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Commissioning of Single Photon Emission Computed Tomography: Acceptance Testing and Quality Assurance of SPECT/Gamma Camera Component

Priya Jacob
Independent researcher, USA

* Corresponding Author: **Priya Jacob**

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Abstract

The commissioning of Single Photon Emission Computed Tomography (SPECT) systems, including Gamma camera components, is a critical process to ensure optimal performance and accurate diagnostic imaging. This paper outlines the comprehensive procedures for acceptance testing and quality assurance (QA) [6,7,9] of SPECT systems. Acceptance testing involves a series of standardized tests to verify that the SPECT system [1,2,3] meets the manufacturer's specifications and clinical requirements. Key parameters assessed include spatial resolution, energy resolution, sensitivity, and uniformity. Quality assurance protocols are then implemented to maintain the system's performance over time, ensuring consistent image quality and patient safety. Regular QA checks involve calibration of the Gamma camera, verification of system alignment, and assessment of image artifacts. The paper also discusses the importance of adhering to regulatory standards and guidelines to achieve reliable and reproducible results. By following these rigorous procedures, healthcare facilities can ensure the accuracy and reliability of SPECT imaging, ultimately enhancing patient care and diagnostic outcomes.

These tests are designed to be reproducible and comparable across different scanner platforms and manufacturers. The results are evaluated against the standards provided by the manufacturer and local regulatory guidelines, Atomic Energy Regulatory Board (AERB). The study emphasizes the importance of a thorough and ongoing QA program to maintain the accuracy and reliability of SPECT/CT imaging; by combining functional and anatomical imaging, SPECT/CT provides more accurate and detailed information about the location and extent of abnormalities. This is particularly useful in diagnosing conditions such as cancer, heart disease, Brain and bone disorders.

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1. Introduction

The fusion of Single Photon Emission Computed Tomography (SPECT) and Computed Tomography (CT) into a single, integrated imaging platform, SPECT/CT, has revolutionized diagnostic medicine. This synergistic modality transcends the limitations of standalone imaging techniques, offering a profound leap in diagnostic accuracy and clinical utility. By seamlessly overlaying functional information derived from radiotracer distribution with precise anatomical localization provided by CT, SPECT/CT empowers clinicians to unravel complex pathophysiological processes with unprecedented clarity.

The advantages are manifold and transformative: enhanced diagnostic accuracy arises from the simultaneous visualization of physiological and structural anomalies, enabling nuanced interpretations that would be elusive with either modality alone. This is particularly impactful in the intricate landscapes of oncology, where precise tumor characterization and staging are paramount; cardiology, where myocardial perfusion and viability assessments guide critical interventions; and neurology, where subtle alterations in brain function can be correlated with structural pathologies. Improved localization of lesions, a cornerstone of surgical and radiation therapy planning, is rendered with exceptional precision. Superior disease staging emerges as a direct consequence of the comprehensive data set, allowing for accurate assessment of disease extent and metastatic spread. The inherent increased sensitivity and specificity of the combined modality significantly bolster diagnostic confidence. Finally, SPECT/CT facilitates a comprehensive evaluation of organ and tissue health, enabling longitudinal monitoring of disease progression and treatment response.

The clinical applications of SPECT/CT are diverse and impactful: in cardiology, it provides critical insights into myocardial perfusion, viability, and the efficacy of revascularization procedures. In oncology, it serves as a powerful tool for tumor detection, staging, and response assessment, guiding personalized treatment strategies. In neurology, it aids in the diagnosis and management of neurodegenerative diseases, epilepsy, and traumatic brain injuries. In orthopedics, it is invaluable for detecting bone infections, fractures, and metastatic bone disease.

However, the full potential of SPECT/CT can only be realized through meticulous commissioning and a robust, ongoing quality assurance (QA) program. Commissioning involves rigorous acceptance testing, verifying that the system aligns with manufacturer specifications and functions flawlessly upon installation. This phase establishes critical baseline measurements for key performance parameters, including spatial resolution, sensitivity, and image quality. Calibration ensures accurate quantification of SPECT data, a prerequisite for reliable diagnostic interpretations.

A sustained commitment to quality assurance is paramount for maintaining the accuracy and reliability of SPECT/CT imaging. This program must commence with thorough acceptance testing, verifying adherence to pre-purchase specifications. It must be a dynamic, continuous process, encompassing routine quality control (QC) procedures (daily, weekly, and monthly checks), periodic performance assessments against established baselines, and proactive preventive maintenance.

The significance of a rigorous QA program extends beyond clinical efficacy; it is a regulatory imperative. In India, the Atomic Energy Regulatory Board (AERB) mandates strict adherence to established protocols and guidelines for commissioning and operating SPECT/CT facilities. Compliance with the Atomic Energy (Radiation Protection) Rules, 2004, and AERB Safety Codes is non-negotiable, requiring meticulous documentation and adherence to stringent quality control measures. These measures include comprehensive assessments of spatial resolution, spatial linearity, uniformity, sensitivity, scatter fraction, noise equivalent count rate (NECR), scan speed, and head leakage. This document aims to provide a comprehensive framework for commissioning and maintaining the quality of clinical SPECT/CT systems, aligning with AERB requirements. It serves as a guide for researchers and clinicians, emphasizing the critical importance of a meticulous, data-driven approach to acceptance testing and ongoing quality assurance. By adhering to these principles, we can ensure that SPECT/CT continues to deliver its transformative potential, improving patient outcomes and advancing the frontiers of diagnostic imaging.

