-geebee-international/nuclear-medicine/technetium-99m-generator-specifications)