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QA/QC of Nuclear Medicine Imaging Equipment – Current Practices

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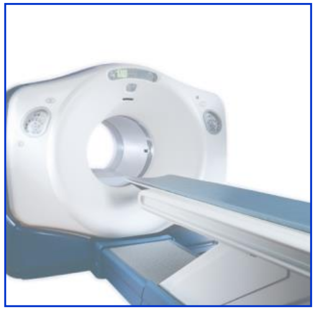
Outline: QA/QC of Nuclear Medicine Imaging Equipment – Current Practices

- QA & QC of NM imaging equipment,
- Planar performance parameters of Gamma Camera,
- Performance parameters for SPECT systems,
- Performance parameters of PET/CT systems,
- Frequency of QC tests on NM imaging equipment,
- Summary.



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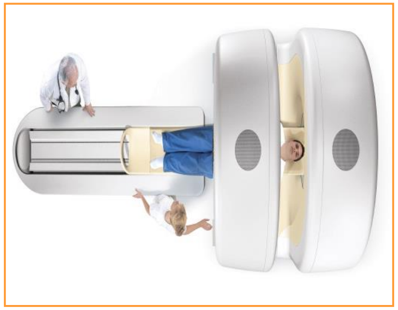
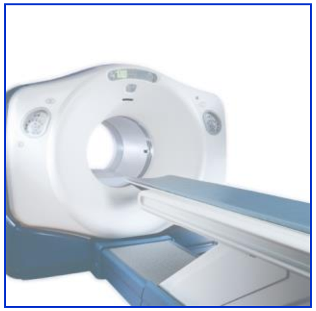
QA/QC of Nuclear Medicine Imaging Equipment – Current Practices



- The high standards of efficiency and reliability in the practice of nuclear medicine:
  - requires an appropriate Quality Assurance programme.
  - QA embraces all efforts made to ensure a given procedure approaches an ideal result, free from all errors and artefacts.

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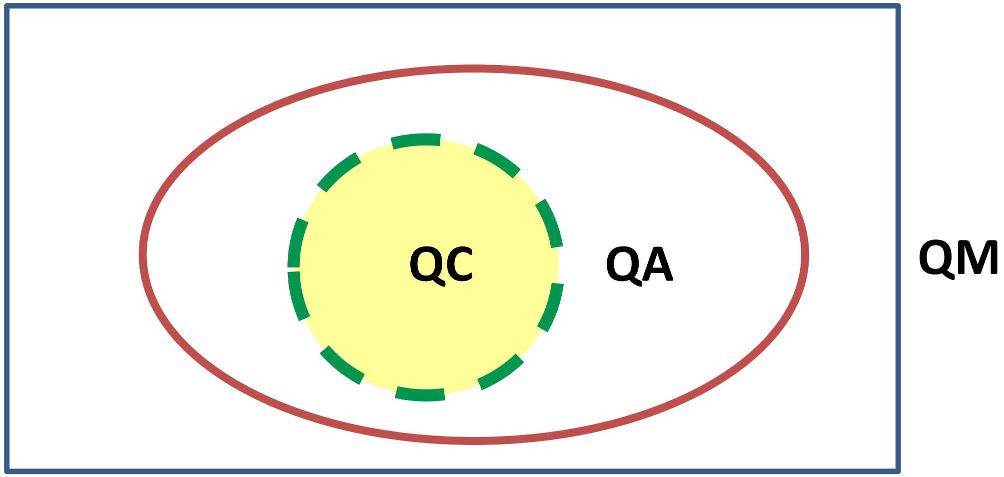
QA/QC of Nuclear Medicine Imaging Equipment

- QC is crucial to all aspects of nuclear medicine practice
  - measurement of radioactivity, preparation of radiopharmaceuticals, use of instrumentation to obtain images, computations to calculate functional parameters, and interpretation of the results by the physician.
- QC refers to the testing designed to identify equipment problems
  - Uniformity or energy resolution in a gamma camera.



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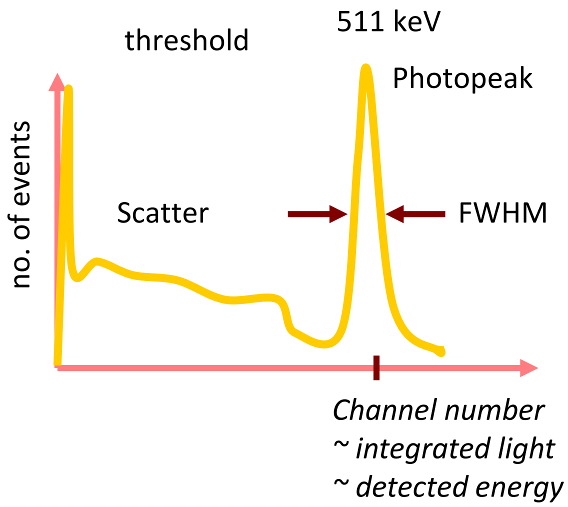
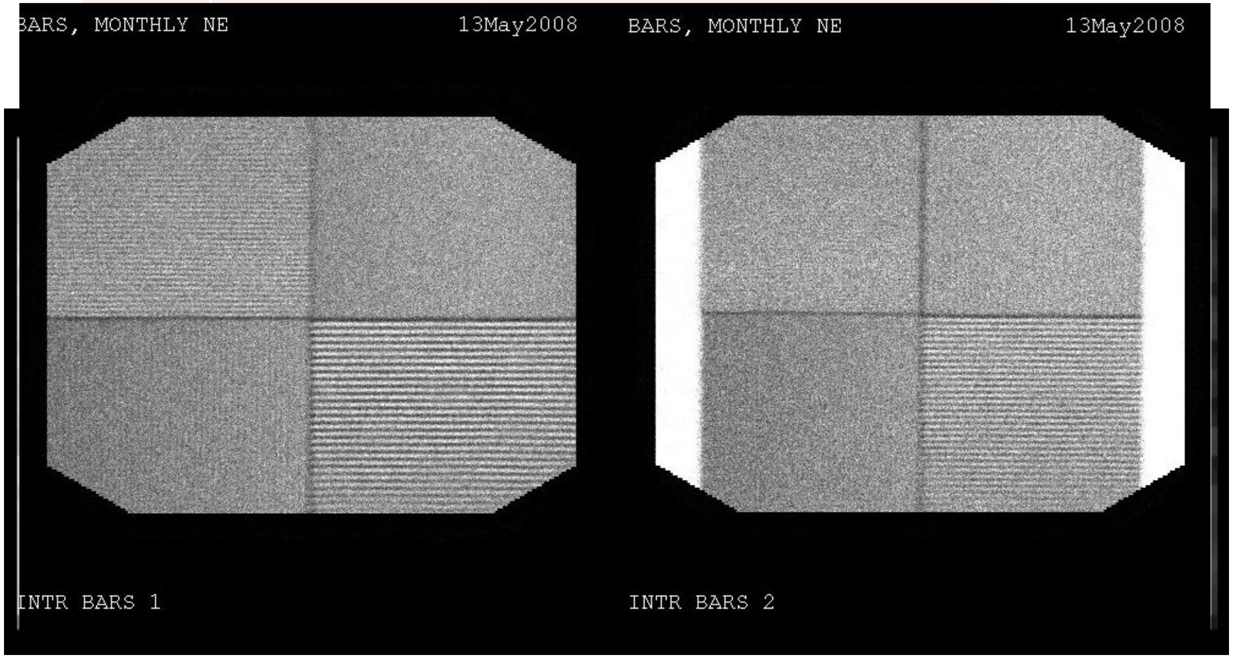
QA/QC of Nuclear Medicine Imaging Equipment

- Quality control is carried out throughout the life cycle of equipment,
  - i.e. from planning, procurement to decommissioning.
- QC plays an integral part in fulfilling the regulatory requirement for establishing a comprehensive QA programme,
- QC plays an important role in:
  - helping maintain image quality and
  - better utilization of nuclear medicine imaging instruments.

Performance parameters of Gamma Camera

	Parameters performance
1	Uniformity
2	Spatial Resolution
3	Sensitivity
4	linearity
5	Energy Resolution
6	Count rate characteristics





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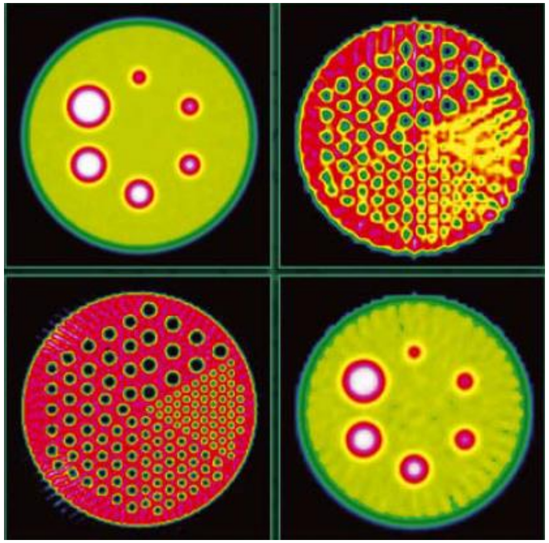
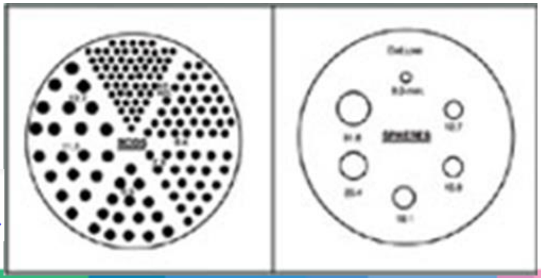
Significance of QC in SPECT systems

- Reconstruction techniques amplify gamma camera imperfection such as poor uniformity & spatial resolution resulting in significant artifacts.
- Rotation motion in SPECT introduces artifacts such as detector head tilt & COR not seen in planar imaging.
- Electrical & mechanical camera performance more stringent for SPECT imaging.