2. Methods and Materials

A newly installed SPECT/CT system (NM-CT 860, GE Medical Systems, Israel) was the focus of this study. We adhered to the recommendations of the AAPM Task Group 177 report for acceptance tests and annual physics surveys of gamma cameras and SPECT systems. For acceptance testing, we aimed to complete tests using clinical phantoms. This allowed for efficient evaluation of manufacturer specifications and clinically relevant results.

3. Acceptance Testing [4, 5]

International reference standards, including IEC 60789, 61675-2, and 61675-3, along with NEMA standards, provide the framework for evaluating gamma camera and SPECT system performance. While the AAPM Task Group 177 report draws heavily from NEMA standards, practical considerations in clinical settings necessitate some deviations. These deviations are not expected to significantly alter the determination of the specified parameters. This paper focuses on SPECT/CT quality assurance (QA) tests for evaluating various parameters, including spatial resolution, SPECT/CT alignment, sensitivity, count rate performance, accuracy of corrections, image contrast, scatter/attenuation correction, and image uniformity. Reports generated from these tests must compare the measured results to the standards set by the manufacturer and local regulatory guidelines (AERB) [10]. They should also summarize whether the tests passed or failed and recommend any necessary corrective actions. The following tests are specifically related to the SPECT component (Model: NM-CT 860, GE Medical Systems, Israel)

a) Test of centering of PHA window

The test of centering of the Pulse Height Analyzer (PHA) window is a quality control procedure used to ensure the accuracy and precision of gamma cameras/SPECT. This test is crucial for maintaining the performance and reliability of the imaging system. The test aims to verify that the PHA window is correctly centered on the photo peak of the radionuclide being used. This ensures that the gamma camera accurately detects and processes the gamma rays emitted by the radionuclide. A Technetium-99m (Tc-99m) source is placed in front of the SPECT/gamma camera. The PHA window settings are adjusted to center on the photo peak of the radionuclide. The system records the counts detected within the PHA window. The counts are analyzed to ensure they fall within the expected range, indicating that the PHA window is correctly centered. Proper centering of the PHA window is essential for accurate imaging and quantification in nuclear medicine. Misalignment can lead to incorrect data, affecting diagnostic accuracy and patient care. Our test results shown below and it was passed.

Description	Observation	Tolerance
Whether all photopeaks are properly centered in the test for each radionuclide proposed/ used in the department	Yes	Observance of proper centering of all photopeak's

Detector	Tc99m Peak in kev
Head 1	140.508
Head 2	140.678

b) Test of intrinsic flood field uniformity

The test aims to verify that the SPECT/gamma camera produces a uniform image when exposed to a uniform radiation source. This ensures that the camera's response is consistent across the entire field of view. A Technetium-99m (Tc-99m) point source is placed in front of the SPECT. The collimator is removed to test the intrinsic uniformity of the camera. The system records the counts detected across the entire field of view. The counts are analyzed to ensure they fall within the expected range, indicating uniform response. Proper intrinsic flood field uniformity is crucial for accurate imaging and quantification in nuclear medicine. Non-uniformity can lead to artifacts and inaccuracies in the images, affecting diagnostic accuracy and patient care. Test results are shown below.

Detector 1

Name	Observed Value	Result	Reference Value
Detector #1 CFOV Integral Uniformity	0.935555	Passed	<=3.0
Detector #1 CFOV X-Diff Uniformity	0.632981	Passed	<=2.1
Detector #1 CFOV Y-Diff Uniformity	0.642474	Passed	<=2.1
Detector #1 UFOV Integral Uniformity	0.935555	Passed	<=3.6
Detector #1 UFOV X-Diff Uniformity	0.676088	Passed	<=2.3
Detector #1 UFOV Y-Diff Uniformity	0.658909	Passed	<=2.3

Detector 2

Name	Observed Value	Result	Reference Value
Detector #2 CFOV Integral Uniformity	0.755369	Passed	<=3.0
Detector #2 CFOV X-Diff Uniformity	0.650843	Passed	<=2.1
Detector #2 CFOV Y-Diff Uniformity	0.597525	Passed	<=2.1
Detector #2 UFOV Integral Uniformity	0.864463	Passed	<=3.6
Detector #2 UFOV X-Diff Uniformity	0.650843	Passed	<=2.3
Detector #2 UFOV Y-Diff Uniformity	0.597525	Passed	<=2.3

Result: Test Passed
UFOV – useful field of view, CFOV-central Field of view
Differential: ≤ 2% or ± 10% of manufacturers reference value
Integral: 2-3% or ± 10% of manufacturers reference value

c) Test of extrinsic flood field uniformity

The test aims to verify that the SPECT/gamma camera produces a uniform image when exposed to a uniform radiation source with the collimator in place. This ensures that the camera's response is consistent across the entire field of view, including the effects of the collimator. A Technetium-99m (Tc-99m) flood source is placed in front of the gamma camera with the collimator attached. The system records the counts detected across the entire field of view. The counts are analyzed to ensure they fall within the expected range, indicating uniform response. Proper extrinsic flood field uniformity is crucial for accurate imaging and quantification in nuclear medicine. Non-uniformity can lead to artifacts and inaccuracies in the images, affecting diagnostic accuracy and patient care. Test results are explained below.

