Chapter 15: Devices for evaluating imaging systems

Slide set of 141 slides based on the chapter authored by
O. Demirkaya, R. Al-Mazrou **of the IAEA publication** **(ISBN 978–92–0–143810–2):**
Review of Nuclear Medicine Physics:
A Handbook for Teachers and Students

Objective:

To familiarize the student with the most frequently used devices to evaluate nuclear medicine imaging systems.

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TABLE OF CONTENTS

15.1 Developing a quality management system approach to instrument quality assurance

15.1 DEVELOPING A QUALITY MANAGEMENT SYSTEM APPROACH TO INSTRUMENT QUALITY ASSURANCE

Components of the quality management system (QMS)

- Quality assurance
- Quality improvement
- Quality control

The aim of a QMS is to ensure that the deliverables meet the requirements set forth by the users.

15.1 DEVELOPING A QUALITY MANAGEMENT SYSTEM APPROACH TO INSTRUMENT QUALITY ASSURANCE

15.1.1 Methods for routine quality assurance procedures

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Quality assurance

- Quality assurance (QA) is a systematic programme for monitoring and evaluation of the process of production.
- QA in diagnostic imaging can help minimize the uncertainties and errors in equipment performance by supervising the entire image production process.

Quality control

Quality control (QC) is the process by which the performance level of a product is measured and then compared against the existing standards or tolerance values.

Quality control

QC with regard to imaging systems may entail:

- A series of performance measurements to assess the quality of the imaging system.
- Keeping the record of measurements.
- Monitoring the accuracy and precision of the results.
- Taking corrective actions in case the performance measurements are outside the tolerance levels or above the predetermined action levels.

Levels, interventions and records

- Tolerance levels define the range within which the results are acceptable while action levels define the range beyond which a corrective action is required.
- Record keeping is critical and essential for trending the performance parameters to monitor the system and to intervene, when necessary, in an effective and timely manner.

15.1.1 Methods for routine quality assurance procedures

Quality control requires:

- Defining the performance parameters to be measured.
- Preparing written procedures as to how and by whom the measurements should be carried out.
- Establishment of the frequency of performance tests and expected results in the form of tolerance and action levels.
- Training the persons who perform these measurements.
- Designing record forms (preferably electronic) to keep the measurement values.
- Logging and reporting all of the problems and actions taken.

Phantoms

- Phantoms are indispensable tools for QC measurements.
- They are utilized to evaluate diagnostic imaging systems, as well as for other reasons in radiation protection, radiobiology and radiotherapy.

Nuclear Medicine phantoms

- Phantoms used in nuclear medicine are usually injected with a radioisotope simulating a particular organ or tissue structure containing a particular radiopharmaceutical.
- They are simplified structures, with different geometric characteristics, according to their function or role.

15.2 HARDWARE (PHYSICAL) PHANTOMS

15.2 HARDWARE (PHYSICAL) PHANTOMS

Definition of phantom (ICRU)

The International Commission on Radiation Units and Measurements (ICRU) in ICRU Report 48 defines the phantom as a material object that includes one or more tissue substitutes and is used to simulate radiation interaction in the body.

15.2 HARDWARE (PHYSICAL) PHANTOMS

Physical and software phantoms

- The ICRU distinguishes the ‘physical phantoms’ from what are usually called ‘software phantoms’ by defining them as ‘phantoms’ and ‘computational models’, respectively.
- In this chapter, the convention of the ICRU is followed for consistency in the terminology and to avoid any potential misunderstanding that the other naming conventions may lead to.

15.2 HARDWARE (PHYSICAL) PHANTOMS

Categories of phantoms

- Dosimetric
  - Used to measure the absorbed dose.
- Calibration
  - Used to calibrate a particular photon detection system.
- Imaging
  - Used for assessing image quality or characterizing imaging systems.

Under these categories, three subcategories are defined: body, standard and reference phantoms.

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15.2 HARDWARE (PHYSICAL) PHANTOMS

Advantages of physical phantoms

- The use of phantoms dates back to the beginning of the 20th century.
- As compared to computational models, physical phantoms may be advantageous in that data are acquired with an actual scanner and contain the effect of the parameters that impact on the entire photon detection process.

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15.2 HARDWARE (PHYSICAL) PHANTOMS

Phantoms and performance of imaging equipment

- In this section, the hardware phantoms that are used to measure the performance characteristics of gamma cameras and PET scanners are discussed.
- As equipment evolved, also phantoms have evolved to be able to assess the new performance characteristics.

15.2 HARDWARE (PHYSICAL) PHANTOMS

15.2.1 Gamma camera phantoms

15.2 HARDWARE (PHYSICAL) PHANTOMS

15.2.1 Gamma camera phantoms

Gamma camera testing

- Gamma cameras are the most widely used diagnostic system available in nuclear medicine departments.

- Owing to their physical characteristics, they require very close attention and, therefore, more frequent and a larger number of tests than any other diagnostic imaging modality in radiology.

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Uniformity test

- One of the important QC tests that has to be carried out daily on every gamma camera is the uniformity test.
- Uniformity is affected by several variables and has an obvious importance in the final image.
- For daily tests, phantoms should be easy to handle and have an easy and reproducible way to be set.

15.2 HARDWARE (PHYSICAL) PHANTOMS

15.2.1 Gamma camera phantoms

15.2.1.1 Point source holders

Use of the phantom

- This phantom is used to hold point sources that are employed in intrinsic uniformity, resolution and linearity measurements.
- The point source should produce a uniform irradiation of the detector, which is practically obtained locating the source holder at a distance greater than 5 times the maximal dimension of the detector.

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15.2.1.1 Point source holders

Materials and purpose

- It is made up of lead and its main purpose is to shield the walls, ceiling and personnel, and collimate the γ radiation to the detector.
- Copper plates (1–2 mm thick) should be placed in front of the source holder to act as absorbers and stop the low energy photons.

15.2.1.1 Point source holders

Point source holders in a slanted position so that they can point to the detectors from the floor.

15.2.1.2 ^{57}Co flood sheets

Uniform radioactive sheet source

- A faster and reliable way to obtain a uniform irradiation of the detector is to use a sheet source.
- ^{57}Co is the isotope of choice, due to its energy close to the energy of ^{99m}Tc.
- Gamma cameras should also be tested extrinsically (collimator in place), which is simple using a ^{57}Co sheet source.

15.2.1.2 ^{57}Co flood sheets

Characteristics and recommendations

- The cost of ^{57}Co sheet sources is relatively high and they should be replaced every 2 years.
- It is advisable to place the sheet source at a distance of 5-10 cm from the collimator during the scan.

15.2 HARDWARE (PHYSICAL) PHANTOMS

15.2.1 Gamma camera phantoms

15.2.1.2 ^{57}Co flood sheets

Commercial ^{57}Co flood source

15.2.1.3 Fillable flood phantoms

Advantages of fillable flood phantoms

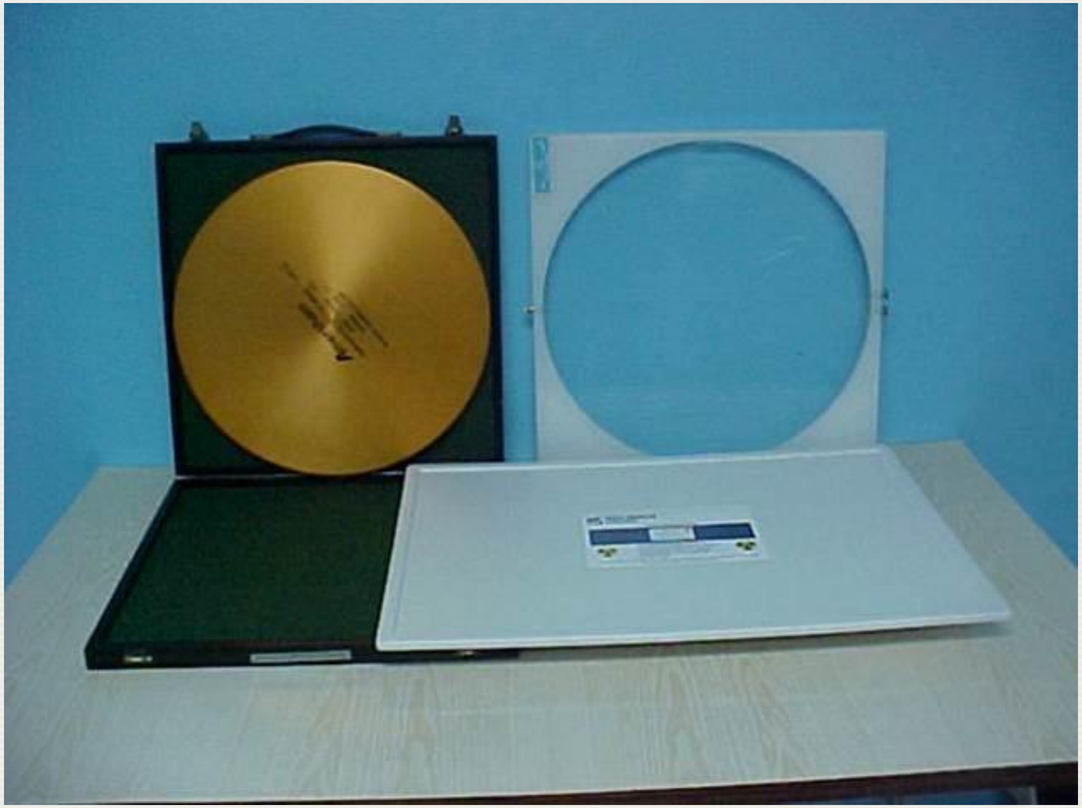
- A fillable water phantom source is a good alternative to ^{57}Co flood sources, due to their cost.
- They have the advantage that they can be filled with the same radionuclide used for imaging (i.e. ^{99m}Tc), so no additional energy correction has to be made to their uniformity tables.