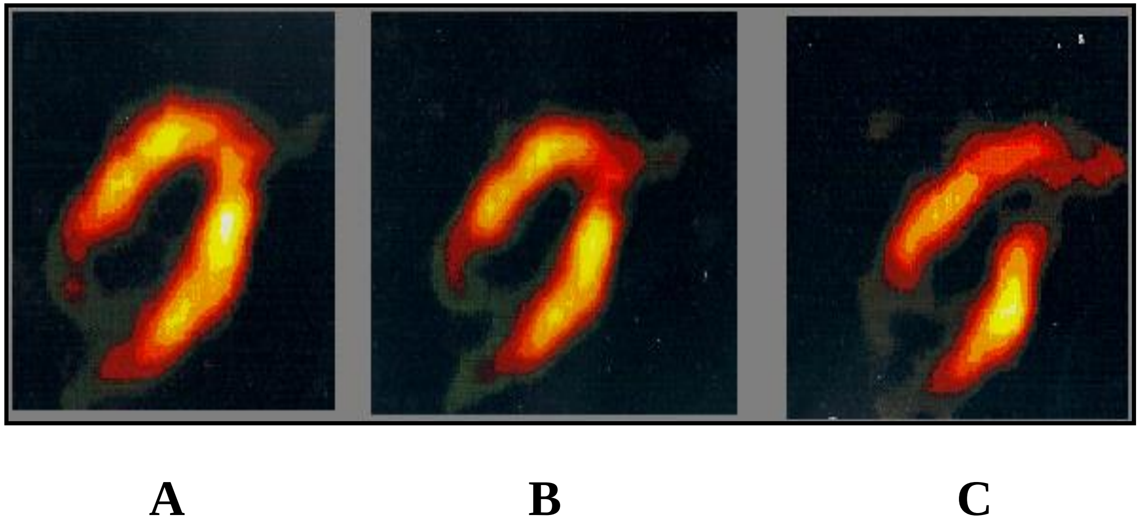
Performance parameters for SPECT systems

	Parameters that affect SPECT performance
1	Slice thickness;
2	Tomographic signal-to-noise ratio;
3	Tomographic contrast;
4	Tomographic uniformity;
5	Tomographic resolution;
6	Linearity of tomographic response;
7	Quantitative accuracy in tomography
8	Precision of estimation of the COR;
9	Tomographic sensitivity — slice and volume.





Effect of COR error on myocardial perfusion images



A. No error
B. COR error = 1 pixels
C. COR error = 3 pixels

Conclusion: COR error < 0.5 pixels

Simulations of a point source reconstructed with different COR offset errors

TL: 0 pixel offset (perfect data)

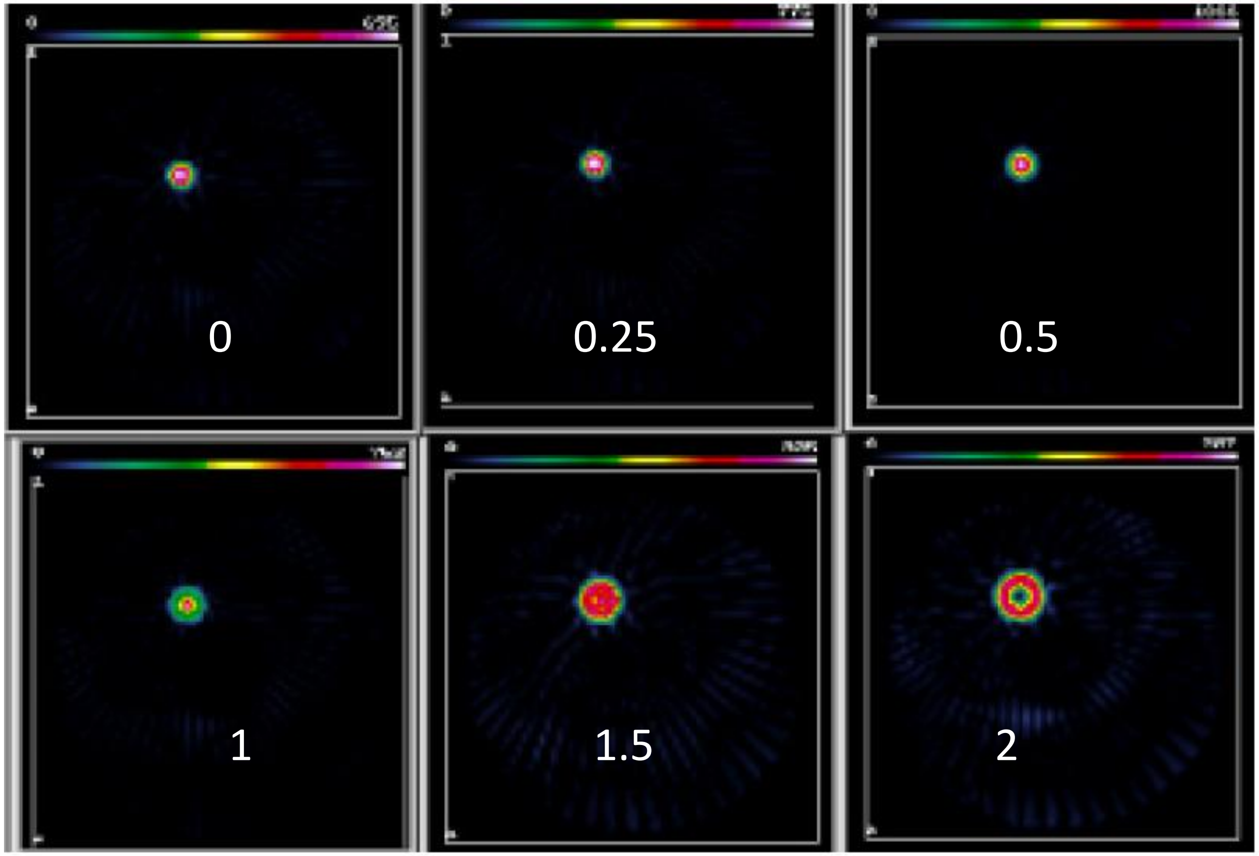
TM: 0.25 pixel offset error

TR: 0.5 pixel offset error

BL: 1 pixel offset error

BM: 1.5 pixel offset error

BR: 2 pixel offset error

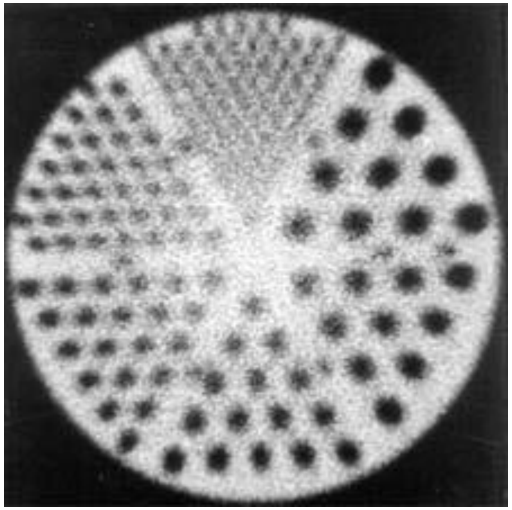


- The effect of a COR offset is a loss of reconstructed spatial resolution and contrast. A correction for an offset error must be made.

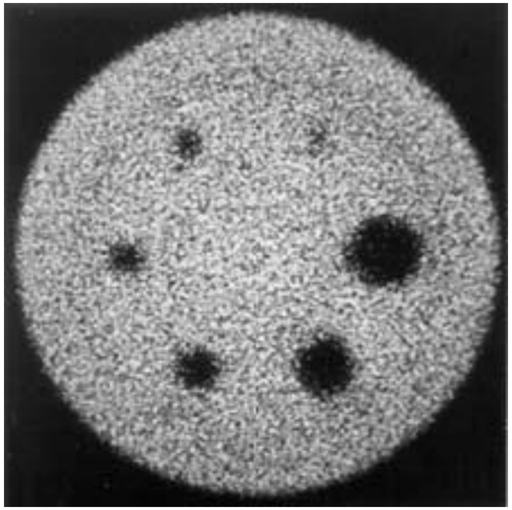
Jaszczak™ Phantoms for PET and SPECT

- The Jaszczak SPECT Phantom provides consistent performance information for any SPECT or PET system.
- Multiple performance characteristics of systems are evaluated from a single scan of the phantom.

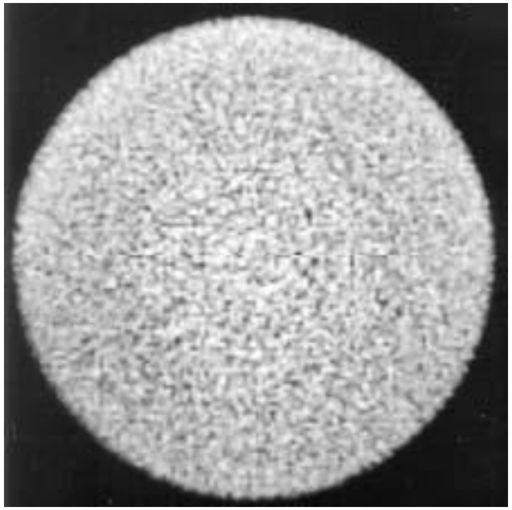
Images were obtained with the Deluxe Jaszczak™ Phantom Model ECT/DLX/P)



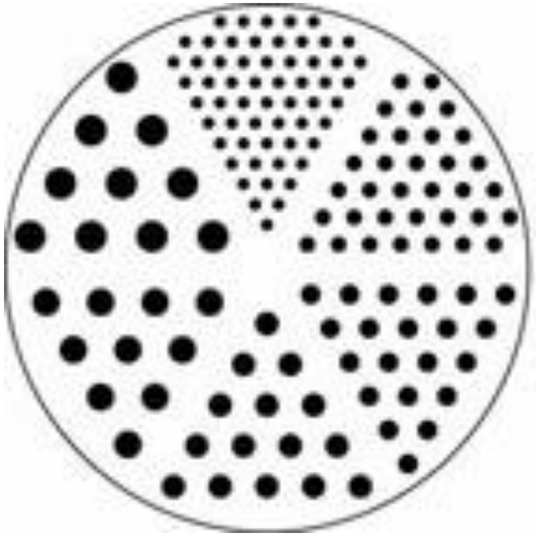
Cold Rods

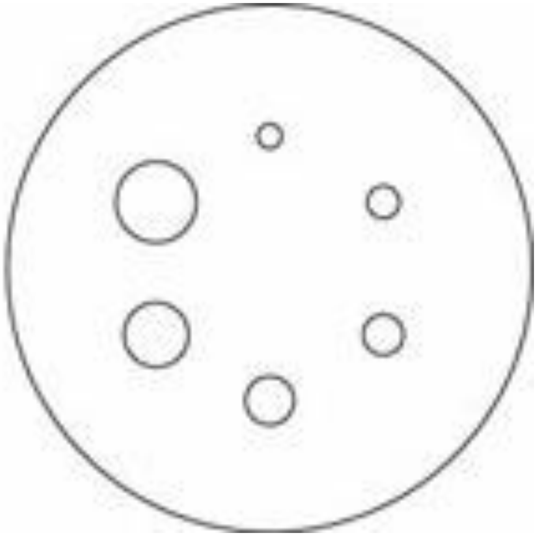


Cold Spheres



Uniform





Deluxe Jaszczak Phantom™
Model ECT/DLX/P (Biodex 043-750)