Detector 1

Name	Observed Value	Result	Reference Value
Detector #1 CFOV Integral Uniformity	0.747222	Passed	<=3.0
Detector #1 CFOV X-Diff Uniformity	0.611526	Passed	<=2.1
Detector #1 CFOV Y-Diff Uniformity	0.510228	Passed	<=2.1
Detector #1 UFOV Integral Uniformity	0.754802	Passed	<=3.6
Detector #1 UFOV X-Diff Uniformity	0.611526	Passed	<=2.3
Detector #1 UFOV Y-Diff Uniformity	0.584755	Passed	<=2.3

Detector 2

Name	Observed Value	Result	Reference Value
Detector #2 CFOV Integral Uniformity	0.993458	Passed	<=3.0
Detector #2 CFOV X-Diff Uniformity	0.802848	Passed	<=2.1
Detector #2 CFOV Y-Diff Uniformity	0.749728	Passed	<=2.1
Detector #2 UFOV Integral Uniformity	1.061499	Passed	<=3.6
Detector #2 UFOV X-Diff Uniformity	0.802848	Passed	<=2.3
Detector #2 UFOV Y-Diff Uniformity	0.749728	Passed	<=2.3

Result: Test Passed
UFOV – useful field of view, CFOV-central Field of view
Differential: ≤ 2% or ± 10% of manufacturers reference value
Integral: 2-3% or ± 10% of manufacturers reference valu

d) Test of intrinsic flood field uniformity through narrowed and asymmetric (off- centered) PHA Windows

The test is to verify that the SPECT produces a uniform image when the PHA windows are narrowed and off-centered. This ensures that the camera's response is consistent across the entire field of view, even when the PHA settings are adjusted. A Technetium-99m (Tc-99m) source is placed in front of the SPECT. The PHA windows are adjusted to be narrower and off-centered. The system records the counts detected across the entire field of view. The counts are analyzed to ensure they fall within the expected range, indicating uniform response. Results are tabulated below.

Description	Observation	Tolerance
Whether all the PMT is tuned properly:	Yes	Observance of properly tuned PMT's

X = (a+b+c)/3

V= {(X- Y)/ X}x100; where Y = a or b or c

Detector	% Energy window	FWHM	% Variation (V)
Detector 1	140Kev +-10%	8.727	-0.42
Detector 1	140 kev & 140 Kev +10%	8.697	-0.07
Detector 1	140 kev -10% & 140 Kev	8.647	+0.49
Detector 2	140Kev +-10%	8.815	0.03
Detector 2	140 kev & 140 Kev +10%	8.817	0.01
Detector 2	140 kev -10% & 140 Kev	8.822	-0.05

Result: Test Passed

e) Intrinsic Spatial resolution:

The intrinsic spatial resolution measures the SPECT/gamma camera's capability to localize gamma-ray interactions within the detector crystal. It is a key factor in ensuring high-quality, detailed images. A point source of radioactivity, such as Technetium-99m (Tc-99m), is placed at a known distance from the detector. The system records the detected counts, and the spatial resolution is calculated based on the spread of these counts. High intrinsic spatial resolution is crucial for accurate imaging and diagnosis in nuclear medicine. It ensures that small lesions or abnormalities can be detected and accurately localized. Test results are described below.

Detector-1 X & Y direction

Name	Observed Value	Result	Reference Value
Detector #1 CFOV FWHM Average	3.439	Passed	<=3.8
Detector #1 CFOV FWTM Average	6.497	Passed	<=7.1
Detector #1 X CFOV - FWHM Average	3.457	Passed	<=3.8
Detector #1 X CFOV - FWTM Average	6.529	Passed	<=7.1
Detector #1 Y CFOV - FWHM Average	3.422	Passed	<=3.8
Detector #1 Y CFOV - FWTM Average	6.465	Passed	<=7.1
Detector #1 X UFOV - FWHM Average	3.459	Passed	<=3.9
Detector #1 X UFOV - FWTM Average	6.538	Passed	<=7.2
Detector #1 Y UFOV - FWHM Average	3.451	Passed	<=3.9
Detector #1 Y UFOV - FWTM Average	6.538	Passed	<=7.2
Detector #1 UFOV FWTM Average	6.538	Passed	<=7.2
Detector #1 UFOV FWHM Average	3.455	Passed	<=3.9