15.2.1.3 Fillable flood phantoms

Disadvantages and recommendations

- It is necessary to be careful in filling these phantoms to prevent bubble formation, contamination of the outside surface of the phantom or the work place, and bulging of the phantom in the centre.
- Depending on the size and volume of the phantom, around 370 MBq (10 mCi) of ^{99m}Tc activity will be sufficient to give a count rate of 20 kcounts/s in the image.

15.2.1.3 Fillable flood phantoms



Images of fillable flood phantom (back row, right) and ^{57}Co flood sources for circular (back row, left) and rectangular (on table) FOV cameras.

15.2.1.4 Slit phantom

Use of the phantom

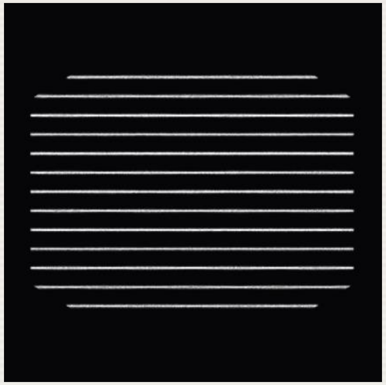
- Slit phantoms are used to measure the intrinsic resolution of a gamma camera detector.
- They produce a pattern of parallel equidistant lines of minimal width.
- These masks are placed in the closest possible proximity to the crystal covering its entire area.

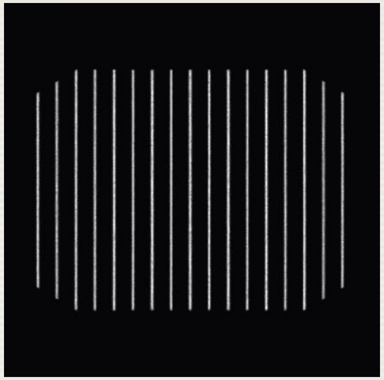
15.2.1.4 Slit phantom

Characteristics and materials

- The phantom is made of a 3 mm thick lead mask consisting of 1 mm wide parallel slits.
- The centre of each slit is 30 mm away from the adjacent slit centre.
- Similar masks, with other line spacing (normally smaller) are used for calibration purposes and not performance evaluation.

15.2.1.4. Slit phantom





Top: picture of the slit phantom . Bottom: acquired images of the slit phantoms in the Y (left image) and X (right image) directions.

15.2.1.5 Dual-line source phantom and scattering medium

Use of the phantom

- This phantom, suggested by NEMA NU 1-2007, is used to measure the extrinsic resolution of the system with and without a scattering medium.
- It produces a pattern of parallel lines, with and without the presence of scatter.

15.2.1.5 Dual-line source phantom and scattering medium

Characteristics and materials

- It consists of two parallel line sources 1 mm in internal diameter and with a centre to centre distance of 5 cm.
- The line sources are built so that they are positioned 10 cm above the collimator.
- Due to its simplicity, its is frequently built locally.

15.2.1.5 Dual-line source phantom and scattering medium

A custom built, dual-line source phantom. On the left is the phantom positioned on the detector, and on the right the same line sources are immersed in a scattering medium.

15.2.1.6 Bar phantom

Use of the phantom

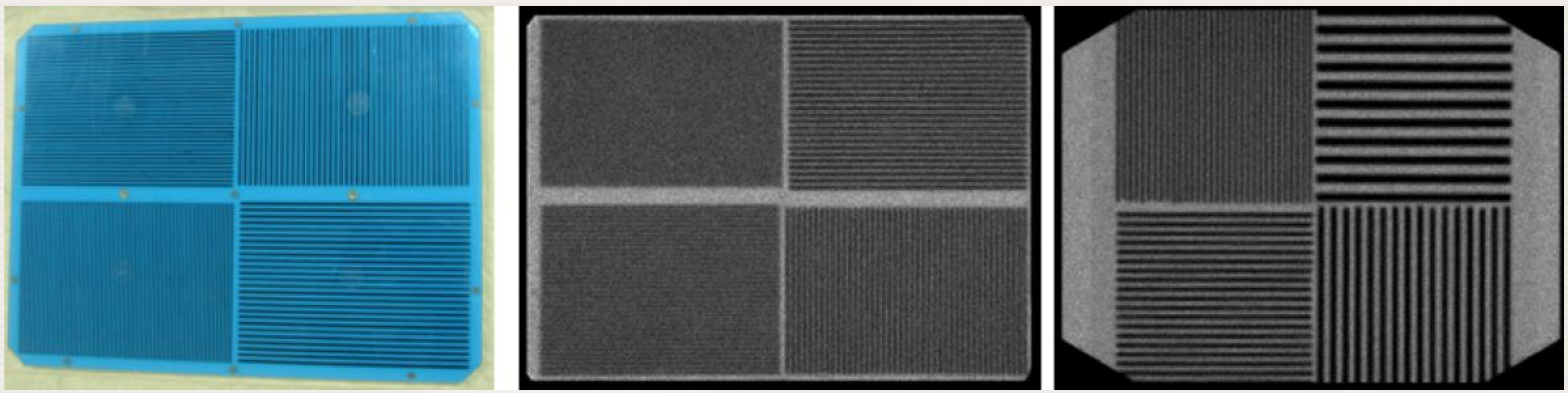
- Bar phantoms can be used to measure, semi-quantitatively (i.e. visually), the extrinsic as well as the intrinsic resolution of a gamma camera and the qualitative evaluation of the gamma camera linearity.
- A 10 Mcount image of the bar phantom is normally acquired and evaluated visually to check the detector resolution and linearity.

15.2.1.6 Bar phantom

Characteristics and materials

- Bar phantoms are made of lead strips embedded into plastic and typically arranged in four quadrants.
- In a bar phantom, the strips are separated with the same distance as the strip width.

15.2.1.6 Bar phantom



Left: picture of a typical four-quadrant rectangular bar phantom.
Middle: image of the left bar phantom acquired by an ECAM gamma camera.
Right: image of a bar phantom acquired with an ADAC FORTE gamma camera.

15.2.1.6 Bar phantom

Assessment of extrinsic and intrinsic resolution

- In routine QC tests bar phantoms are used for the visual assessment of the extrinsic resolution (collimator mounted), together with a flood source.
- For assessment of the intrinsic resolution, the bar phantom is placed on the detector without the collimator in place, and a ^{99m}Tc point source is placed at a distance five times the largest dimension of the crystal away from the bar phantom.

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15.2.1.7 Dual-line phantom for whole body imaging

Use of the phantom

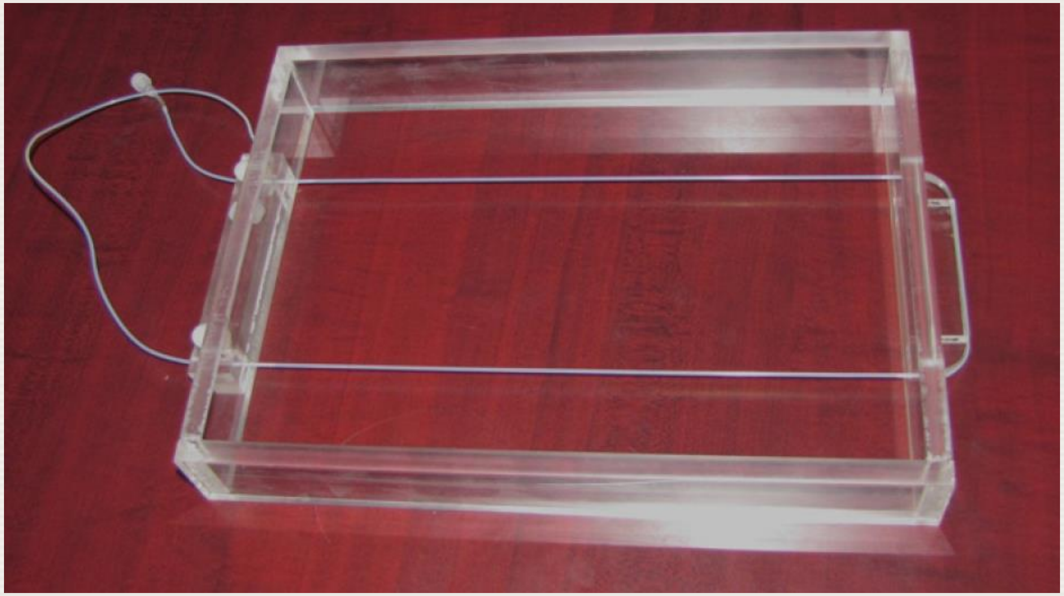
- This phantom is used to test the whole body resolution of a gamma camera system.
- Images of parallel lines are obtained, both parallel and perpendicular to the direction of motion of the scanner.

15.2.1.7 Dual-line phantom for whole body imaging

Characteristics and materials

- It consists of two line sources which are 1 mm in internal diameter and 10 cm centre to centre.
- The line is usually filled with ^{99m}Tc activity with a concentration of about 370 MBq/mL (10 mCi/mL) to achieve an adequate count rate.