<u>Specifications:</u>
Rod diameters: 4.8, 6.4, 7.9, 9.5, 11.1 and 12.7 mm
Solid sphere diameters: 9.5, 12.7, 15.9, 19.1, 25.4, and 31.8 mm

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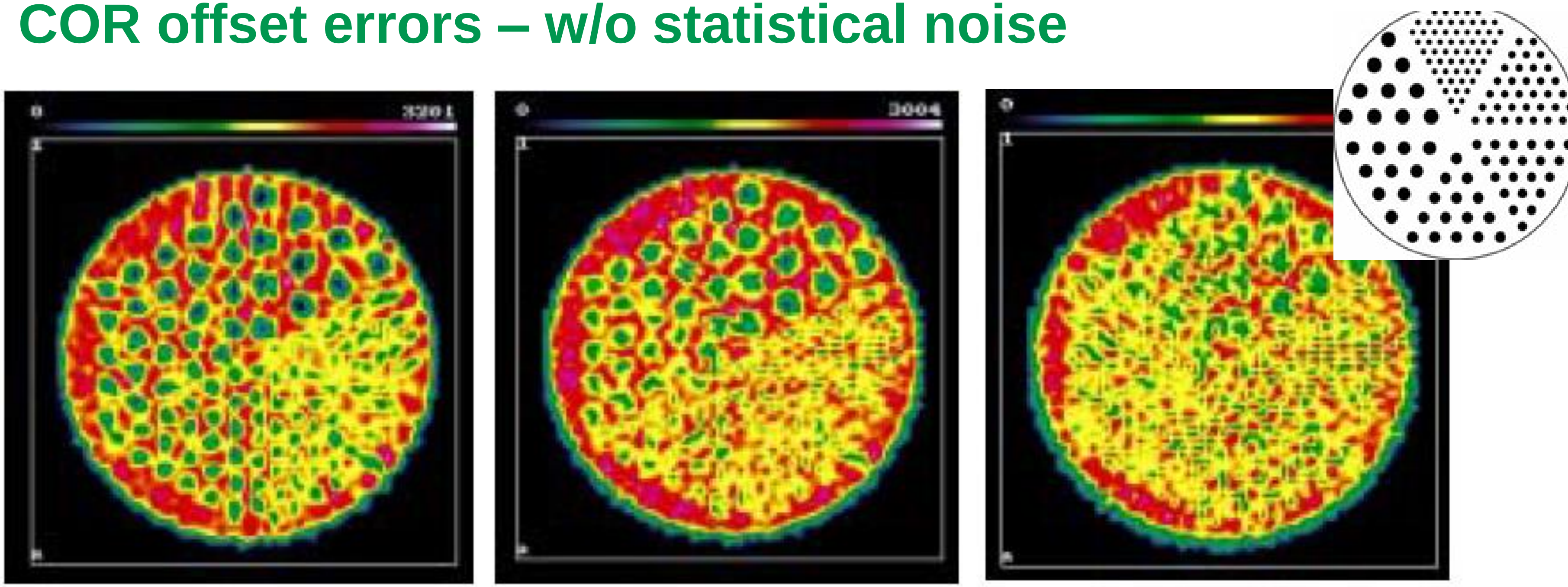
Simulations of a phantom reconstructed with different COR offset errors – w/o statistical noise



L: 0 pixel offset (perfect data) ; M: 0.25 pixel offset error; R: 0.5 pixel offset error

- A COR offset error of 0.5 pixel already has an impact on the quality of the image.
- The offset error needs to be well below this value, or a <u>COR offset correction</u> must be made.
- Note that in modern SPECT systems the acceptable limit for <u>COR offset is ±1 mm</u>, which corresponds to about 0.25 pixel offset.

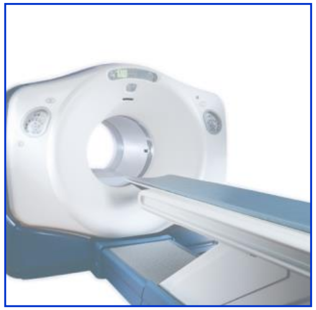
Quality Control Tests And Optimum Testing Frequency

Performance parameters	Testing frequency
Energy peaking	Daily
Field uniformity	Daily
Spatial resolution	Quarterly
Spatial linearity	Quarterly
Center of rotation	Weekly
Sensitivity	Annually

These tests should be performed following repair or adjustment of the SPECT scanner.

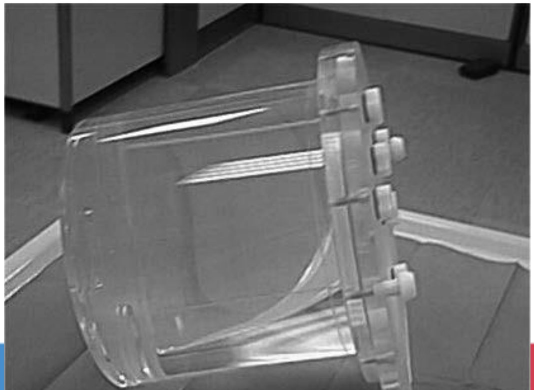
Performance parameters of PET/CT systems

- The following recommended NEMA NU2-2007 test's for the PET/CT after the installation.
  - Radioactivity concentration calibration
  - Spatial Resolution Test
  - Sensitivity Test
  - Scatter Correction Test
  - Image Quality, Attenuation, Accuracy



1. Radioactivity concentration calibration

- Vendors call it differently.
  - GE calls it well counter Calibration (WCC)
  - Siemens calls it Cross Calibrator Calibration (CCC)
- Aim: Ensure counts and activity calibration is accurate
  - These factors used in SUV calculation,
  - Cross calibrates PET scanner and dose calibrator,
  - Performed quarterly,
  - inaccurate calibration factors – will compromise image based quantitation.
  - https://www.youtube.com/watch?v=2sL3WeAftPg&feature=youtube



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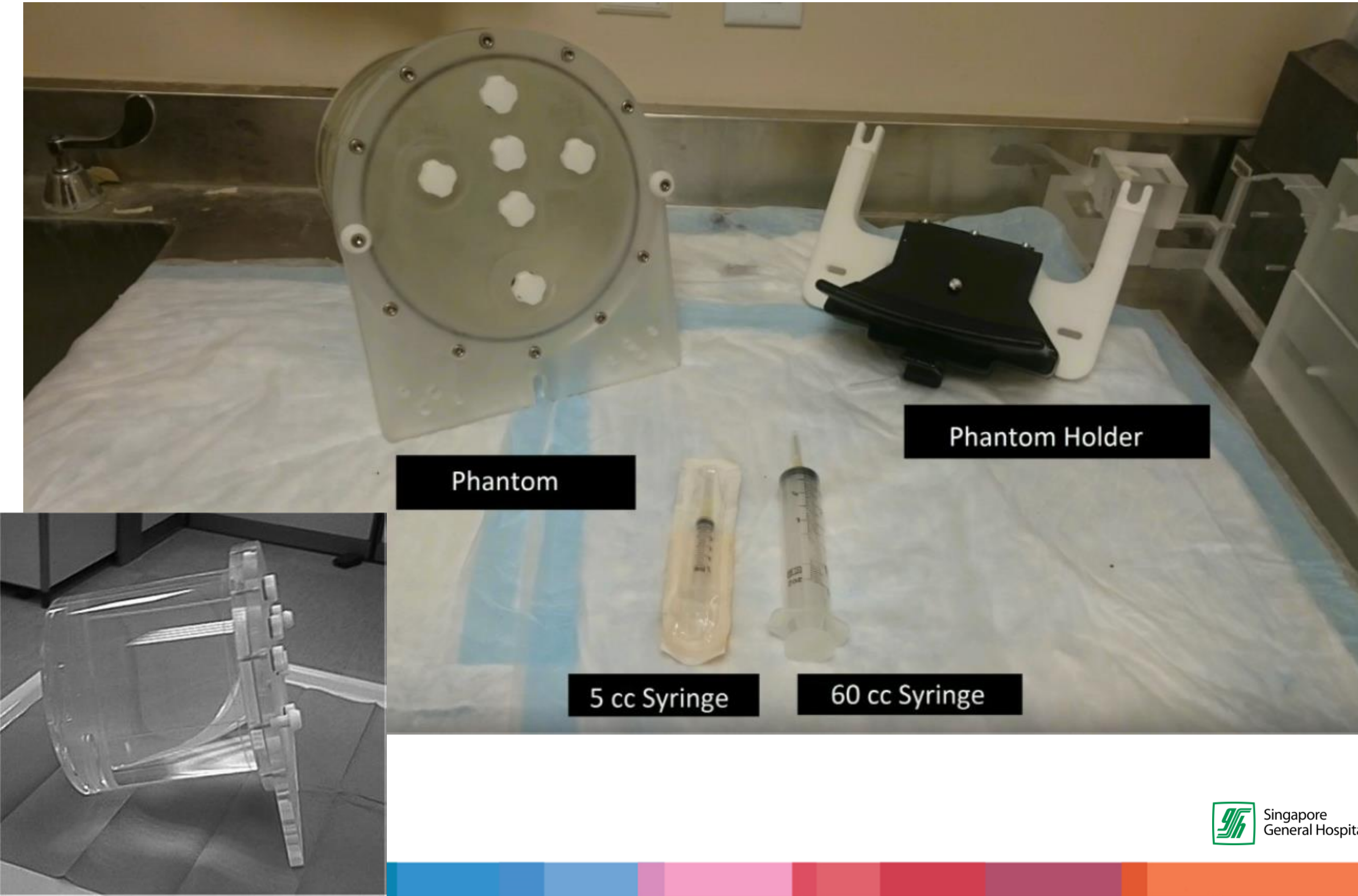
Radioactivity concentration calibration