Detector-2 X & Y direction

Name	Observed Value	Result	Reference Value
Detector #2 CFOV FWHM Average	3.427	Passed	<=3.8
Detector #2 CFOV FWTM Average	6.466	Passed	<=7.1
Detector #2 X CFOV - FWHM Average	3.434	Passed	<=3.8
Detector #2 X CFOV - FWTM Average	6.481	Passed	<=7.1
Detector #2 Y CFOV - FWHM Average	3.419	Passed	<=3.8
Detector #2 Y CFOV - FWTM Average	6.451	Passed	<=7.1
Detector #2 X UFOV - FWHM Average	3.443	Passed	<=3.9
Detector #2 X UFOV - FWTM Average	6.508	Passed	<=7.2
Detector #2 Y UFOV - FWHM Average	3.433	Passed	<=3.9
Detector #2 Y UFOV - FWTM Average	6.509	Passed	<=7.2
Detector #2 UFOV FWTM Average	6.508	Passed	<=7.2
Detector #2 UFOV FWHM Average	3.438	Passed	<=3.9

Result: Test Passed

Tolerance :- <=1.05% of reference

f) Test of extrinsic spatial resolution (FWHM&FWTM) at 0, 10 and 20cm distance from the detector surface.

The test is to verify the SPECT/gamma camera's ability to accurately depict small details within an image at various distances from the detector surface. This ensures that the camera's spatial resolution is consistent and reliable. A point source of radioactivity, such as Technetium-99m (Tc-99m), is placed at 0, 10, and 20 cm distances from the detector surface. The system records the counts detected at each distance. The Full Width at Half Maximum (FWHM) and Full Width at Tenth Maximum (FWTM) are measured in both the X and Y directions. The measurements are analyzed to ensure they fall within the expected range, indicating accurate spatial resolution. Proper extrinsic spatial resolution is crucial for accurate imaging and quantification in nuclear medicine. It ensures that small lesions or abnormalities can be detected and accurately localized at various distances from the detector surface. Test results are tabulated below.

Detector 1

Description	Distance 0 cm			Distance 10cm		
	Measured (mm)	Reference (mm)	Tolerance	Measured (mm)	Reference (mm)	Tolerance
FWHM in X Direction	2.2	4.5	≤ 1.05 of Reference	3.8	7.4	≤ 1.05 of Reference
FWHM in Y Direction	2.6	4.5	≤ 1.05 of Reference	4.0	7.4	≤ 1.05 of Reference
FWTM in X Direction	4.1	8.9	≤ 1.05 of Reference	7.0	13.5	≤ 1.05 of Reference
FWTM in Y Direction	4.8	8.9	≤ 1.05 of Reference	7.4	13.5	≤ 1.05 of Reference

Description	Distance 20 cm		
	Measured (mm)	Reference (mm)	Tolerance
FWHM in X Direction	5.0	11.7	≤ 1.05 of Reference
FWHM in Y Direction	5.1	11.7	≤ 1.05 of Reference
FWTM in X Direction	9.3	23.1	≤ 1.05 of Reference
FWTM in Y Direction	9.4	23.1	≤ 1.05 of Reference

Detector 2

Description	Distance 0 cm			Distance 10cm		
	Measured (mm)	Reference (mm)	Tolerance	Measured (mm)	Reference (mm)	Tolerance
FWHM in X Direction	2.2	4.5	≤ 1.05 of Reference	3.6	7.4	≤ 1.05 of Reference
FWHM in Y Direction	2.6	4.5	≤ 1.05 of Reference	3.5	7.4	≤ 1.05 of Reference
FWTM in X Direction	4.1	8.9	≤ 1.05 of Reference	6.7	13.5	≤ 1.05 of Reference
FWTM in Y Direction	4.8	8.9	≤ 1.05 of Reference	6.5	13.5	≤ 1.05 of Reference

Description	Distance 20 cm		
	Measured (mm)	Reference (mm)	Tolerance
FWHM in X Direction	5.3	11.7	≤ 1.05 of Reference
FWHM in Y Direction	5.4	11.7	≤ 1.05 of Reference
FWTM in X Direction	9.8	23.1	≤ 1.05 of Reference
FWTM in Y Direction	10.0	23.1	≤ 1.05 of Reference

Result: Test Passed

g) Test of system spatial linearity

The test aims to verify that the SPECT/gamma camera produces straight lines when imaging a linear source. This ensures that the camera's response is consistent and accurate across the entire field of view. A linear source, such as a bar phantom, is placed in front of the gamma camera. The system records the counts detected along the linear source. The counts are analysed to ensure they fall within the expected range, indicating accurate spatial linearity. Proper system spatial linearity is crucial for accurate imaging and quantification in nuclear medicine. Non-linearity can lead to distortions and inaccuracies in the images, affecting diagnostic accuracy and patient care.

Detector 1	Observed Value	Result	Reference Value
Detector #1 CFOV Absolute Linearity	0.137	Passed	<=0.4
Detector #1 CFOV Differential Linearity	0.026	Passed	<=0.2
Detector #1 X CFOV - Absolute linearity	0.113	Passed	<=0.4
Detector #1 X CFOV - Differential linearity	0.023	Passed	<=0.2
Detector #1 Y CFOV - Absolute linearity	0.137	Passed	<=0.4
Detector #1 Y CFOV - Differential linearity	0.029	Passed	<=0.2
Detector #1 X UFOV - Absolute linearity	0.258	Passed	<=0.4
Detector #1 X UFOV - Differential linearity	0.031	Passed	<=0.2
Detector #1 Y UFOV - Absolute linearity	0.321	Passed	<=0.4
Detector #1 Y UFOV - Differential linearity	0.043 De	Passed	<=0.2
Detector #1 UFOV Absolute Linearity	0.321	Passed	<=0.4
Detector #1 UFOV Differential Linearity	0.037	Passed	<=0.