15.2.1.7 Dual-line phantom for whole body imaging



Dual-line phantom for whole body resolution tests

15.2.1.7 Dual-line phantom for whole body imaging

Test procedure

- During the testing, the line sources are placed at a distance of 10 cm from both collimators.
- When measuring the perpendicular resolution, the lines should be placed parallel to the bed direction with one of them being in the centre of the bed.
- When measuring the parallel resolution, the lines should be positioned perpendicular to the direction of the bed movement.
- The whole body resolution is calculated from the FWHMs of the line profiles extracted from the image of the dual-line sources.

15.2.1.8 Planar sensitivity phantom

Use of the phantom

- This phantom is used to test the planar sensitivity of a gamma camera system.
- In a planar sensitivity test, the accuracy of the response of the detector to a radioactive source of known activity is measured for the particular collimator.

15.2.1.8 Planar sensitivity phantom

Characteristics and materials

- It is suggested to use a Petri dish containing around 3 mm of water homogeneously mixed with a suitable activity (around 40 MBq) of ^{99m}Tc.
- This dish should be placed at a distance of 10 cm from the face of the collimator.

15.2.1.9 Multiple window spatial registration phantom: lead lined point source holders

Use of the phantom

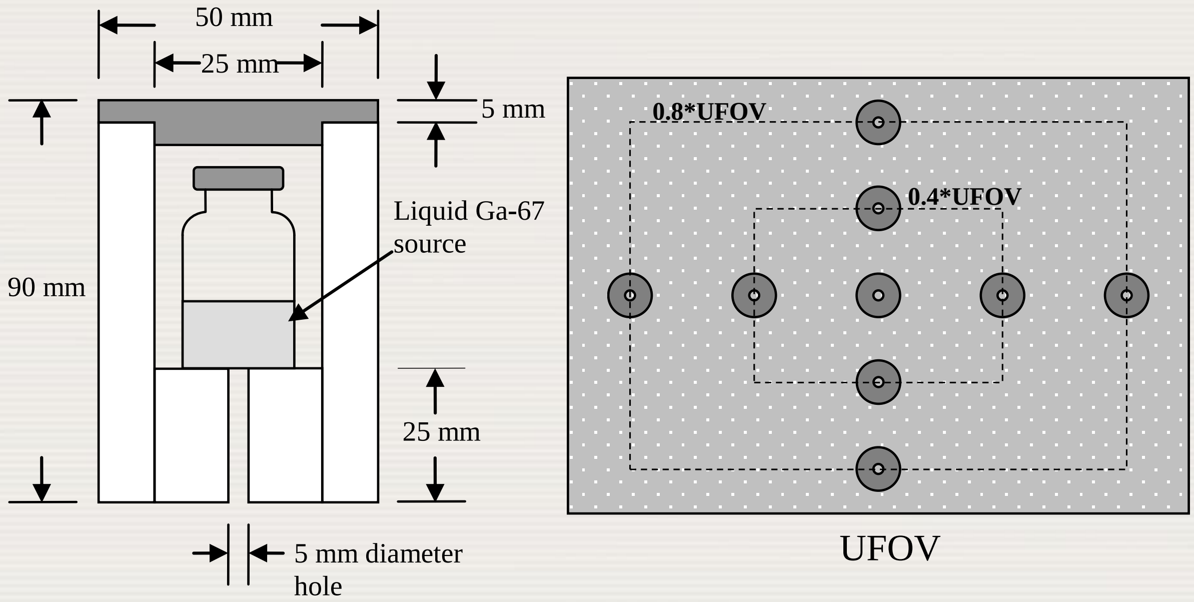
- A multiple window spatial registration test measures the camera's ability to position photons of different energies.
- Images of nine (or four) point sources of ^{67}Ga are acquired normally at three different photopeak energy windows (the three photopeaks for ^{67}Ga are 93, 185 and 296 keV).

15.2.1.9 Multiple window spatial registration phantom: lead-lined point source holders

Characteristics of the test

- The aim of the subsequent calculation is to find the centroids of these points in the image acquired at different energy windows and to compare the displacement between the point source images acquired at different energy windows.
- The maximum displacement between the centroids of point sources is the performance parameter indicating the error in multiple window spatial registration.

15.2.1.9 Multiple window spatial registration phantom: lead-lined point source holders



Multiple window spatial registration phantom lead-lined point source holders

15.2 HARDWARE (PHYSICAL) PHANTOMS

15.2.2 SPECT phantoms

15.2.2.1 Triple-point source for SPECT resolution

Use of the phantom

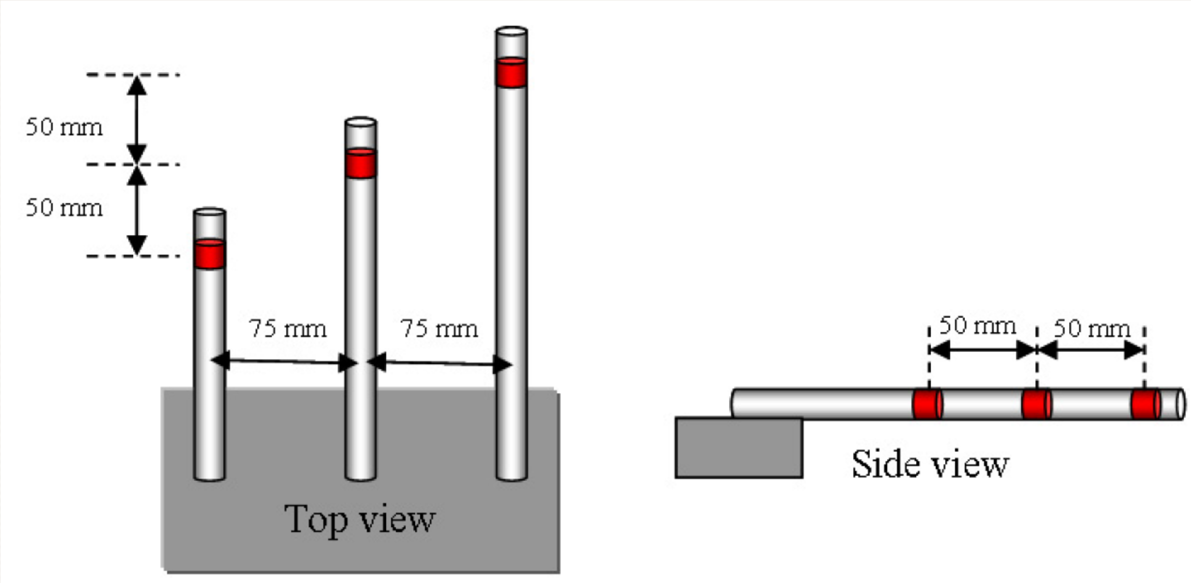
- Triple-point source phantoms are used for measuring the SPECT resolution in air (i.e. under no scatter conditions) or measuring centre of rotation (COR) alignment.
- Some manufacturers provide a source holder with the equipment, also to be used for calibration purposes.

15.2.2.1 Triple-point source for SPECT resolution

Characteristics and materials

- Thin-walled glass capillary tubes with an internal diameter of less than 2 mm are used.
- The point sources should be made as spherical as possible, that is, their trans-axial and axial extents should be similar in length. Their maximum dimension (the axial extent of the activity) should not exceed 2 mm.

15.2.2.1 Triple-point source for SPECT resolution



Top and side views of the position of the point sources as suggested by NEMA

15.2.2.2 Triple-line source phantom for SPECT resolution

Use of the phantom

- The SPECT resolution with scatter is measured using the triple-line source phantom.
- This performance test is normally performed as part of the acceptance testing and annual testing.

15.2.2.2 Triple-line source phantom for SPECT resolution

Characteristics and materials

- The line sources are available either as inserts of ^{57}Co lines or hollow metal tubes to be filled with ^{99m}Tc solution.
- The inner diameter of the line sources is less than 2 mm.
- During measurement the centre line source should be on the axis of rotation centred in the FOV within ±5 mm.