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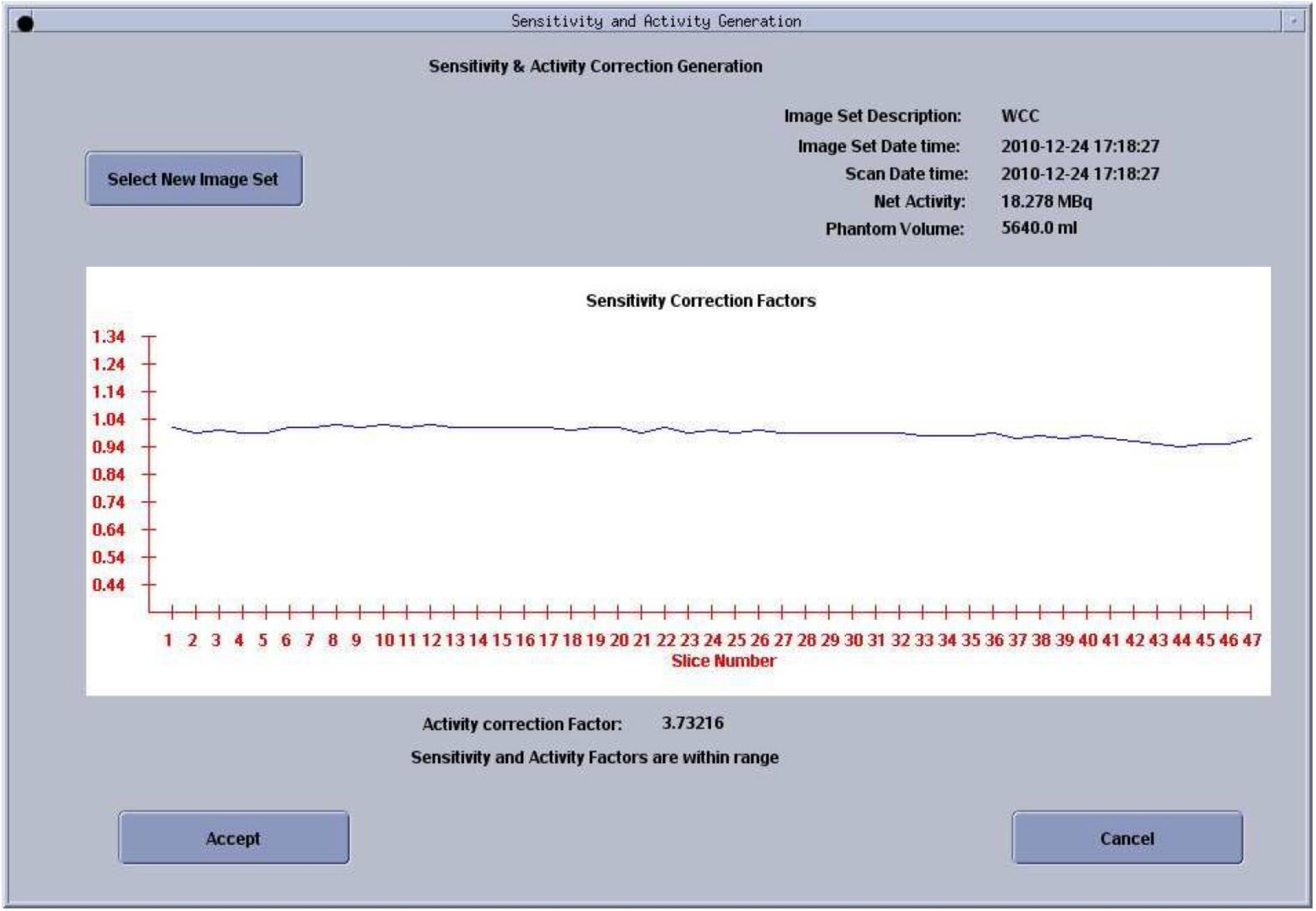
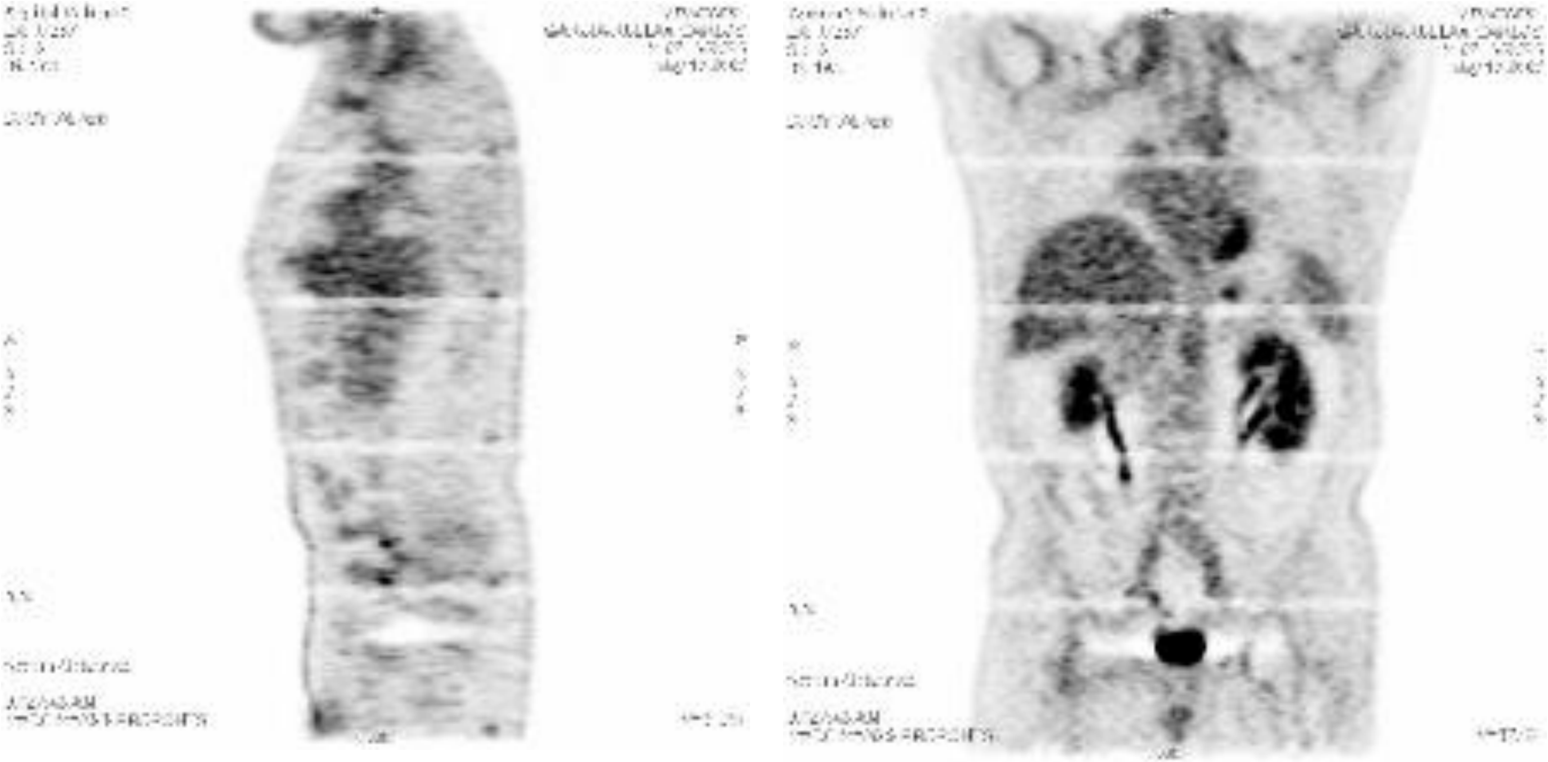
3D Well Counter Correction (WCC)
Scanner Cross Calibration Correction (CCC)



Effect of wrong WCC/ CCC



ACF not accurate, see streaks

2. Spatial Resolution

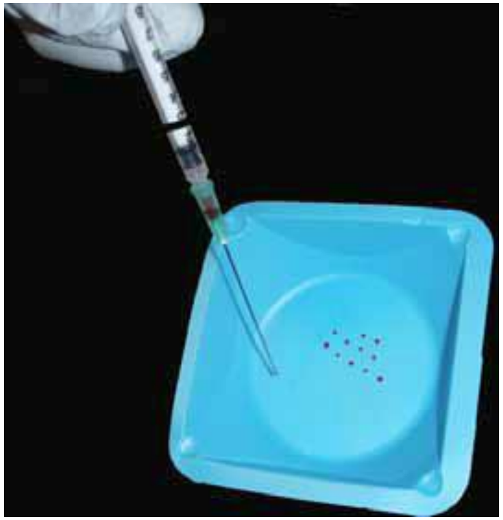
- Aim: measure the tomographic spatial resolution of the system in air and to ensure that spatial resolution is not degraded by either the acquisition or the reconstruction process.
- This test is based on the NEMA NU2-2007 spatial resolution test [1].
- This was performed with 3 samples of F-18 point sources with 5mCi/ml activity concentration to limit the % of dead time losses and randoms.

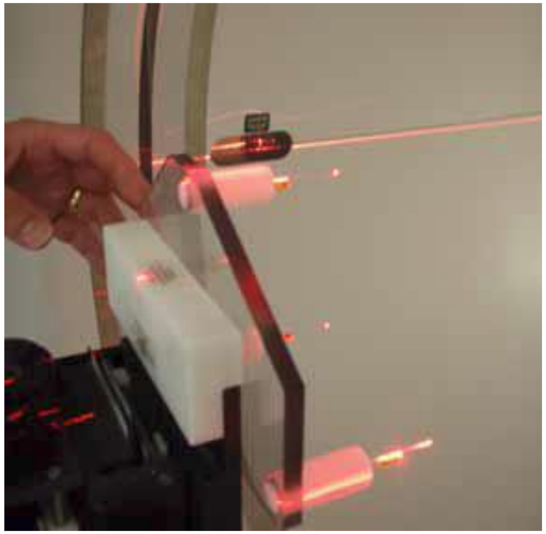
[1] NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION, Performance Measurements of Positron Emission Tomographs, NEMA Standard NU2-2007, NEMA, Washington, DC (2007).