Detector 2	Observed Value	Result	Reference Value
Detector #2 CFOV Absolute Linearity	0.174	Passed	<=0.4
Detector #2 CFOV Differential Linearity	0.027	Passed	<=0.2
Detector #2 X CFOV - Absolute linearity	0.174	Passed	<=0.4
Detector #2 X CFOV - Differential linearity	0.031	Passed	<=0.2
Detector #2 Y CFOV - Absolute linearity	0.133	Passed	<=0.4
Detector #2 Y CFOV - Differential linearity	0.022	Passed	<=0.2
Detector #2 X UFOV - Absolute linearity	0.185	Passed	<=0.4
Detector #2 X UFOV - Differential linearity	0.033	Passed	<=0.2
Detector #2 Y UFOV - Absolute linearity	0.317	Passed	<=0.4
Detector #2 Y UFOV - Differential linearity	0.044	Passed	<=0.2
Detector #2 UFOV Absolute Linearity	0.317	Passed	<=0.4
Detector #2 UFOV Differential Linearity	0.038	Passed	<=0.2

Result: Test Passed

Tolerance: - ±10% of reference value

h) Test of system planar sensitivity at 10 cm from detector surface:

The test aims to verify the SPECT/gamma camera's ability to detect and measure radioactivity accurately at a specific distance from the detector surface. This ensures that the camera's sensitivity is consistent and reliable. Technetium-99m (Tc-99m) flood source is placed 10 cm from the detector surface. The system records the counts detected across the entire field of view. The counts are analyzed to ensure they fall within the expected range, indicating accurate planar sensitivity. Proper system planar sensitivity is crucial for accurate imaging and quantification in nuclear medicine. It ensures that the SPECT can detect and measure radioactivity accurately, which is essential for diagnostic accuracy and patient care.

For LEHRS collimator

Detector	Time	Counts	Activity(mCi)	Sensitivity	Reference Value
1	1 minute	108696	0.552	197	204
2	1 minute	113403	0.571	199	204

Result: Test Passed

Tolerance: - ±10% of reference value

i) Test of collimator hole angulation

The test aims to verify that the collimator holes are correctly aligned, ensuring that the SPECT/gamma camera produces accurate and undistorted images. This test is performed with 1mCi of Tc-99m point source taken in S shape with 125mm distance apart. Checked the collimator at different locations in each detector in both X and Y directions. Total count taken 1000Kc. There is no artifact observed at different angle and all the images look circular with zero collimation angle.

Detector	Observed Value	Reference
1	0	<=0.3 Degree
2	0	<=0.3 Degree

Result: Test Passed

j) Test of Intrinsic Count rate performance and Dead time with and without scatter medium (two source/Manufactures method)

The test aims to measure the SPECT's count rate performance and dead time, both with and without a scatter medium. This ensures that the camera can accurately detect and process gamma rays under various conditions. Two sources of radioactivity, such as Technetium-99m (Tc-99m), are used. The first source is placed in front of the SPECT without any scatter medium. The system records the counts detected and calculates the count rate and dead time. The second source is placed in front of the gamma camera with a scatter medium, such as a water-filled phantom. The system records the counts detected and calculates the count rate and dead time. The results are compared to ensure that the camera performs accurately under both conditions.

Without Scatter

Head	R1 counts/s	R2 counts/s	R12 counts/s	Dead Time (µS)	Observed Count Rate per/µS	Input Count Rate per/ µS
Detector 1	131384.29	92088.571	118257.14	3.0141	0.07734	0.06187
Detector2	135737.14	96720	123311.43	2.89356	0.08056	0.06445

With Scatter

Head	R1 counts/s	R2 counts/s	R12 counts/s	Dead Time (µS)	Observed Count Rate per/ µS	Input Count Rate per/ µS
Detector1	99948.889	83338.889	97246.667	3.6694	0.06353	0.05082
Detector2	98945	90922	60912	3.84197	0.06067	0.04854

Result: Test Passed

k) Test of maximum count rate:

The test aims to determine the maximum count rate that the SPECT/gamma camera can handle without significant loss of data or image quality. This ensures that the camera can accurately detect and process gamma rays even at high count rates. A high-activity source of radioactivity, such as Technetium-99m (Tc-99m), is placed in front of the SPECT. The system records the counts detected at various activity levels. The count rate is plotted against the activity level to determine the maximum count rate. The results are analyzed to ensure they fall within the expected range, indicating accurate performance at high count rates.

Description	Observed Value	Reference Value	Tolerance
maximum count rate D1	478	460	±20% of reference value.
maximum count rate D2	474	460	±20% of reference value.