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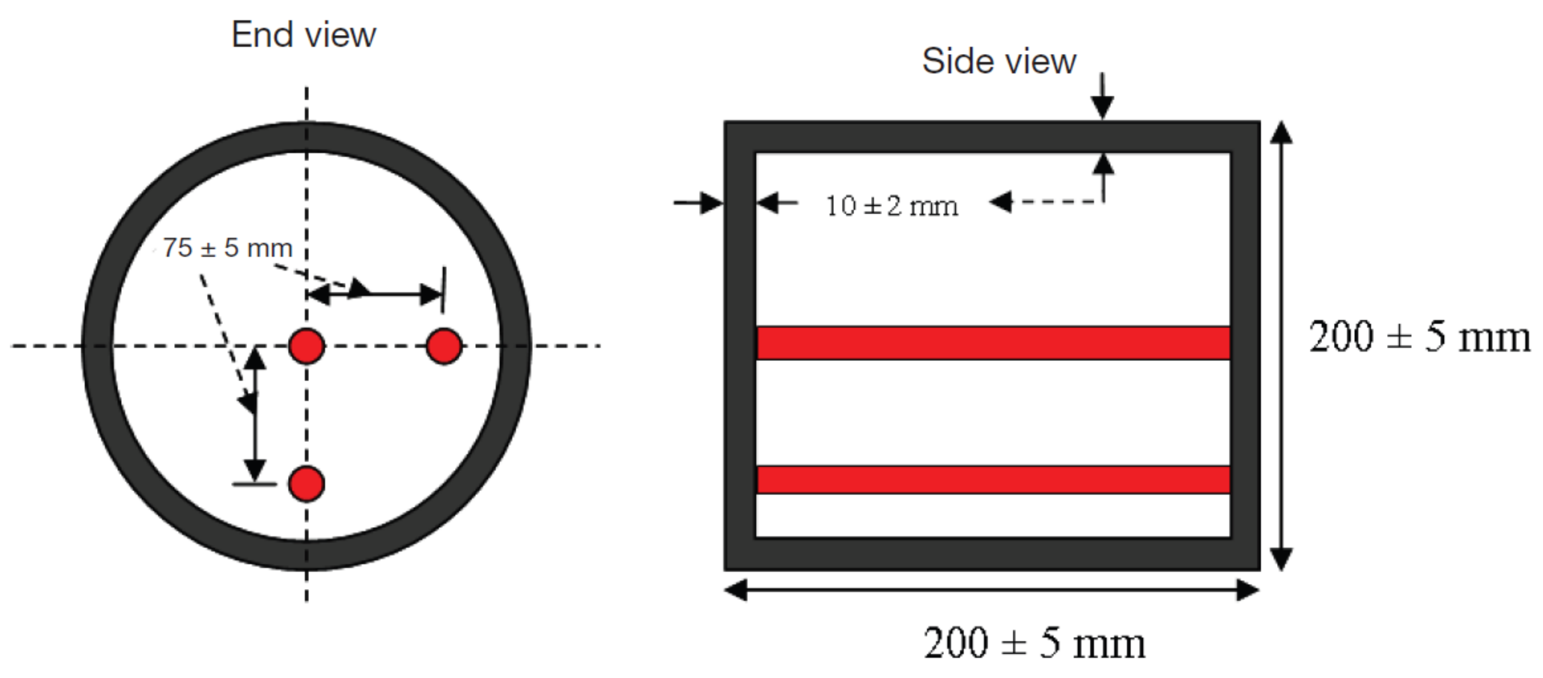
15.2.2.2 Triple-line source phantom for SPECT resolution



Schematic drawing of the side and front views of a triple-line source phantom

15.2.2.2 Triple-line source phantom for SPECT resolution

A commercial triple-line source phantom with three line sources inside.

15.2.2.2 Triple-line source phantom for SPECT resolution

ACQUISITION PARAMETERS AND CAMERA SETTINGS FOR THE SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY RESOLUTION WITH SCATTER TEST

Radionuclide	**^{99m}Tc**
Count rate (kcounts/s)	<20
Total kilocounts per view	100
Scan time/view	~ 5 s at 20 kcounts/s
Energy window	15%
Collimator	Low energy high resolution
Radius of rotation	150 ± 5 mm
Total number of views	≥120
Pixel size	<2.5 mm

15.2.2.3 Volume sensitivity and detector to detector variation measurement phantom

Use of the phantom

- The phantom is used to determine the volume sensitivity and detector to detector sensitivity variation.
- Volume sensitivity is the total system sensitivity to a uniform concentration of activity in a specific cylindrical phantom.
- Detector to detector sensitivity variation is the relative difference in sensitivity of the individual detector heads in a tomographic mode.

15.2.2.3 Volume sensitivity and detector to detector variation measurement phantom

Characteristics and materials

- The volume sensitivity in SPECT is measured using a cylindrical phantom with an inner diameter and a length of 200 $\pm$ 5 mm.
- The phantom is filled with water uniformly mixed with a known amount of activity (approximately 350 MBq) of ^{99m}Tc.

15.2.2.4 Total performance test phantoms

Use of these phantoms

- Total performance phantoms are used to obtain image quality measures or overall SPECT system performance parameters such as noise, tomographic uniformity, contrast and lesion detectability.
- They characterize the ability of the system to distinguish known structures (rods, spheres, etc.) in variable background activities.
- The more elaborate phantoms also simulate organs and tissues.

15.2.2.4 Total performance test phantoms

Commercial total performance phantoms

- Carlson phantom
- Jaszczak phantom
- Anthropomorphic torso phantoms
- Hoffman brain phantom
- Defrise phantoms

15.2.2.5 Carlson phantom

Use of the phantom

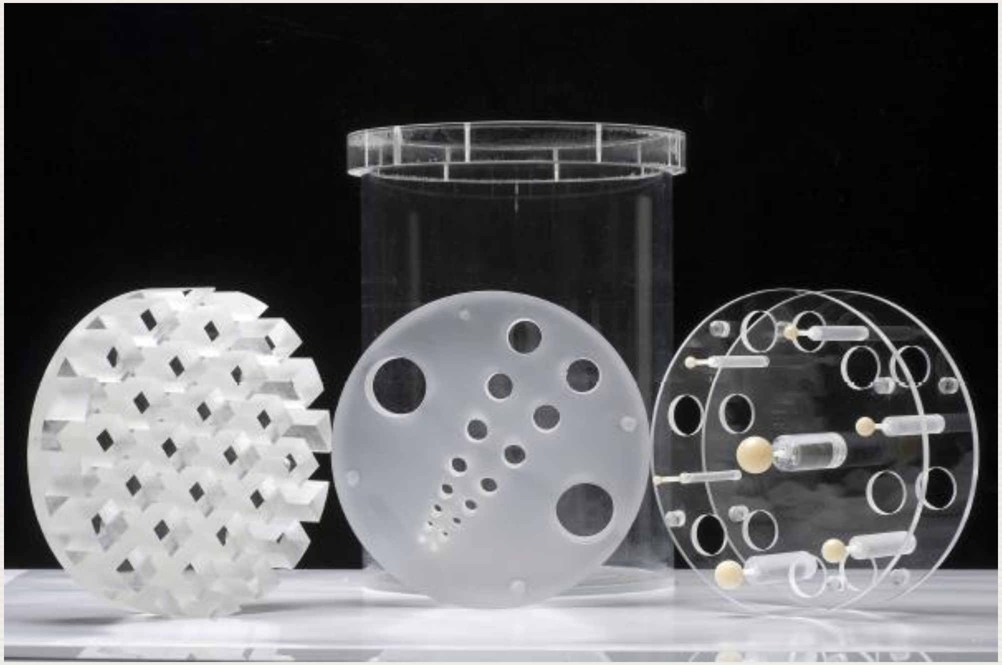
- This phantom is frequently used for evaluating the tomographic uniformity, image contrast, noise and linearity.
- The different sections provide images for the calculation of the above mentioned parameters.

15.2.2.5 Carlson phantom

Characteristics and materials

- The main source tank is made of acrylic with dimensions: 20.32 cm inside diameter, 21.59 cm outside diameter and 30.48 cm length.
- The phantom comes with various inserts, which are demonstrated in the next slide, to evaluate the performance parameters noted above.
- There is an insert or section for each performance measure.

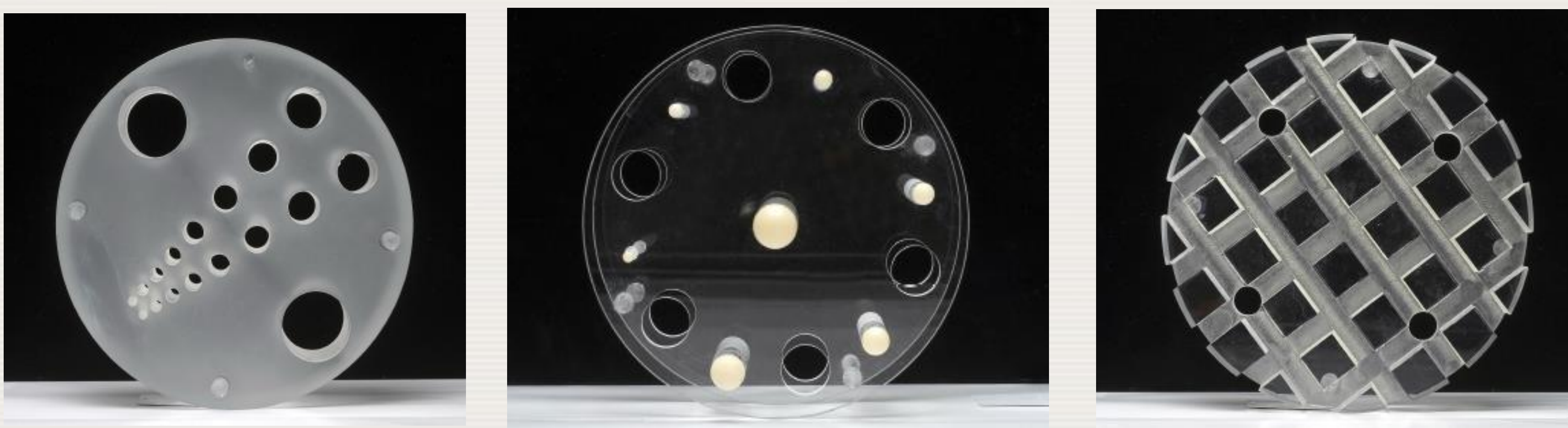
15.2.2.5 Carlson phantom



Carlson phantom and its inserts.

15.2.2.5 Carlson phantom

A **B** **C**



(A) Hot lesions, (B) cold lesions and spheres, and (C) linearity inserts

15.2.2.6 Jaszczak circular and elliptical phantoms

Use of the phantom

- Similar to Carlson phantoms, Jaszczak elliptical and circular phantoms are used to evaluate the overall performance of SPECT systems.
- These different models are designed to test a range of systems, from low resolution to ultra-high resolution.

