NUCLEAR MEDICINE - TESTING OF GAMMA CAMERA, SPECT AND SPECT/CT SYSTEMS IN A CLINICAL ENVIRONMENT

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OBJECTIVES

1. Become familiar with routine performance tests (daily, monthly, annual, …) performed on gamma cameras, SPECT, and SPECT/CT systems.
2. Become knowledgeable of procedures and additional tests for trouble shooting problems.
3. Develop a quality assurance program for the nuclear medicine department that involves both the technologist and physicist.

RELEVANT DOCUMENTS

- NEMA Standards:
  - NU 1-2007: Performance Measurements of Gamma Cameras
- International Standards:
  - IEC 60789: Characteristics and Test Conditions of Radionuclide Imaging Devices Anger Type Gamma Cameras, 2005
  - IEC 61675-2: Characteristics and Test Conditions – Part 2: Single Photon Computed Tomographs (SPECT), 2005
- AAPM Task Group Reports
  - TG 9: Computer Aided Scintillation Camera Acceptance Testing, 1981
  - TG 22: Rotating Scintillation Camera SPECT Acceptance Testing and Quality Control, 1987
  - TG 177: Currently active planning to release document for review in July, 2012.

OUTLINE

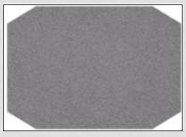
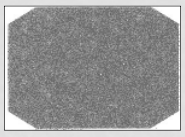
1. Tests for planar Gamma Camera imaging including uniformity, resolution, linearity, and sensitivity
2. Tests for SPECT systems with SPECT phantom
3. Tests for SPECT/CT systems with SPECT phantom and fiducial volume registration sources.

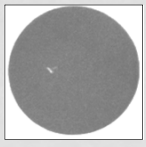
PLANAR IMAGING - UNIFORMITY

Measure by flooding the detector with uniform gamma irradiation

- **A DAILY REQUIREMENT** – extrinsic acquisition with collimator and Co-57 sheet source of 3-5 million counts.
- **Intrinsic Flood Measurements** of Tc-99m, TI-201, Ga-67 or In-111 of 10-15 million counts at least annually and at acceptance testing.
- **Extrinsic Flood Measurements** with Co-57 of all collimators in service at least annually.
- **Quantitate Flood Images** whenever possible to set acceptable thresholds and track changes. Typical IU thresholds are 5-6% or extrinsic floods and 3-4% for intrinsic floods. Uniformity calibration may be needed.

COMMON ARTIFACTS

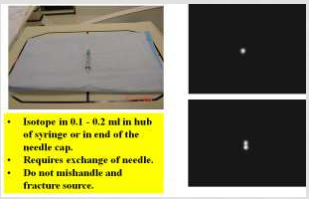



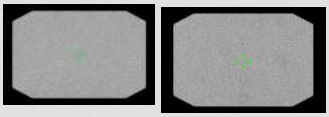



UNIFORMITY – COMMON PITFALLS

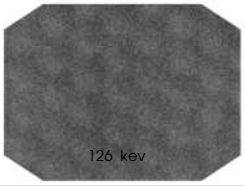
- **Extrinsic** – age of the Co-57 source. New sources may produce excessive high count rate (>40 Kcps) and have high energy contaminants. Old sources go without saying more – too low count rate!
- **Intrinsic** – requires a non-fractured point source (< 0.5 ml) placed at distance of least 4 times diameter of detector, properly centered and of activity to obtain 20-50 Kcps.
- **Uniformity Calibration** – not following the manufacturer's calibration procedure. Read and follow the manual! If unsure, request field service perform the task.

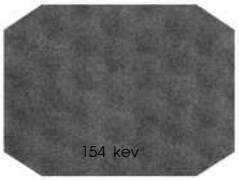
UNIFORMITY CALIBRATION PITFALLS





OFF-PEAK FLOODS





- Look for patterns other than from PMT.
- At edges measly appearance becomes apparent from crystal hydration.
- A single sore-thumb tube may indicate poor tube coupling.