Result: Test Passed

l) Test of detector head shielding leakage: Head 1

This test evaluates the effectiveness of the detector head shielding in attenuating extraneous radiation. A Tc-99m point source is positioned at a standardized distance (typically 10 cm) from the detector head. The gamma camera records detected counts, and these are analyzed to quantify any radiation leakage through the shielding. Effective shielding is essential for minimizing artifacts and ensuring accurate image representation.

Detector shielding Leakage checked performed with 1mCi TC99m point source around the detector a different positions with LEHRS collimator mounted

	Background Kc/S	Position 90 Kc/S	Position150 Kc/S	Position270 Kc/S	Position 330 Kc/S
Detector 1	0.04	0.05	0.42	0.44	0.05
Detector 2	0.05	0.04	0.04	0.05	0.04

There is no leakage observed in each detector at different angles. The background test counts and shielding leakage counts have no significant difference.

Result: Test passed

m) Test of scan speed (Using Flood Source):

This assessment verifies the system's ability to maintain image uniformity across a range of scan speeds. A Tc-99m flood source is employed, and the gamma camera acquires images at varying scan speeds. The resulting images are analyzed to ensure consistent count distribution across the field of view, confirming reliable performance regardless of scanning velocity.

Carried out SPECT acquisition using Jaszczak Phantom with 12mCi Tc99m uniform source, taken tomo study viewing angle and checked stop on time through stopwatch no significant deviation noticed.

Description	Observed Value	Reference	Error %	Tolerance
Scan speed	28.02.43	28.03.00	0.04%	≤ 1.05 of reference

Result: Test Passed

n) Energy resolution determination

Energy resolution quantifies the system's capacity to discriminate between gamma rays of differing energies. A Tc-99m source is used, and the system records the energy spectrum of detected gamma rays. This parameter is crucial for distinguishing between radionuclides and minimizing the impact of scattered radiation on image quality.

Detector	Energy resolution	Reference	Tolerance
1	8.727	<=9.5%	≤ 1.05 of reference
2	8.822	<=9.5%	≤ 1.05 of reference

Result: Test Passed

o) Pixel Size (X and Y direction)

This involves a direct physical measurement of the pixel dimensions in the X and Y axes, typically expressed in millimetres. This parameter defines the spatial resolution capabilities of the detector.

Test done using a 1mCi S shaped line source at a distance of 125mm in between the lines Taken static acquisition at 0cm from both the detector. Post processing done on Xeleris in both X and Y direction using profile statistics method.

Pixel Size= Distance between the Source /Distance between the 1st and 2nd Peak

Detector Name	First Peak	Second Peak	Pixel Size
D1 X	70	127	2.2
D1 Y	71	128	2.2
D2 X	69	126	2.2
D2 Y	64	121	2.2

Limits of acceptability: - The difference between the values in X and Y should be less than 10%.

Result : Test passed

p) Test of Integral Tomographic uniformity, RMS Noise with flood correction:[8]

The assessment of integral tomographic uniformity and RMS noise with flood correction is a crucial quality control procedure in nuclear medicine, designed to uphold the accuracy and reliability of SPECT systems, thereby ensuring sustained optimal performance of the imaging equipment. This test serves to validate the homogeneity of reconstructed tomographic images and to quantify the level of Root Mean Square (RMS) noise present after the application of flood correction, thus guaranteeing the SPECT system's capacity to generate consistent and accurate images. To conduct this evaluation, a uniform flood source, typically Technetium-99m (Tc-99m), is utilized for the acquisition of tomographic images, which are subsequently reconstructed and subjected to flood correction; the resulting images are then quantitatively analyzed to determine integral uniformity and RMS noise, with the measured values compared against predefined acceptance criteria.

Test	Formulae	Observed
Tomographic Uniformity%	(Cmax-Cmin)/(Cmax+Cmin)	(578-410)/(578+410)
Test	Formulae	
RMS Noise	SD/Mean pixel	39.24/489.76

Description	Observed Value	Reference	Tolerance
Integral Tomographic Uniformity	17.00	<20	≤ 1.05 of Reference
RMS Noise	8.01	<25	≤ 1.05 of Reference

Result: Test Passed

q) Contrast Evaluation

Contrast refers to the discernible difference in intensity or color between an object and its surrounding background within an image. This parameter is crucial for visualizing subtle differences in radiotracer uptake and delineating anatomical structures.

Contrast= (Avg Count- Min Count)/ Avg Count

Sphere size (mm)	Measured	Reference	Tolerance
31.8	0.62	=>0.4	≤ 1.05 of reference
25.4	0.51	=>0.28	≤ 1.05 of reference
19.1	0.43	=>0.25	≤ 1.05 of reference
15.4	0.26	=>0.2	≤ 1.05 of reference

Result: Test Passed

r) Test of tomographic resolution in air (X and Y direction)

The assessment of tomographic resolution in air, conducted along both the X and Y axes, aims to quantify the system's ability to resolve fine details within tomographic reconstructions, ensuring that neither the acquisition nor reconstruction processes introduce degradations. To achieve this, a small point source of Technetium-99m (Tc-99m) is positioned in air, within one centimeter of the center of rotation, near the central field of view. A circular orbit of rotation, with a radius of approximately 15 cm or as small as practically feasible, is utilized. A tomographic acquisition is then performed, employing clinical matrix sizes and angular sampling, with approximately 10,000 counts collected per view. The acquired data is subsequently reconstructed using filtered back projection, employing either a ramp filter or the sharpest filter permissible by the system. A standard planar (static) acquisition is also performed at the home position, utilizing the same matrix size as the tomographic acquisition, to provide a comparative baseline. These procedures are then repeated with the point source repositioned approximately eight centimeters off-axis, followed by a final repetition with the source positioned on the axis of rotation, near the periphery of the field of view.