15.2.2.6 Jaszczak circular and elliptical phantoms

Characteristics and materials

- Jaszczak phantoms consist of a main cylinder or tank made of acrylic with several inserts (rods and solid spheres).
- The principle differences between the different models of the Jaszczak phantoms are the diameters of the rods and solid sphere inserts. They are related to the resolution of the system being tested.

15.2.2.6 Jaszczak circular and elliptical phantoms

Jaszczak circular flanged phantom

15.2.2.7 Anthropomorphic torso phantoms

Uses of the phantom

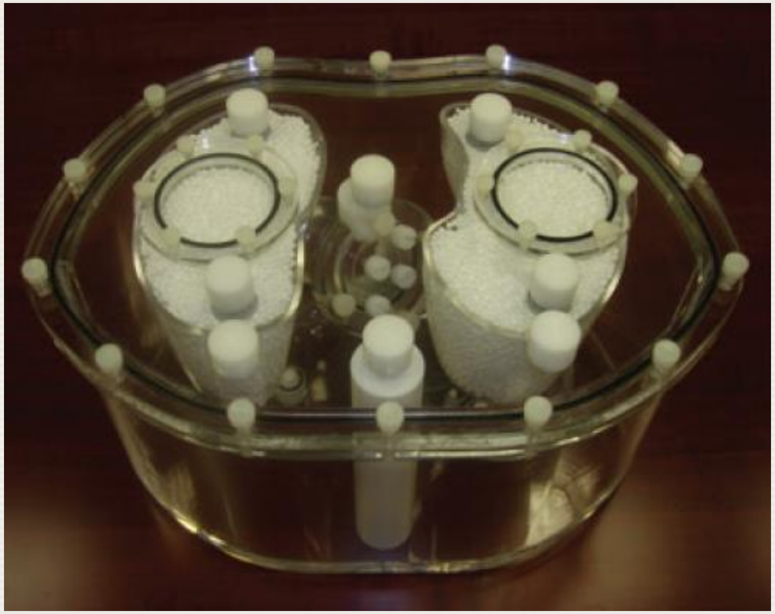
- Anthropomorphic torso phantoms are used in testing gamma cameras in SPECT mode to evaluate data acquisition, attenuation correction and image reconstruction methods.
- They normally simulate or model the upper torso of the body (from the heart down to the diaphragm) of an average male or female patient.

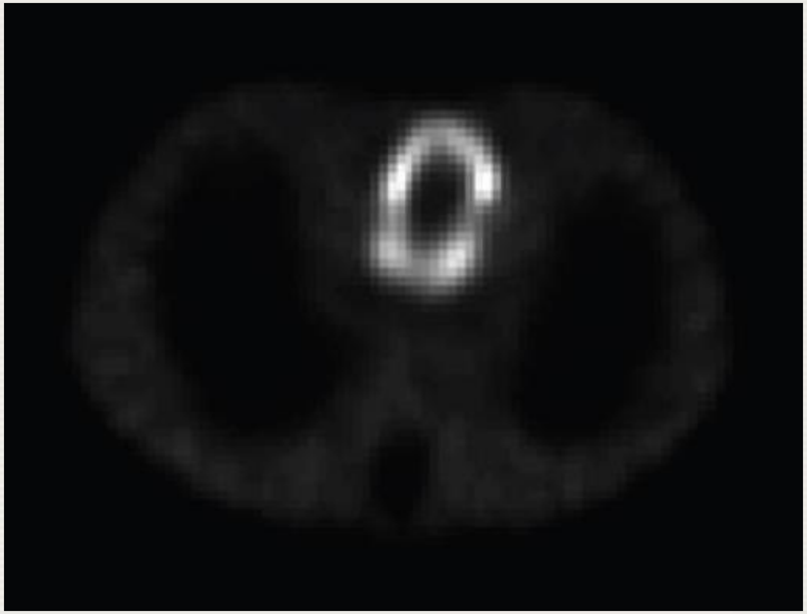
15.2.2.7 Anthropomorphic torso phantoms

Characteristics and materials

- These phantoms consist of a body-shaped (elliptical) cylinder with fillable inserts for organs such as the heart, lungs and liver.
- Different activities are added to inserts and defects can also be added to the phantom.

15.2.2.7 Anthropomorphic torso phantoms





A commercial anthropomorphic phantom and a trans-axial slice cutting through the heart and lungs from its image acquired by a SPECT/CT system.

15.2.2.7 Anthropomorphic torso phantoms

SUGGESTED ACTIVITY CONCENTRATIONS AND MEASURED VOLUMES OF INSERTS FOR THE ANTHROPOMORPHIC TORSO PHANTOM

Section	Volume (mL) *	Activity Concentration, (µCi/mL (kBq/mL))	Total activity (mCi (MBq))
Heart	117	6.8 (251.6)	0.796 (29.44)
Tissue	8620	0.7 (25.9)	6.034 (223.3)
Liver	1177	4.0 (148)	4.708 (174.2)
Lungs		0.0	0

* The volumes in the second column are the measured volumes of the torso phantom inserts

15.2.2.8 Hoffman brain phantom

Use of the phantom

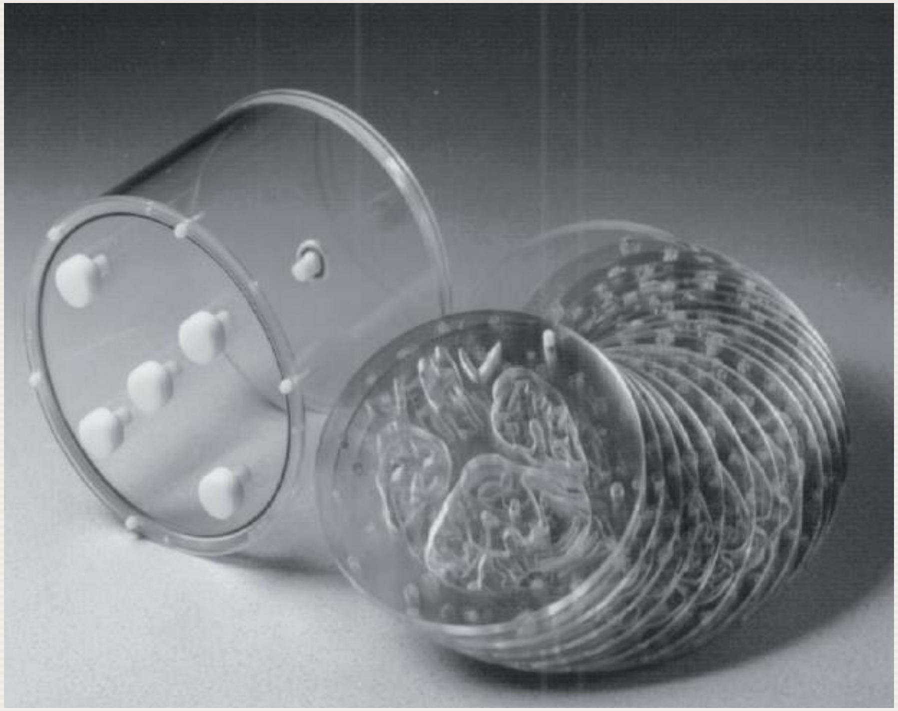
- This phantom provides an anatomically accurate simulation of the radioactivity distribution in normal brain.
- Using this phantom, cerebral blood flow and metabolic activity in the brain can be simulated.

15.2.2.8 Hoffman brain phantom

Characteristics and materials

- It consists of a water-fillable cylinder (i.e. a single-fillable chamber) containing 19 separate layers each 6.4 mm thick.
- Water freely permeates between layers to simulate concentration ratios of 4:1:0 between grey, white and ventricle, respectively, in normal brain.

15.2.2.8 Hoffman brain phantom



Three dimensional Hoffman phantom with a water fillable cylinder and layers of inserts

15.2.2.9 Defrise phantoms

Use of the phantom

- These phantoms are designed for measuring the performance of small animal imaging systems (both SPECT and PET).
- They can be used to investigate image quality or resolution.

15.2.2.9 Defrise phantoms

Characteristics and materials.

- This phantom is a miniaturized version of the image quality phantoms mentioned in the previous slides.
- The materials are similar, dimensions varied according to the different purpose.

15.2.2.9 Defrise phantoms

Defrise phantom with inserts

15.2 HARDWARE (PHYSICAL) PHANTOMS

15.2.3 PET phantoms

15.2.3.1 National Electrical Manufacturers Association image quality phantom

Use of the phantom

- It is used to determine image quality in PET, by calculating performance parameters, such as uniformity, noise, lesion contrast, spatial resolution, and the accuracy of the attenuation and scatter correction techniques.
- In addition to the above performance parameters, the image registration accuracy between the PET and CT gantries in a PET/CT scanner can be assessed using this phantom.