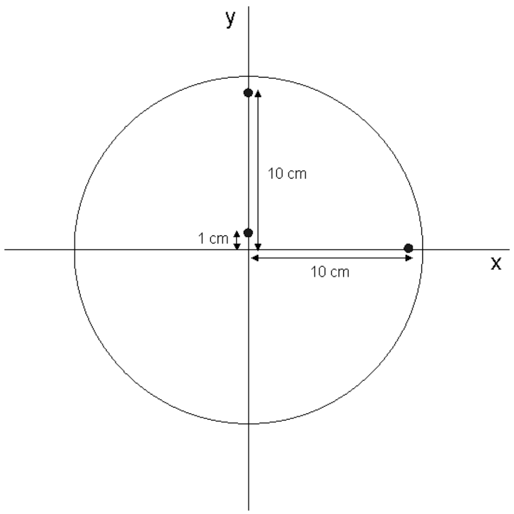
\NEMA test procedure (2).pdf https://www.youtube.com/watch?v=m7aQu4PyNr0&feature=youtu.be

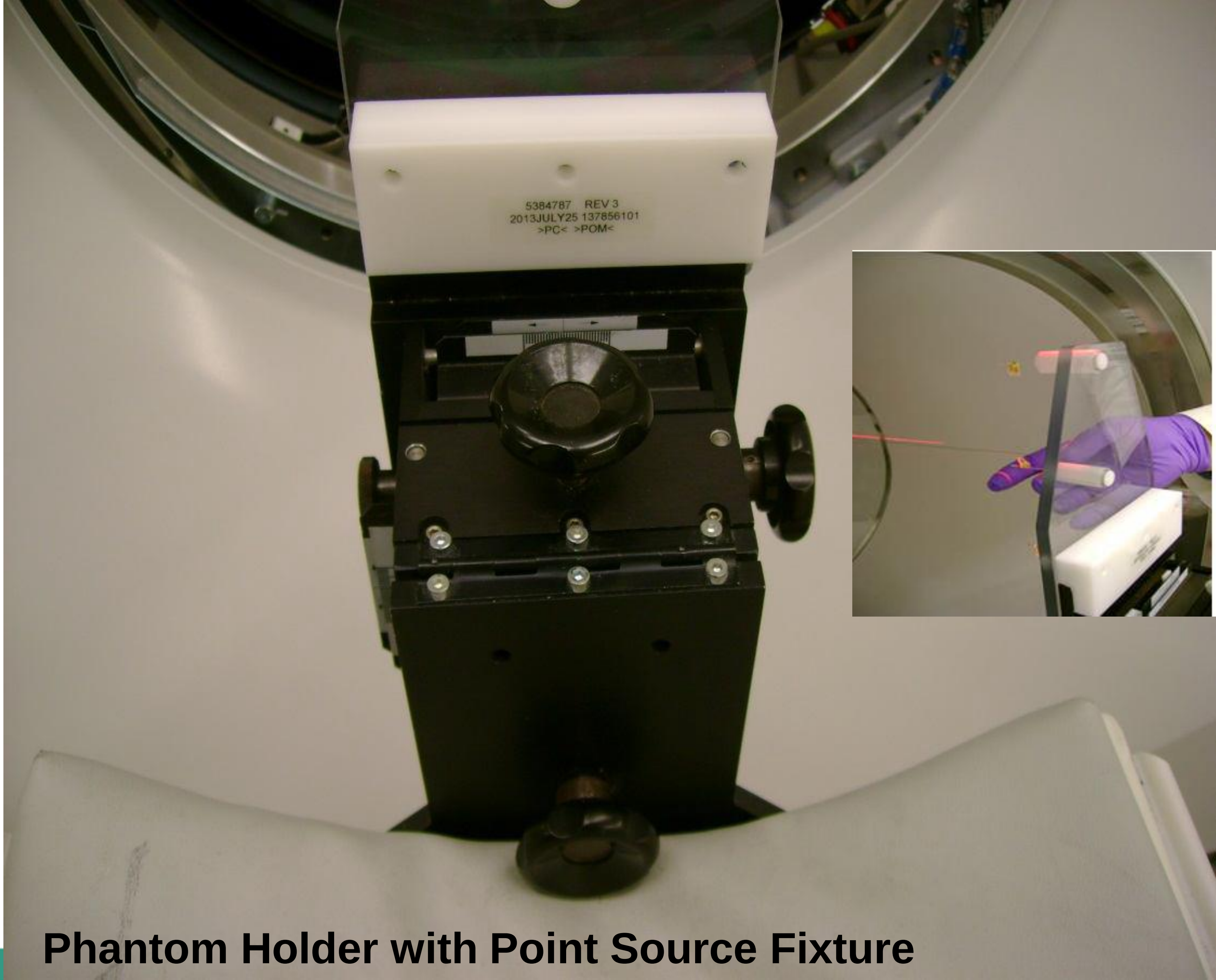
Spatial Resolution - Preparation

- There were three point sources of F-18, positioned with a spatial extent of less than 1 mm in both the transaxial and axial directions.
- The sources (*in capillary tubes*) were suspended in air, to minimize the effect of scattered radiation.
- It is recommended to use or construct a source holder to hold the sources securely in the correct positions.





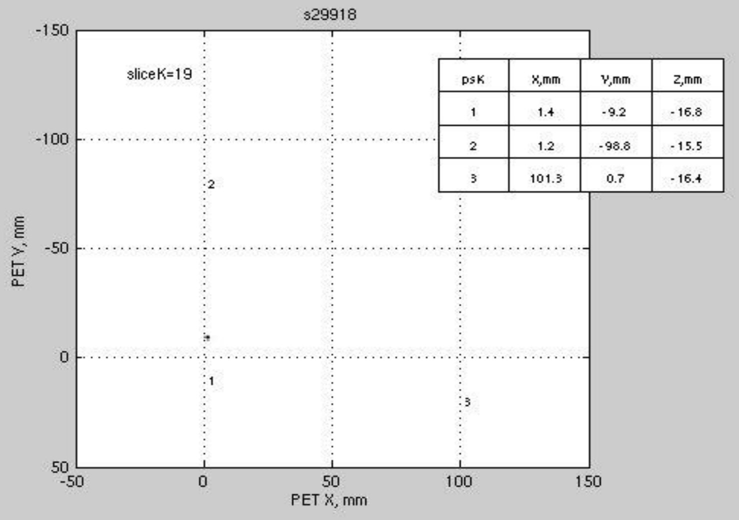




Phantom Holder with Point Source Fixture

Figure 30001

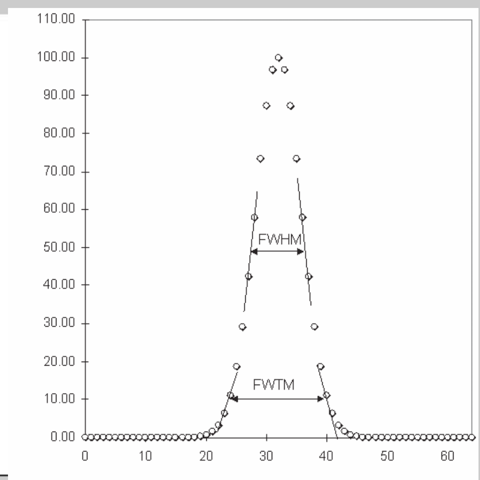
File



Scan Type	*Measured Value (mm FWHM)*	*Upper Limit (mm FWHM)*
Transverse @ 1cm	4.58	5.4
Transaxial @ 10cm	5.08	6.1
Axial @ 1cm	5.31	6.2
Axial @ 10cm	6.06	6.9

[1]Transaxial Resolution at 10 cm is evaluated as the average of the radial and tangential measurements.

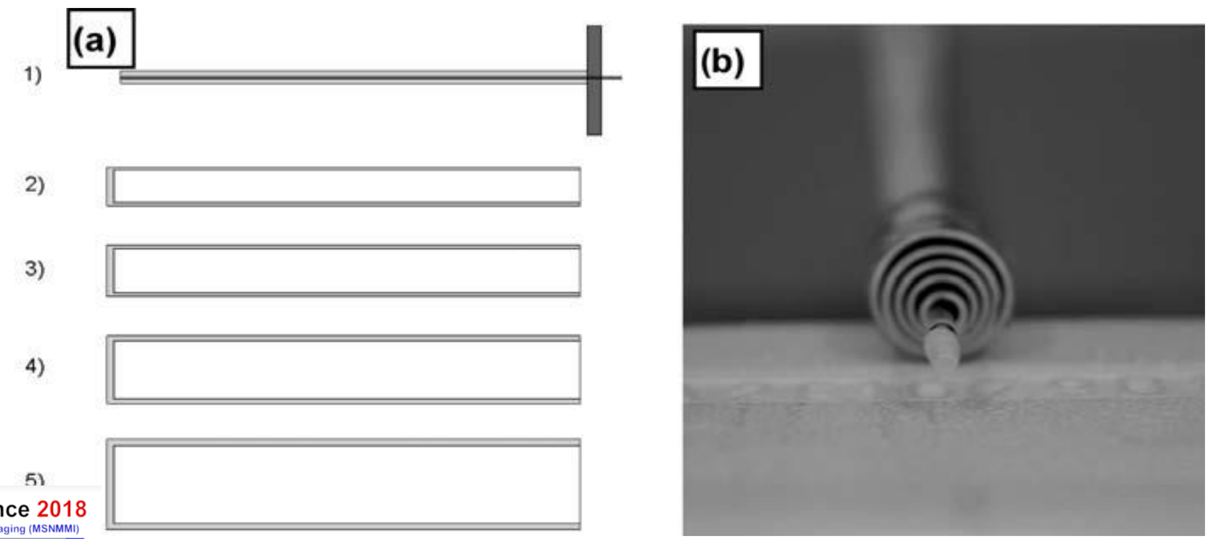
NEMA Spatial Res
Acquisition :
date: 27-Dec-2010
time: 11:04:09