Description	X			Y		
	Observed Value	Reference	Tolerance	Observed Value	Reference	Tolerance
Tomographic resolution	6.4	=<10.2	≤ 1.10 of Reference	6.4	=<10.2	≤ 1.10 of Reference

Result: Test Passed

s) Test of the center of rotation offset and alignment of axis

The evaluation of the center of rotation (COR) offset and axis alignment is performed to confirm the accurate determination of the COR and the proper alignment of the rotational axis, thereby ensuring the production of precise and undistorted SPECT images. This procedure involves placing a point source of Technetium-99m (Tc-99m) at a defined distance from the detector, followed by the acquisition of images as the gamma camera rotates around the source. The system records the detected counts at multiple angular positions, and the resulting data is then analyzed to quantify the COR offset and assess the alignment of the rotational axis. This analysis entails calculating the deviation of the detected counts from their expected values, allowing for a precise determination of any misalignment that could introduce artifacts into the reconstructed images.

Description	Observed Value	Reference Value
Series 0 Delta X – detector 1	-0.0038	>=0.55 &<= 0.55
Series 0 Delta X – detector 2	0.0017	>=0.55 &<= 0.55
Series 0 Delta Y – detector 1	0	<=0
Series 0Delta Y – detector 2	-0.0088	>=0.55 &<= 0.55
Series 1 Delta X – detector 1	0.0071	>=0.55 &<= 0.55
Series 1 Delta X – detector 2	-0.0031	>=0.55 &<= 0.55
Series 1 Delta Y – detector 1	0	<=0
Series 1 Delta Y – detector 2	0.0166	>=0.55 &<= 0.55
Series 2 Delta X – detector 1	-0.0033	>=0.55 &<= 0.55
Series 2 Delta X – detector 2	0.0015	>=0.55 &<= 0.55
Series 2 Delta Y – detector 1	0	<=0
Series 2 Delta Y – detector 2	-0.0078	>=0.55 &<= 0.55

LEHRS COR QC values in L – Mode:

Description	Observed Value	Reference Value
Series 0 Delta X – detector 1	0.0345	>=0.55 &<= 0.55
Series 0 Delta X – detector 2	0.1187	>=0.55 &<= 0.55
Series 0 Delta Y – detector 1	0	<=0
Series 0Delta Y – detector 2	-0.0082	>=0.55 &<= 0.55
Series 1 Delta X – detector 1	-0.0694	>=0.55 &<= 0.55
Series 1 Delta X – detector 2	-0.1990	>=0.55 &<= 0.55
Series 1 Delta Y – detector 1	0	<=0
Series 1 Delta Y – detector 2	0.0158	>=0.55 &<= 0.55
Series 2 Delta X – detector 1	0.0362	>=0.55 &<= 0.55
Series 2 Delta X – detector 2	0.0161	>=0.55 &<= 0.55
Series 2 Delta Y – detector 1	0	<=0
Series 2 Delta Y – detector 2	-0.0066	>=0.55 &<= 0.55
Series 3 Delta X – detector 1	-0.0012	>=0.55 &<= 0.55
Series 3 Delta X – detector 2	0.0641	>=0.55 &<= 0.55
Series 3 Delta Y – detector 1	0	<=0
Series 3 Delta Y – detector 2	-0.0010	>=0.55 &<= 0.55

MEGP COR QC values in H – Mode:

Description	Observed Value	Reference Value
Series 0 Delta X – detector 1	-0.0027	>=0.55 &<= 0.55
Series 0 Delta X – detector 2	0.0029	>=0.55 &<= 0.55
Series 0 Delta Y – detector 1	0	<=0
Series 0Delta Y – detector 2	-0.0069	>=0.55 &<= 0.55
Series 1 Delta X – detector 1	0.0053	>=0.55 &<= 0.55
Series 1 Delta X – detector 2	-0.0054	>=0.55 &<= 0.55
Series 1 Delta Y – detector 1	0	<=0
Series 1 Delta Y – detector 2	0.0131	>=0.55 &<= 0.55
Series 2 Delta X – detector 1	-0.0024	>=0.55 &<= 0.55
Series 2 Delta X – detector 2	0.0025	>=0.55 &<= 0.55
Series 2 Delta Y – detector 1	0	<=0
Series 2 Delta Y – detector 2	-0.0061	>=0.55 &<= 0.55

HEGP COR QC values in H – Mode:

Description	Observed Value	Reference Value
Series 0 Delta X – detector 1	-0.0037	>=0.55 &<= 0.55
Series 0 Delta X – detector 2	0.0016	>=0.55 &<= 0.55
Series 0 Delta Y – detector 1	0	<=0
Series 0Delta Y – detector 2	-0.0088	>=0.55 &<= 0.55
Series 1 Delta X – detector 1	0.0071	>=0.55 &<= 0.55
Series 1 Delta X – detector 2	-0.0031	>=0.55 &<= 0.55
Series 1 Delta Y – detector 1	0	<=0
Series 1 Delta Y – detector 2	0.0166	>=0.55 &<= 0.55
Series 2 Delta X – detector 1	-0.0033	>=0.55 &<= 0.55
Series 2 Delta X – detector 2	0.0015	>=0.55 &<= 0.55
Series 2 Delta Y – detector 1	0	<=0
Series 2 Delta Y – detector 2	-0.0078	>=0.55 &<= 0.55

t) Test of slice thickness at the center of the field of view:

The test is conducted to quantify the thickness of reconstructed tomographic slices, ensuring the SPECT system generates accurate and consistent slice dimensions, which is vital for precise diagnostic interpretations. To perform this test, a small point source of Technetium-99m (Tc-99m) is positioned at the center of the field of view. The SPECT system then acquires tomographic images of this point source. Subsequently, the acquired data is reconstructed, and the slice thickness is directly measured at the center of the reconstructed volume, thereby verifying adherence to the system's specifications and ensuring reliable image representation.

Description	Measured	Reference	Tolerance
Slice thickness	8.8	<=10.5	±10% of reference

Result: Test Passed

u) Test of variation of sensitivity with angle:

The assessment of sensitivity variation across angular projections was conducted utilizing a Jaszczak phantom, employing a 5 mCi uniform source and a Low Energy High Resolution Sensitivity (LEHRS) collimator, with static images acquired throughout a 360-degree rotational span. Visual inspection of these images revealed no discernible variations in sensitivity or uniformity across the full angular range. Further, acquisitions performed at discrete angular intervals confirmed the absence of uniformity deviations.

Test done using Jaszczak Phantom at 0-to-360-degree rotation using static images with 5mCi uniform source and LEHRS collimator. There is no visible deviation in sensitivity and uniformity in 360 degrees angles. Acquisition done for different angles and no uniformity deviations observed.

Gantry position in degrees	Observed Count	Sensitivity	Reference
0 Deg	1020	204	204
90Deg	1034	206	204
150 Deg	1028	205	204
270Deg	1016	203	204
330 Deg	1019	204	204

Result: Test Passed

Comment: - Not much variation in counts seen in both detectors at various angles.
Tolerance: - ±10% of reference

v) Alignment (Registration)Calibration SPECT/CT[8]

The meticulous alignment (registration) and calibration of SPECT/CT systems are indispensable for achieving accurate and reliable hybrid imaging. These procedures are specifically designed to guarantee precise spatial correlation between the functional SPECT and anatomical CT datasets, thereby enabling the generation of integrated images that provide congruent and accurate anatomical and functional information. To accomplish this, a dedicated phantom with well-defined geometric characteristics is employed for simultaneous SPECT and CT image acquisition. Subsequently, image registration algorithms are utilized to process the acquired data, effectively aligning the SPECT and CT images by matching corresponding fiducial points or anatomical features. Finally, system calibration is performed to ensure accurate representation of both spatial and intensity information from the SPECT and CT modalities, which may necessitate adjustments to system parameters and the implementation of rigorous quality control measures.

LEHRS Collimator

	X (mm)	Y (mm)	Z (mm)	Test Result
Observed Value	-0.14	-0.01	0.12	Passed
Reference Value	2.2	2.2	3.2	

MEGP Collimator

	X (mm)	Y (mm)	Z (mm)	Test Result
Observed Value	0.01	0.06	0.04	Passed
Reference Value	2.2	2.2	3.2	

HEGP Collimator

	X (mm)	Y (mm)	Z (mm)	Test Result
Observed Value	-0.29	0.04	0.15	Passed
Reference Value	2.2	2.2	3.2	

Result: Test Passed

4. Conclusion

The commissioning and quality assurance of SPECT/CT systems, particularly the SPECT/gamma camera component, are critical to ensuring the accuracy, reliability, and clinical efficacy of this advanced imaging modality. Through rigorous acceptance testing and adherence to international standards such as IEC, NEMA, and AAPM Task Group 177, we have demonstrated the importance of evaluating key performance parameters, including spatial resolution, sensitivity, uniformity, count rate performance, and alignment. These tests not only validate the system's compliance with manufacturer specifications but also ensure its readiness for clinical use. A robust quality assurance program, encompassing routine quality control, periodic performance assessments, and preventive maintenance, is essential for maintaining the system's optimal performance over time. Compliance with regulatory guidelines, such as those mandated by the Atomic Energy Regulatory Board (AERB) in India, further underscores the importance of meticulous documentation and adherence to stringent quality control measures. By implementing these practices, we can ensure that SPECT/CT systems continue to deliver their transformative potential in diagnostic imaging, enhancing patient outcomes and advancing the frontiers of nuclear medicine.

5. References

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