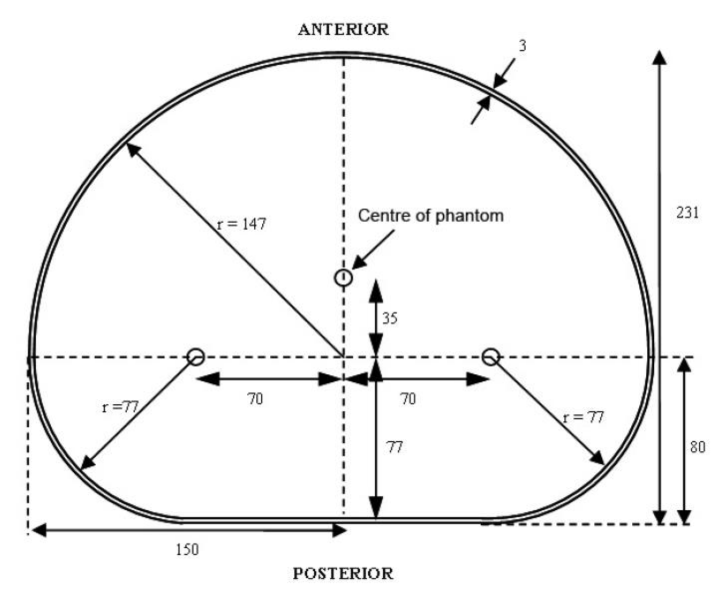
15.2.3.1 National Electrical Manufacturers Association image quality phantom

Characteristics and materials

The IQ phantom consists of four main parts:

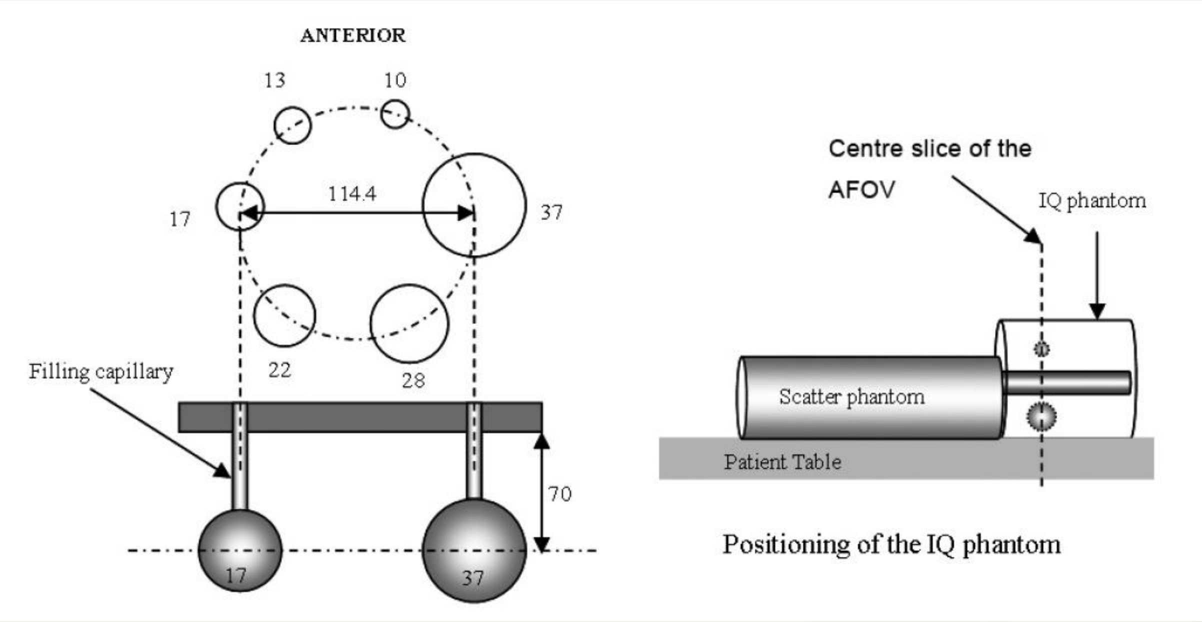
- Body phantom
- Fillable spheres
- Cylindrical insert
- Phantom preparation

15.2.3.1 National Electrical Manufacturers Association image quality phantom



Cross-section of the body part of the International Electrotechnical Commission image quality phantom . The dimensions are given in millimetres (reproduced with permission).

15.2.3.1 National Electrical Manufacturers Association image quality phantom



Trans-axial (top left) and coronal (bottom left) cross-sectional view of the image quality (IQ) phantom through the centres of fillable spheres

15.2.3.1 National Electrical Manufacturers Association image quality phantom

IEC/NEMA IQ phantom with inserts

15.2.3.1 National Electrical Manufacturers Association image quality phantom

MEASURED VOLUMES OF THE IEC/NEMA IMAGE QUALITY PHANTOM AND SUGGESTED ACTIVITIES AT THE TIME OF SCANNING FOR A CONCENTRATION RATIO OF 4:1

Phantom section	Volume (mL)	Typical activity (MBq)	Activity concentration at time of preparation (kBq/mL)	Activity concentration at time of scan (kBq/mL)
Torso cavity	9700	n.a.		
Four hot spheres	Different sizes	n.a.	56	42.4
Two cold spheres	Different sizes	n.a.		
Lung insert	353	n.a.		
Background (torso – all inserts)	9286	65	7	5.3

n.a.: not applicable

15.2.3.2 National Electrical Manufacturers Association scatter phantom

Use of the phantom

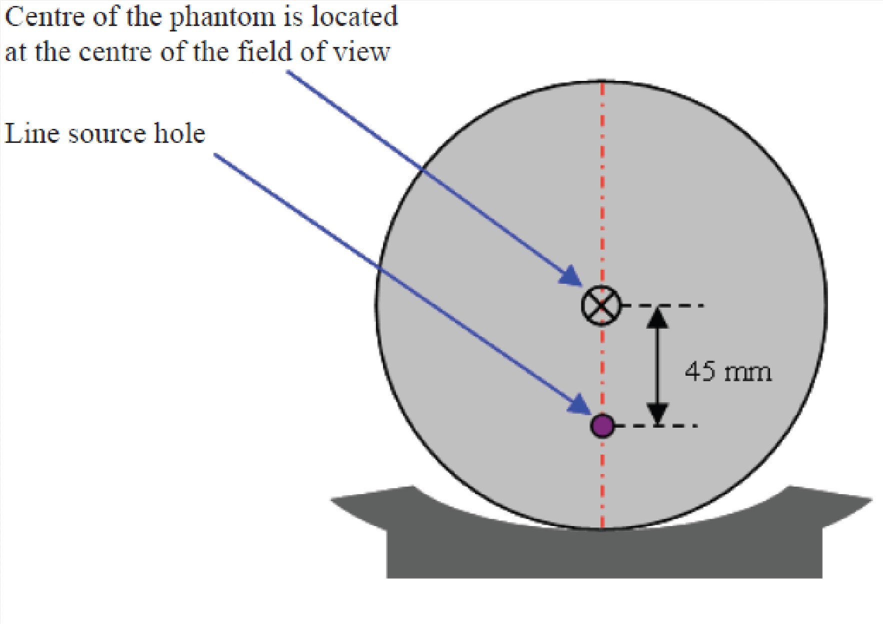
- The scatter phantom is used to measure the count rate performance of PET scanners in the presence of scatter.
- Since the extensive use of whole body PET, scatter evaluation is extremely important for these studies.

15.2.3.2 National Electrical Manufacturers Association scatter phantom

Characteristics and materials

- The phantom consists of a solid, 70 cm long, polyethylene cylinder with an outer diameter of 203 ± 3 mm and a line source insert.
- The line source insert is made of a clear polyethylene tube at least 80 cm in length, and with inner and outer diameters of 3.2 ± 0.2 and 4.8 ± 0.2, respectively.
- A hole (6.4 ± 0.2 mm in diameter) is drilled along the central axis of the cylinder at a radial distance of 45 ± 1 mm to insert the above mentioned line source.

15.2.3.2 National Electrical Manufacturers Association scatter phantom



Positioning of the scatter phantom on the patient bed: trans-axial view (left); picture of the National Electrical Manufacturers Association scatter phantom (right).

15.2.3.3 National Electrical Manufacturers Association sensitivity phantom

Use of the phantom

- This phantom is used to evaluate the sensitivity of the PET scanner.
- Sensitivity is the number of counts per unit time per unit of radioactivity concentration within the FOV.
- In PET, unlike SPECT, the sensitivity is measured using a special phantom, using attenuating concentric sleeves.

15.2.3.3 National Electrical Manufacturers Association sensitivity phantom

Characteristics and materials

- The sensitivity phantom consists of five concentric aluminium sleeves (70 mm in length) each with a wall thickness of 1.25 mm.
- The inner diameters of the five tubes are 3.9, 7, 10.2, 13.4 and 16.6 mm.
- The line source, made from clear polyethylene, is filled uniformly with ^{18}F in solution and inserted into the smallest sleeve and suspended in air within the FOV of the scanner.

15.2.3.3 National Electrical Manufacturers Association sensitivity phantom

Pictures of the National Electrical Manufacturers Association sensitivity phantom: positioning of the phantom within the gantry (right). The aluminum sleeves (left and centre) should coincide with the centre of the axial field of view.