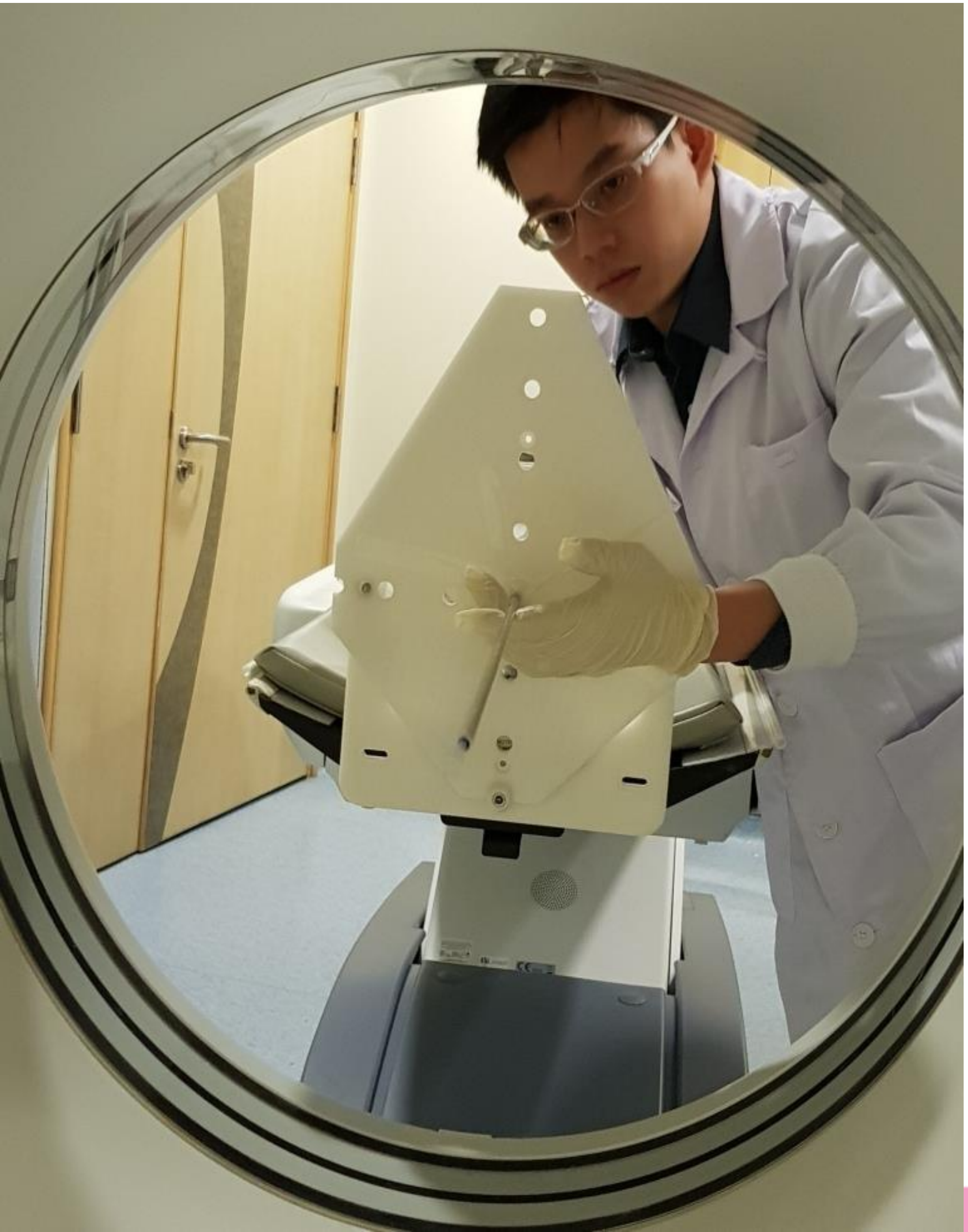
	FWHM	FWTM
at 1cm radius		
Transverse	4.49	8.65
Axial	5.22	11.48
at 10cm radius		
Radial	5.36	9.77
Tangential	4.82	8.94
Axial	6.08	11.97

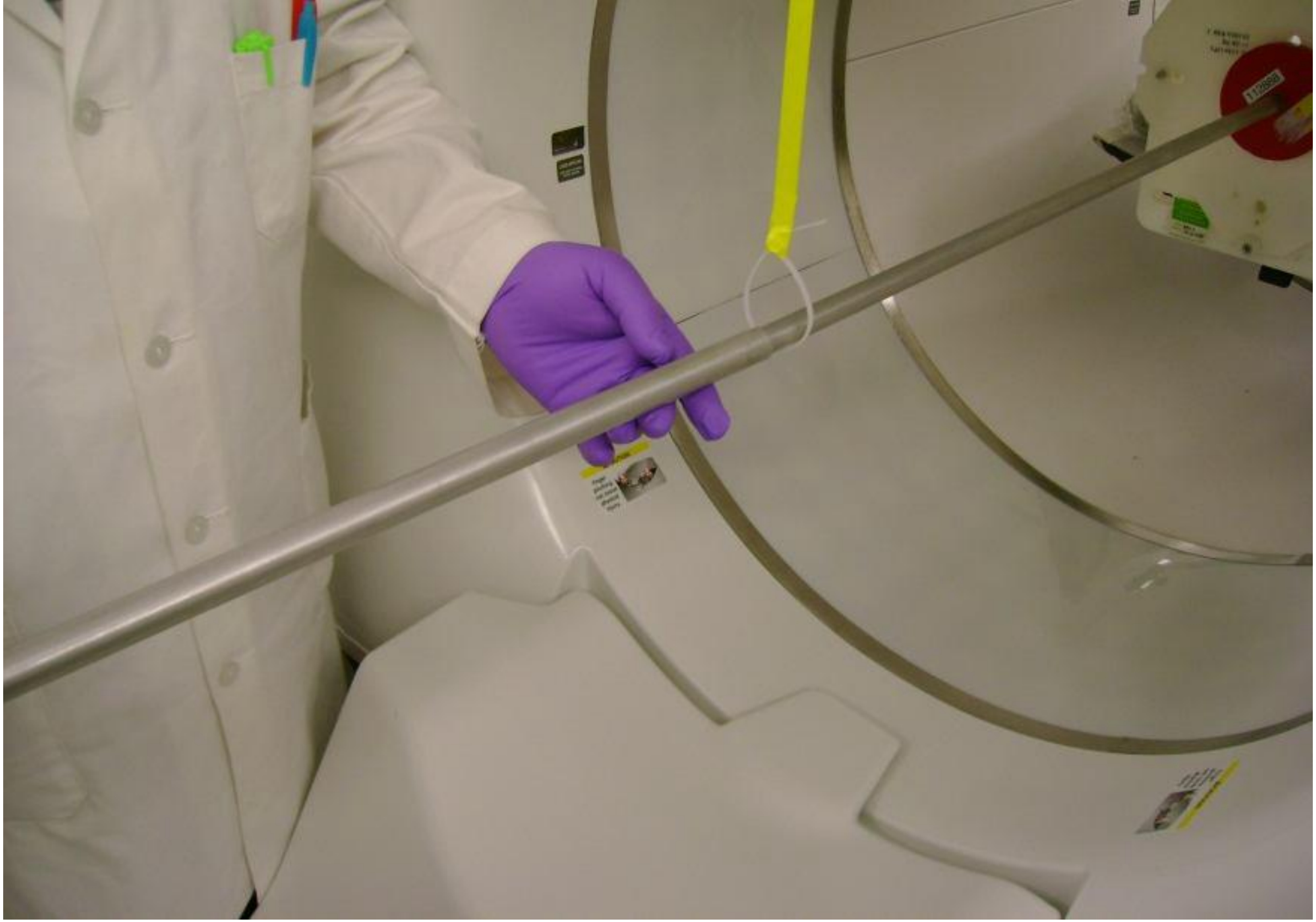
3. Sensitivity

- $\text{Sensitivity} = \dfrac{\text{count rate measured by the device to the}}{\text{amount of radioactivity within the FOV}}$
- Purpose of sensitivity measurement:
  - to determine the rate of detected true coincidence events per unit of radioactivity concentration.
- The source used is a line source, 700 mm long, uniformly filled with F-18 such that count losses were < 1%, and the random event rate is < 5% of the true event rate.
- The phantom for sensitivity measurements is completed by a set of five sleeves consisting of aluminium tubes 700 mm long, each with a wall thickness of 1.25 mm, with increasing diameters.



Sensitivity – Acquisition





- **Slide the next larger sleeve over existing aluminum sleeve(s)**
- https://www.youtube.com/watch?v=vqs-XnckwaI&feature=youtu.be

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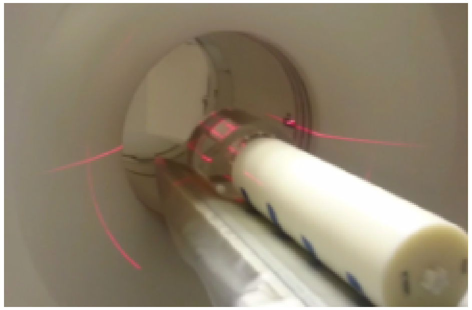
Tutorial videos for Quality Control tests on PET/CT scanners

The IAEA published in 2009 a technical reference book that provides guidance on acceptance testing of PET and PET/CT scanners, including guidelines for routine quality control of the equipment. The PET/CT Quality Control tests described in this publication adhere closely to the NEMA standard. As a supplementary training tool, 8 tutorial videos were produced, demonstrating, in practice, the procedures to perform the tests described in the IAEA Human Health Series No. 1 on Quality Assurance for PET and PET/CT Systems.