15.2.3.4 Triple-point source phantom for spatial resolution

Use of the phantom

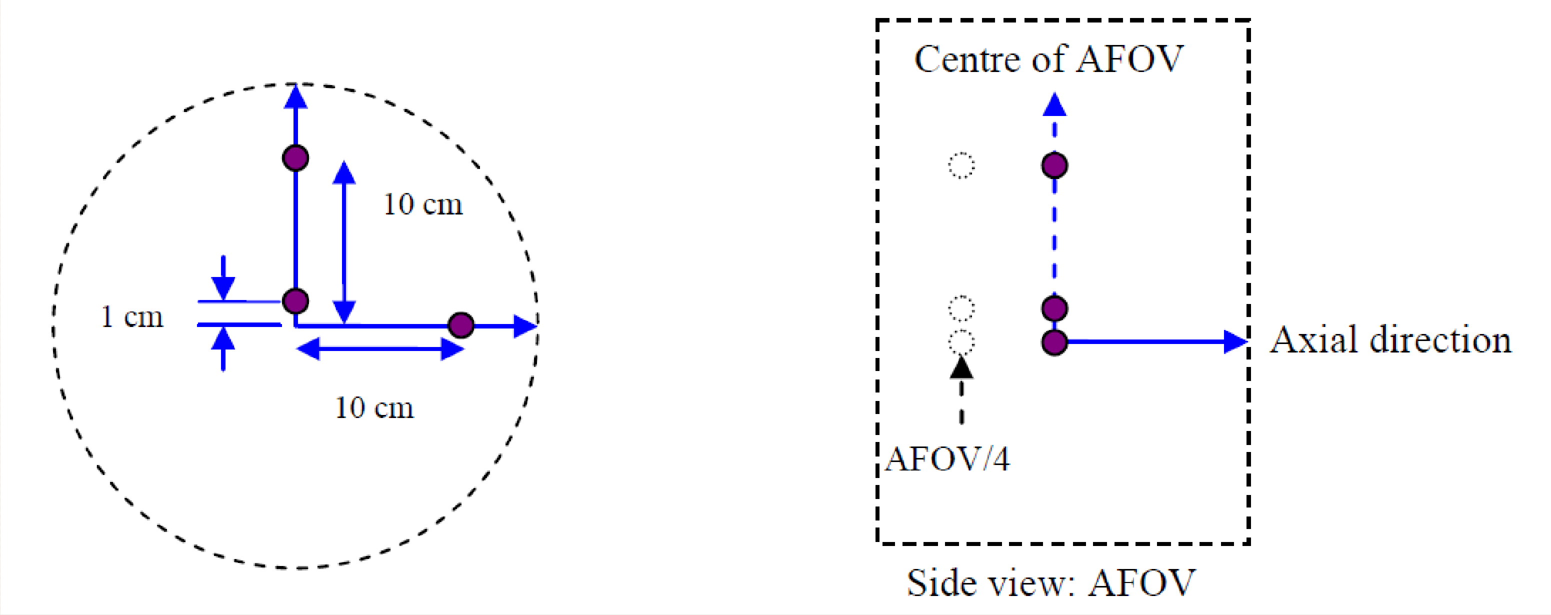
- The phantom is used to measure the spatial resolution of the PET scanner in air.
- Special supports are used to locate the sources in the PET gantry.

15.2.3.4 Triple-point source phantom for spatial resolution

Characteristics and materials

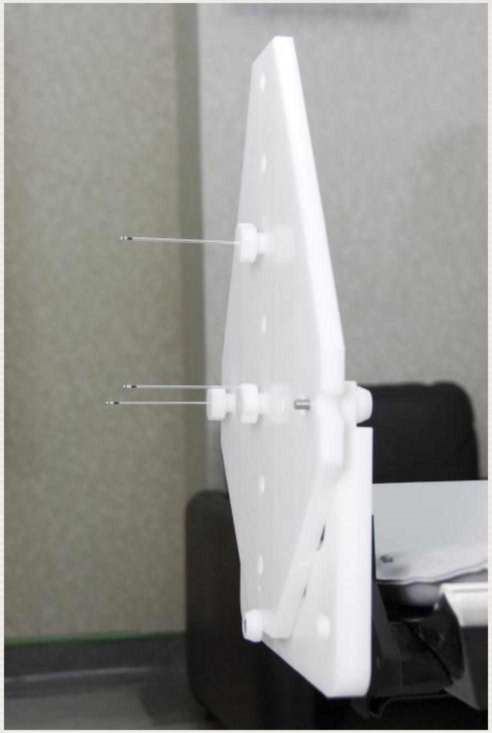
- Hematocrit or capillary tubes are commonly used to create point sources for measuring the spatial resolution of PET scanners.
- Three point sources should be positioned as shown in the next slide.
- It should be noted that the central point source is positioned 1 cm above the centre of the FOV.

15.2.3.4 Triple-point source phantom for spatial resolution



Positioning of the three point sources in the centre of the transverse field of view (FOV). The view into the gantry bore (right) and the side view (left) in which the dashed circles denote the axial position of the sources in the second scan.

15.2.3.4 Triple-point source phantom for spatial resolution



Three capillary point sources mounted on a point source holder used in PET to measure spatial resolution.

15.3 COMPUTATIONAL MODELS

15.3 COMPUTATIONAL MODELS

Computational models can be categorized in three groups:

- Mathematical models
- Voxelized computational models
- Hybrid computational models

Computational models

- Mathematical models
  - They simulate the organs with geometric primitives such as ellipsoids, cylinders, spheres and rectangular ellipsoids.

15.3 COMPUTATIONAL MODELS

Computational models

Voxelized computational models

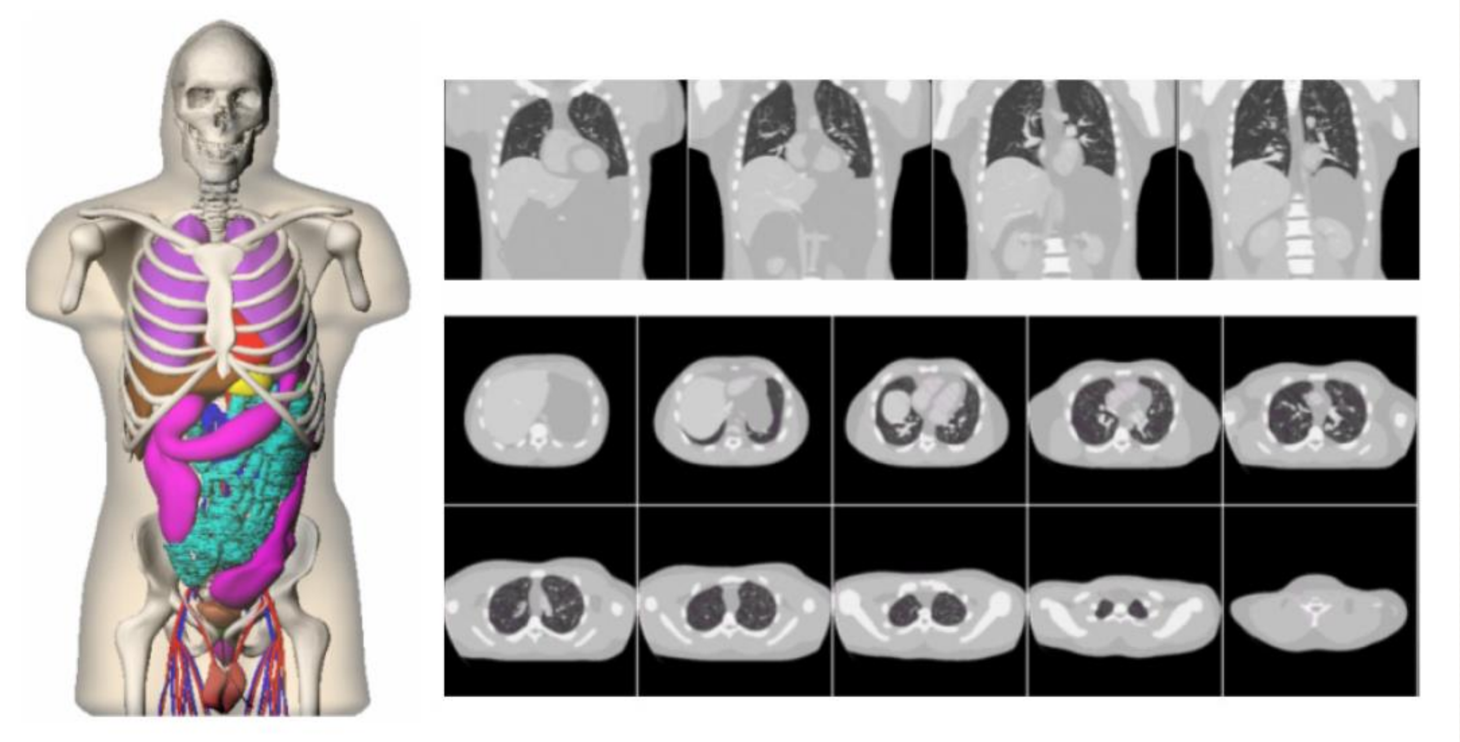
- the organs are defined by the structures segmented from high resolution tomographic images such as X ray CT and MRI.

Computational models

Hybrid computational models

- Surfaces of the segmented structures in voxelized models are defined by mathematical formulations used to define irregularly shaped surfaces such as 3-D B-spline surfaces.

15.3 COMPUTATIONAL MODELS



Left: initial extension of the 4-D XCAT anatomy. Right: simulated chest X ray CT images from the extended 4-D XCAT. Coronal (top row) and trans-axial (bottom two rows) reconstructed slices are shown (reproduced with permission from P. Segars).

15.3 COMPUTATIONAL MODELS

Uses of 4-D models

- Such 4-D models can be used to accurately simulate SPECT and PET images of the torso and can be particularly helpful for optimizing image acquisition protocols and image reconstruction algorithms, and understanding the various effects of these complex motions on the acquired PET or SPECT images.

15.3 COMPUTATIONAL MODELS

Advantages of computational models

- Computational models may be preferred because the use of physical phantoms leads to unnecessary occupational exposure to radiation, and the preparation and repetition of the experiments using physical phantoms can be lengthy and time consuming.

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15.3 COMPUTATIONAL MODELS

15.3.1 Emission tomography simulation toolkits

15.3.1.1 SimSET

- SimSET, first released in 1993 and developed at the University of Washington, is a simulation package that can simulate PET and SPECT emission tomography systems using Monte Carlo simulations.

15.3.1.1 SimSET

Characteristics

- It can model the photon interaction process as well as the imaging detector geometries.
- SimSET allows the use of a different object description such as a Zubal phantom to simulate a whole body phantom.

15.3.1.2 GATE

Limitations of SimSet

- Owing to the limitations of SimSET regarding the modelling of complex detector geometries, the need for a more sophisticated emission tomography simulator arose.
- A simulation toolkit (GATE) for nuclear medicine applications was developed and has been available since 2001.

15.3.1.2 GATE

Characteristics

- GATE uses the existing libraries of Geant4, which is a comprehensive simulation toolkit that simulates the interaction of particles as they traverse through matter.
- It includes validated geometry modelling tools that can model complex scanner geometries, the description and models of several commercially available PET and SPECT scanners, can simulate CT scans and perform dose calculations.

15.4 ACCEPTANCE TESTING

15.4.1 Introduction

15.4 ACCEPTANCE TESTING

15.4.1 Introduction

Levels of testing of imaging equipment

- The first set of tests of imaging equipment is carried out in the factory before shipment.
- The second level of testing is the acceptance testing performed after the scanner arrives at the site.
- During acceptance testing, the user should also conduct reference tests which constitute the third level of testing.
- Routine tests constitute the fourth level of testing.

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Acceptance tests

- These tests should be performed by the user or a third party, usually a qualified medical physicist, to determine whether the system performs according to the manufacturer's specifications and free of any deficiencies, flaws or defects.
- These data provide guidance in the determination of the optimal operating parameters for routine use and ensure that the imaging equipment meets regulatory requirements for radiation safety.

15.4 ACCEPTANCE TESTING

15.4.1 Introduction

Reference tests

- These tests reflect the performance of the system under clinical settings, are easy to perform and can be performed within an acceptable time frame.
- These tests, in addition to some other acceptance tests, will establish the baseline performance characteristics for routine QC tests.

Routine tests

- These are the tests performed on a regular basis by users.
- They are simple, but provide the daily confidence that the equipment is working within acceptable parameters.

15.4 ACCEPTANCE TESTING

15.4.1 Introduction

Issues regarding acceptance testing that should be considered

Related to the vendor

- Some phantoms are used during acceptance testing and after major repair only, and may be included its use in the purchasing contract.
- The calculation of performance parameters from the image data in PET and the gamma cameras and SPECT systems may require sophisticated software applications.
- The documentation for the acceptance test procedures may be made available by the vendor.

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Issues regarding acceptance testing that should be considered

Additional tests

- In multimodality imaging systems, additional tests, which are not discussed in the existing guidelines, must also be conducted.

15.4 ACCEPTANCE TESTING

15.4.1 Introduction

Before starting acceptance testing, the following additional issues should be considered:

Activity for the tests and its measurement

- An accurate dose calibrator is an essential part of acceptance testing and must, therefore, be available.
- The required amount of radioactivity has to be arranged before starting acceptance testing, so that the acceptance testing procedure does not experience any interruption.

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Before starting acceptance testing, the following additional issues should be considered:

Calibration of the imaging system

- Proper calibration of the imaging system prior to acceptance testing is of paramount importance.
- Any major erroneous calibration or lack of calibration may result in an increase in commissioning cost and undue delays in acceptance testing.

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15.4 ACCEPTANCE TESTING

15.4.1 Introduction

Before starting acceptance testing, the following additional issues should be considered:

Tests schedule and calculations

- The order of the tests that will be conducted must be arranged so that any malfunctioning or improper calibration can be discovered early on to minimize the number of tests that must be repeated.
- If the medical physicist is not familiar with the system, a vendor representative who knows how to operate the scanner and how to run the calculation software should be present during acceptance testing.

15.4 ACCEPTANCE TESTING

15.4.1 Introduction

Before starting acceptance testing, the following additional issues should be considered:

Phantoms and auxiliary equipment

- All the phantoms required for the tests should be made ready and prepared in advance.
- Any additional equipment or accessories to be used should also be prepared in advance.

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15.4 ACCEPTANCE TESTING

15.4.2 Procurement and pre-purchase evaluations

15.4 ACCEPTANCE TESTING

15.4.2 Procurement and pre-purchase evaluations

Deciding to buy an imaging system

When an institution decides to buy an imaging system, the administration should start the planning properly by:

- Defining the purpose(s) for acquiring the system.
- Forming a committee of a team of professionals to take on all of the responsibilities from purchasing to setting up the system.

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15.4 ACCEPTANCE TESTING

15.4.2 Procurement and pre-purchase evaluations

Proposal of purchasing committee composition

- Nuclear medicine and radiology physicians.
- A medical physicist with experience in nuclear medicine.
- If buying SPECT/CT or PET/CT, a medical physicist experienced in diagnostic radiological physics should be included.
- A medical physicist experienced in radiation therapy if the system will be used in radiation therapy planning.
- An administrator from the radiology department.
- A radiation protection expert.
- A person qualified in radiochemistry or radiopharmacy, if in-house production of radiopharmaceuticals.
- A nuclear medicine technologist.
- A hospital management expert.
- A bioengineering expert in imaging systems.

15.4 ACCEPTANCE TESTING

15.4.2 Procurement and pre-purchase evaluations

The role of this committee is to:

- Choose the location.
- Set the specifications of the system.
- Prepare the tender documents.
- Choose the proper system.
- Supervise the installation process.
- Supervise the acceptance and commissioning procedure.

Choosing the location

Space considerations and vicinities

- The room should be wide enough to host the scanner, give accessibility to patient stretchers and provide free space to maintenance engineers.
- This location should be inside a radiation-controlled area, with the door of the room opening to a closed vicinity (not to a public corridor).
- If possible, the room should be far away from MRI scanners to avoid any interference from their magnetic field.

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Choosing the location

If there is SPECT/CT and PET/CT equipment

- If buying SPECT/CT and the CT sub-component will be used as a stand alone system occasionally, it is advisable to have the scanner as close as possible to the radiology CT scanner.
- This is also true for the PET/CT systems if there is no on-site cyclotron.
- For scanners inside institutions having a cyclotron, it is advisable to have the PET scanner as close as possible to the cyclotron.

15.4 ACCEPTANCE TESTING

15.4.2 Procurement and pre-purchase evaluations

Steps for setting the specifications of the system

- Agreeing on the purpose for which the scanner will be used.
- Based on the applications that the system will be used for, the different add-on components to be ordered will be decided.
- After defining all of the components, the specifications of the scanner and each component should be set.

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Preparing the tender documents

Equipment

- Name and model of the equipment.
- Terms of pricing; way of payment, site preparation, accessories, etc.
- System upgrade conditions.
- Equipment warranty.

Preparing the tender documents

Information and training

- User and engineering manuals and equipment specifications (NEMA and others).
- Equipment references; short list of current users of similar system, local or international.
- Application specialist training.
- Training of staff.

Preparing the tender documents

Installation

- Scheduling installation process and way of coordination.
- Responsibility of site preparation, including removal of old equipment.
- Specifications of local civil work and materials used.

Preparing the tender documents

Acceptance testing and maintenance

- Acceptance testing to be performed by a medical physicist (the system should comply with NEMA or local specifications).
- Commitments of the vendor to provide maintenance, and spare parts readiness (service contract, if adequate).

Final steps

Decisions

- After thorough evaluation of all systems, the committee decides on the most appropriate system.
- Important points to consider are the cost of the system and the availability of a good maintenance service in the region. Less expensive systems with bad maintenance services can be a real problem in the clinical environment.

Final steps

Supervision of the installation process

- After the system is chosen, the committee should supervise and help the installation process.
- It should help the vendor representative to finalize all of the paper work and get the access permits to the location.
- The system should be installed completely with all the accessories and software ordered.

Final steps

Acceptance testing of the system

- The local medical physicist or a private consultant should perform the acceptance testing on the system.
- The committee should facilitate and make available all of the necessary resources to the medical physicist to complete the job and get the system ready for clinical use.

15.4 ACCEPTANCE TESTING

15.4.3 Acceptance testing as a baseline for regular quality assurance

Reference and routine tests

- The medical physicist should produce reference tests during acceptance testing.
- They should acquire tests that are easy to perform with less sophisticated procedures that can be conducted within an acceptable period by the user.
- These tests should reflect the performance of the system in the working environment.
- The results of the routine tests should be compared against the results of these reference tests.

15.4 ACCEPTANCE TESTING

15.4.4 What to do if the instrument fails acceptance testing

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Problems and actions

If a test fails

- If any of the test results do not meet the specifications, the analyses should be re-evaluated carefully.
- Following this, the test should be repeated again, paying close attention to any possible mistakes made during the acquisition and processing of the data.
- The analysis should also be carried out carefully, making sure that an accurate method has been followed.

15.4.4 What to do if the instrument fails acceptance testing

Problems and actions

If the problem persists

- The engineer should be called to rectify the problem and then it becomes the responsibility of the vendor to resolve the issue.
- If two or three tests of the same parameter fail, the vendor should either replace the affected part (if it was not done before) or replace the system.

15.4 ACCEPTANCE TESTING

15.4.5 Meeting the manufacturer's specifications

15.4.5 Meeting the manufacturer's specifications

Tests results and specifications

- The results of these tests should meet the specifications set by the manufacturer, as they are usually one of the main reasons for selecting a particular system.
- If one or more test results do not meet the manufacturer's specifications, the test should be repeated carefully.
- In the case of similar results, the vendor engineer should rectify the problem at hand and then repeat the calibrations if necessary.