1. Daily PET/CT QC test
2. Radioactivity concentration calibration
3. Spatial resolution
4. Sensitivity
5. Scatter fraction, count losses and randoms measurements
6. Image quality
7. Accuracy of corrections for count losses and randoms
8. Accuracy of PET/CT image registration



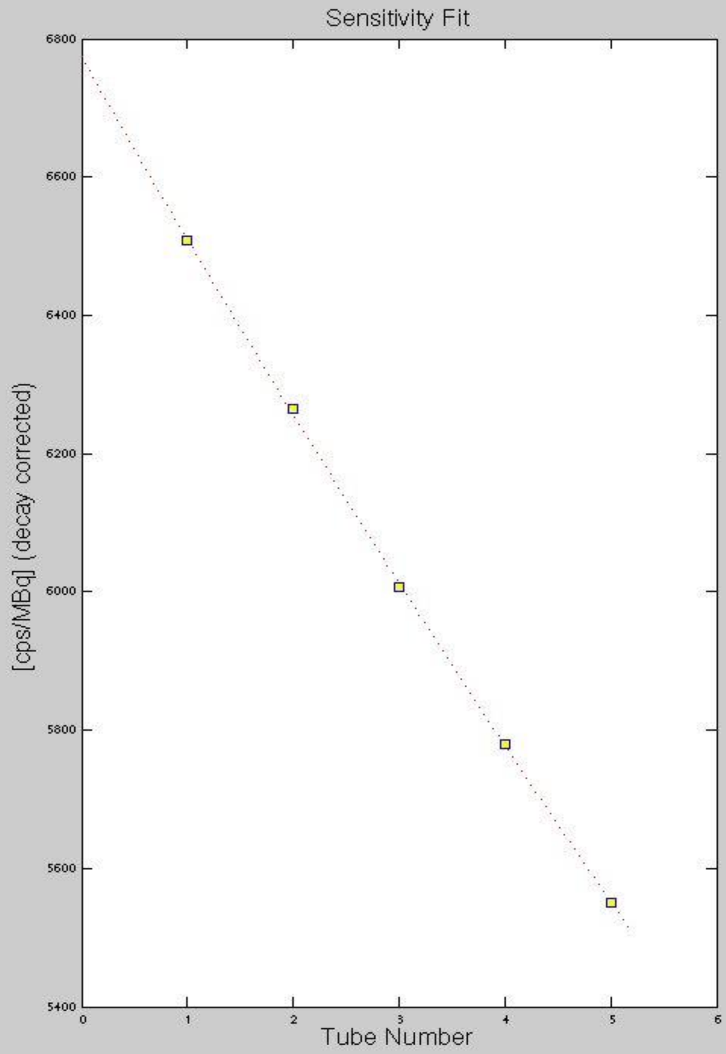
Additional information on PET/CT Quality Control tests can be found in the IAEA Human Health Series No. 27 PET/CT Atlas on Quality Control and Image Artefacts and the IAEA Nuclear Medicine Physics Handbook.

Acknowledgement

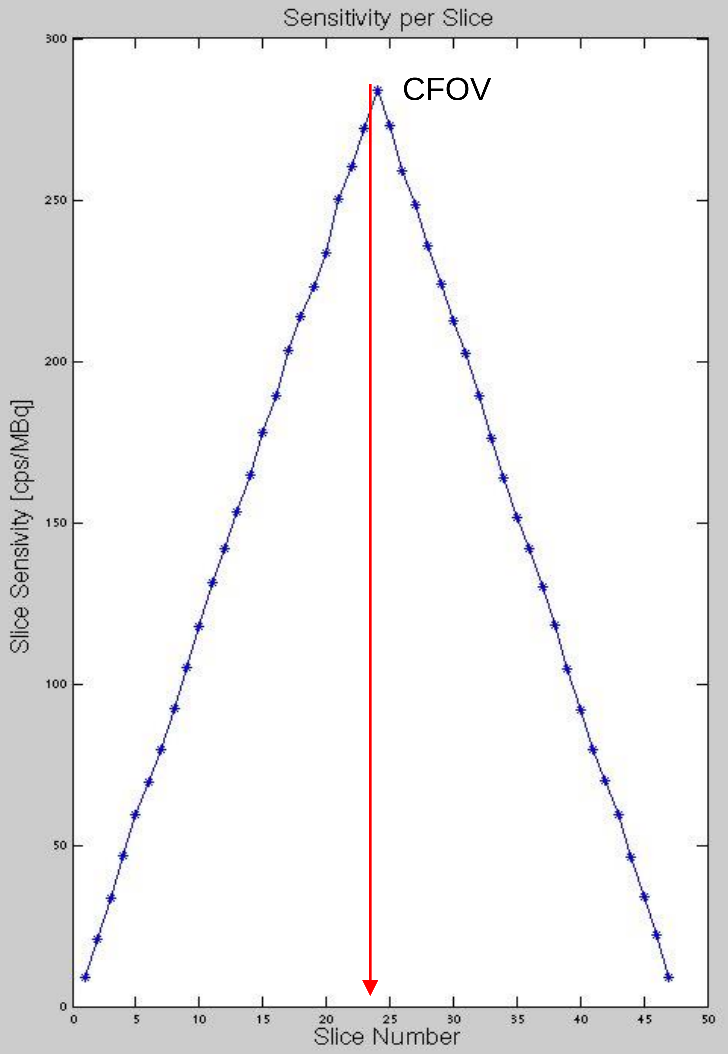
The production of the tutorial videos for Quality Control tests on PET/CT scanners was supported by the Peaceful Uses Initiative (PUI) project of the United States of America.

https://humanhealth.iaea.org/HHW/MedicalPhysics/e-learning/QC_PETCT/index.html

Scan Type	***Measured value (cps/kBq)***	***Lower Limit (cps/kBq)***
Average 0,10cm	6.775	6.3



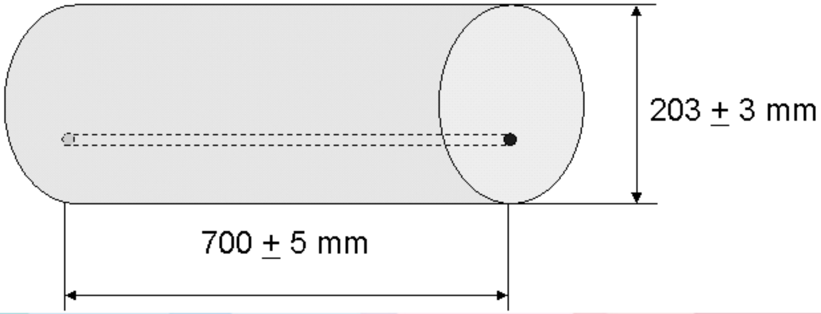
Sensitivity: 6.775 [cps/kBq]
Attenuation: 1.992e-02 [1/mm]
Half Life: 6586.2002 [s]
Fit Type: 5 Point



Study:
Series: frame 1
Acquired: 27-Dec-2010 12:20:56
Printed: 27-Dec-2010 12:22:26

4. Scatter Fraction, Count Losses, and Randoms Test

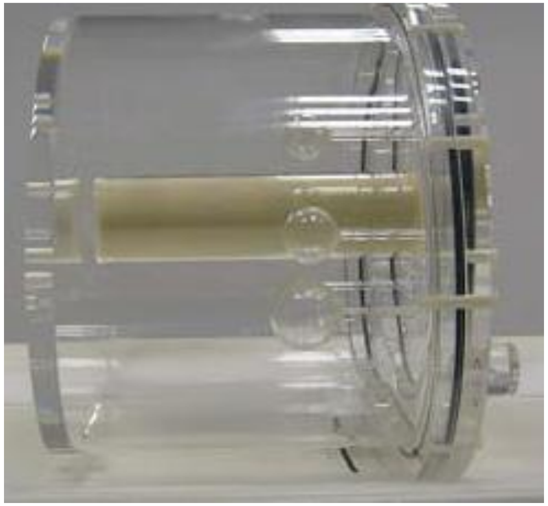
- Scattering, count losses and randoms affect both image quality and quantitation accuracy.
- Scattering and randoms both introduce invalid events.
- The scatter fraction is defined as the ratio of scatter coincidences to the sum of scattered and true coincidences *keeping random event coincidences negligible (i.e. at low count rates).*
- The noise equivalent count (NEC) rate is used to express the tomograph count rate performance as a function of the radioactivity concentration.

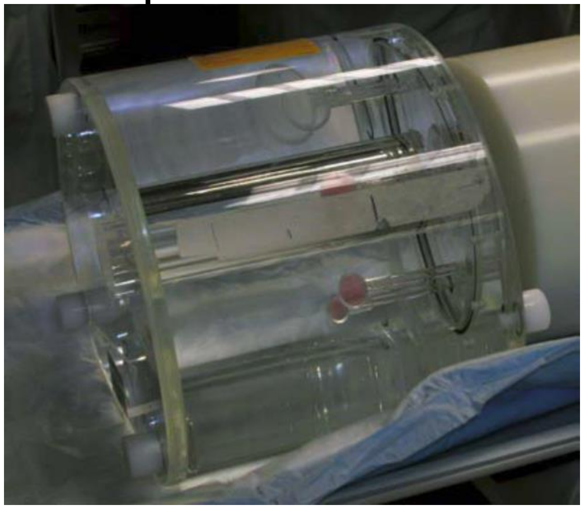


NEMA Scatter Phantom

5. Image Quality

- The image quality test simulates a PET-CT whole body clinical use,
- A NEMA IEC Body phantom models a large body section.
- Prepared with 4 hot and 2 cold spherical lesions, a background activity (~50MBq) and a lung material insert cantered,
  - Additional activity is placed outside the scan FOV, to represent scatter radiation.
- The setup is scanned to supply a test image with known activity contrasts.
- Image quality is reported in terms of image contrast and signal-noise ratios for the hot and cold spheres.





Phantom (NEMA IEC Body Phantom; Data Spectrum Corp.) with multiple fillable spheres and cylindric insert that can be filled with polystyrene to provide minimally attenuating material, simulating lung in otherwise uniform water-filled volume.

NEMA Image Quality (IQ) phantom with hot and cold spheres and a lung insert

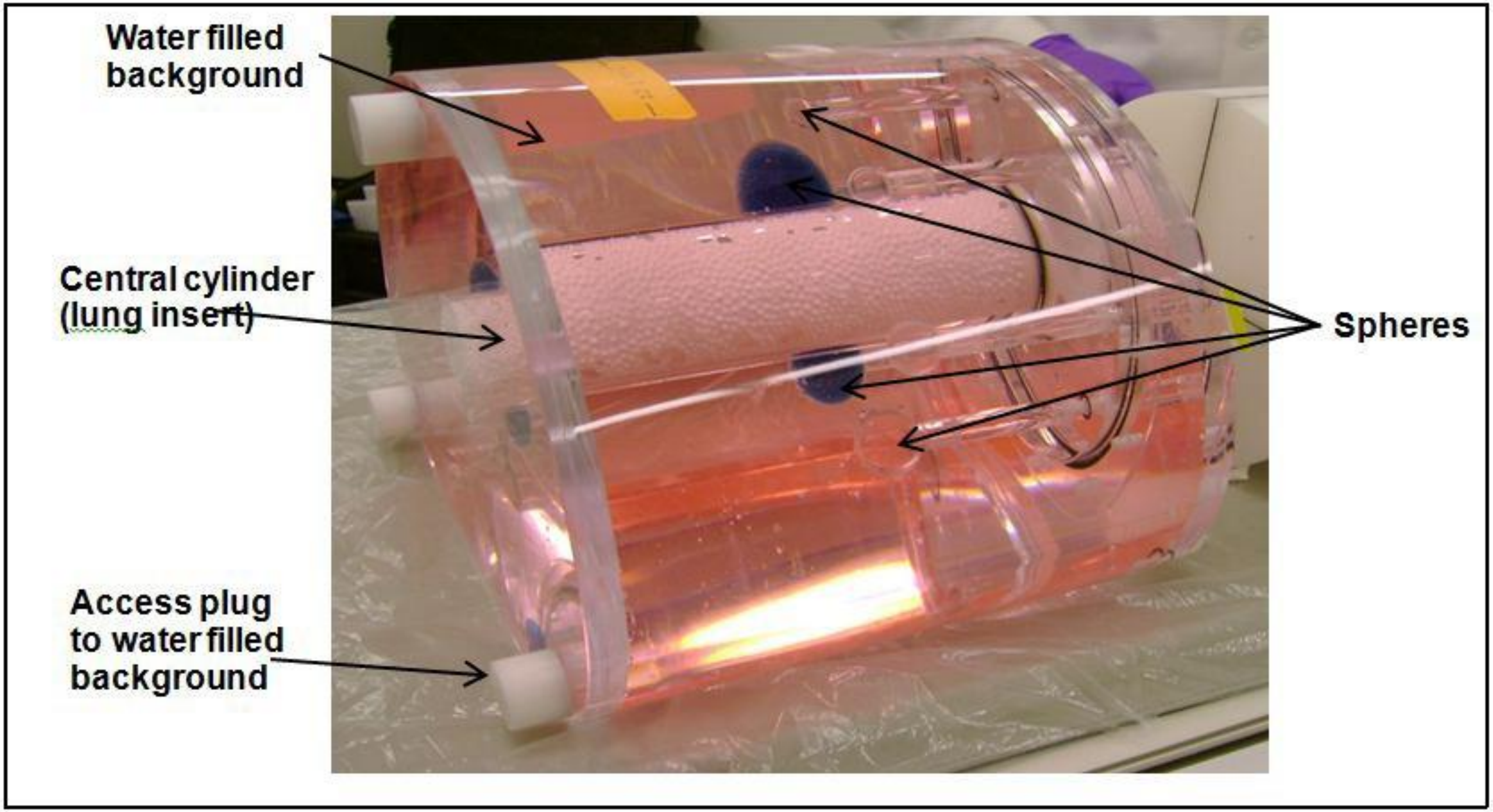
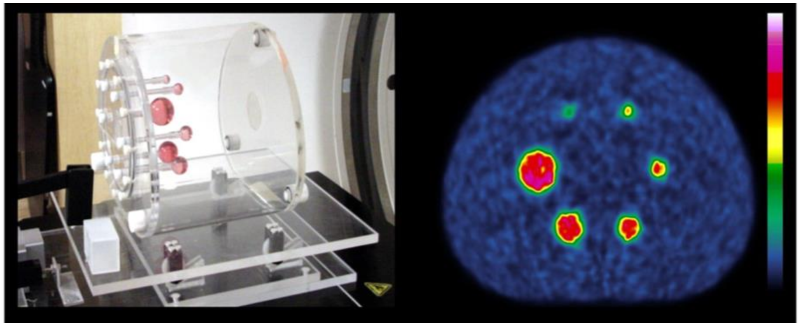


Image quality and recovery coefficients (IQRC)

- SUV quantification varies between centres as a result of differences in the reconstruction and data analysis methodology especially for smaller (< 5cm tumours).
- Significant to determine the accuracy of the SUV using a standardized ‘anthropomorphic’ phantom containing spheres of varying sizes,
- The aim of IQRC quality control procedure is:
  - To determine the correctness of a known quantification,
  - To measure ‘activity concentration recovery coefficients’ as a function of sphere sizes.

Area measured	Activity concentration	
	4 : 1 (kBq/mL)	8 : 1 (kBq/mL)
Background	4.78	5.66
Hot spheres	19.05	46.20
Assayed hot-to-background ratio	3.99	8.17

Activity Concentrations for Image Quality Measurement



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J Nucl Med 2004; 45:813–821 NEMA NU 2-2001 FOR LSO-BASED PET/CT; Erdi et al.

Physica Medica (2011) xx, 1–11

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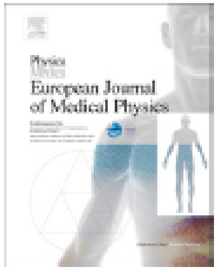

ORIGINAL PAPER

Five-year experience of quality control for a 3D LSO-based whole-body PET scanner: Results and considerations

R. Matheoud [a], A.L. Goertzen [b], L. Vigna [a], J. Ducharme [c], G. Sacchetti [d], M. Brambilla [a,*]

Table 2 Quality control tests for Winnipeg system.

Type of control	Frequency	Test object	Reference
Daily QC	Daily	^{68}Ge cylindrical phantom	Manufacturer manual
Cross-Calibration Verification	Quarterly	Fillable cylinder phantom	Manufacturer manual
Sensitivity	Annual	NEMA sensitivity phantom	NEMA01
Image quality	Annual	IEC phantom + scatter phantom	NEMA01
Resolution	Annual	Capillary sources	NEMA01

Quality Control Tests And Optimum Testing Frequency

Test	Testing frequency	Performed by
PET Daily QA parameters Coincidence Rate, Singles, Block Busy, Timing Change and Gain Change as stipulated in the User manual of PET/CT – *vendor specified overall assessment of PET.*	Daily	Radiographer / NM technologist
Well Counter Calibration	Quarterly	Medical Physicist
Spatial resolution	Annually	Medical Physicist
Image Quality	Annually	Medical Physicist
Sensitivity	Annually	Medical Physicist
Scatter correction	Annually	Medical Physicist

Summary

- State of the art hybrid imaging systems require periodic calibrations & QC tests.
- QA programs helps monitor changes in performance before the need becomes critical and requires cancellation of patient studies.
- A comprehensive QA programme should maximize the quality of diagnostic information available to the physician
- Medical Physicist need to work with NM technologist to ensure hybrid scanners are working optimally.

References

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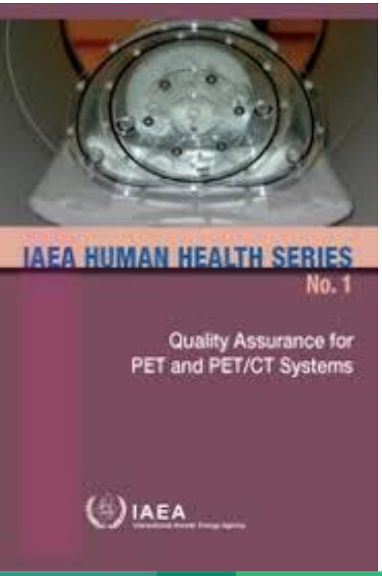

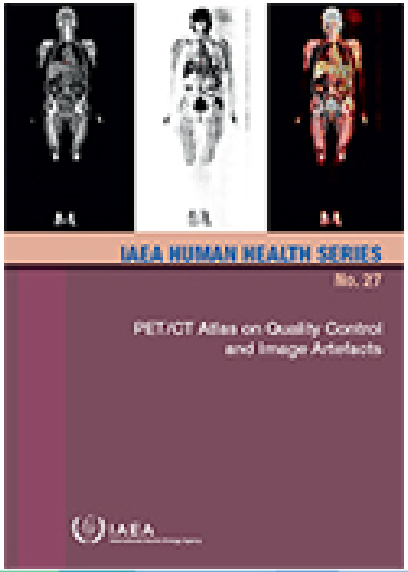

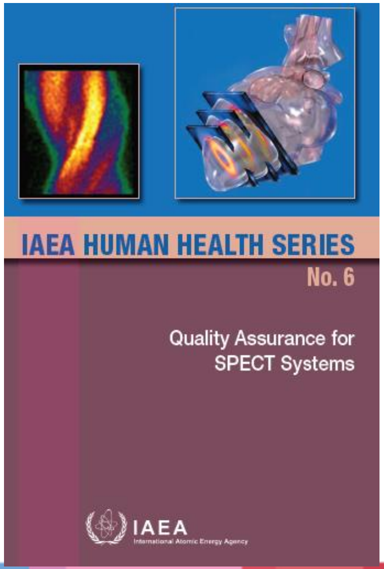

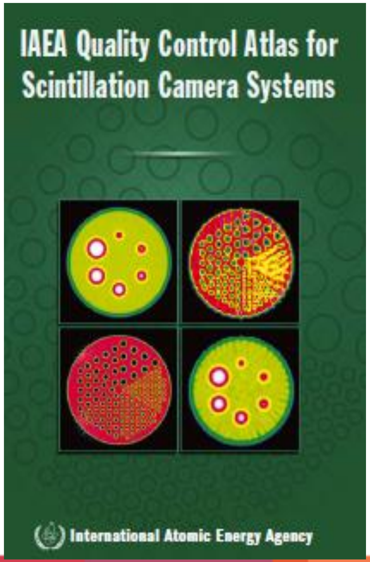

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