SPATIAL RESOLUTION TESTS

Measure with a Four-Quadrant Bar Phantom

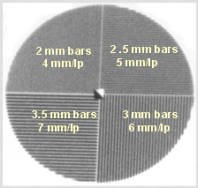
- **Extrinsic Measurement of 3-5 million counts with Co-57 sheet source**
  - Simplest leaving collimator installed.
  - Provides the least information regarding detector resolution.
  - Obtained weekly on any choice of collimator.
- **Intrinsic Measurement of 5-10 million counts with collimator removed and point source**
  - Collimator must be removed with careful placement of bar phantom on the crystal!
  - Provides the best information regarding detector resolution.
  - Obtained at least annually for all isotopes used.
- **Acceptance Testing**
  - Intrinsic using a point source and a NEMA slit phantom obtained from the manufacturer or purchased separately.
  - Extrinsic using a line source with Tc-99m and all low energy collimators.

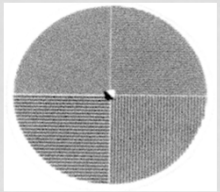
SPATIAL LINEARITY TESTS

Measure with a Four-Quadrant Bar Phantom

- **Use the same images as obtained for spatial resolution** whether extrinsic, intrinsic, or slit-phantom at acceptance testing.
- **Visually inspect images for spatial distortion**. Score as follows:
  - None
  - Barely visible with non-linearity < 1mm and not clinically significant
  - Visible with non-linearity > 1 mm and may be clinically significant

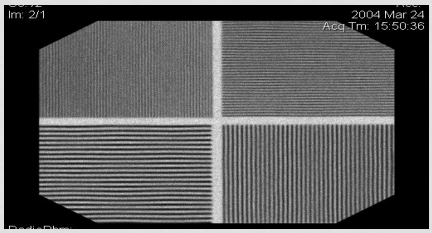
INTRINSIC VS. EXTRINSIC BARS





- Chose bar sizes to match expected spatial resolution.
- Best to purchase from the manufacturer
- Highest detail from intrinsic image acquisition that has more counts and no loss of resolution from collimator
- There may be 1-2 cm gap between bar phantom and detector.

SPATIAL LINEARITY



- Note – wavy bars wrapped around PMT's.
- Distortion is significant > 1 mm

PLANAR SENSITIVITY

Measure Extrinsic Detector Sensitivity as CPM/μCi

- **Measure with Tc-99m of 0.5-1.0 mCi** contained in filled 3cc syringe, 3 cc in a culture flask or petrie dish of minimal attenuation. Carefully assay source making background and residual corrections.
- **Suspend source ~ 10 cm above the collimator** to avoid near-field of affects.
- **Use total field-of-view counts** that are background and decay corrected.
- **The sensitivity variation should be < 5%** between detectors.
- **Performed at annually and at acceptance testing**.

COUNT RATE PERFORMANCE

- **Measurement of the intrinsic maximum achievable count rate ONLY!**
- **Acceptance testing and annually.**
- **NEMA decay source method** useful only when quantitative high-count rate flow studies may be performed. Only at acceptance testing.

ENERGY RESOLUTION

- Consideration for baseline measurement of energy resolution at acceptance testing ONLY!
- Performed intrinsically with Tc-99m only using a displayed energy spectrum to calculate FWHM.
- Repeat measurement to help explain:
  - Loss of image of image contrast in clinical studies
  - Loss of planar sensitivity
  - Loss of spatial resolution
  - Problems with uniformity between isotopes

MULTIPLE WINDOW REGISTRATION

- Consideration for baseline measurement at acceptance testing ONLY!
- Use the NEMA prescribed method with Ga-67. Use multiple source to reduce the measurement time.
- OR acquire an intrinsic four-quadrant bar phantom of Ga-67 using all three energy peaks, and then imaged separately.

ROUTINE QUALITY CONTROL PRACTICES

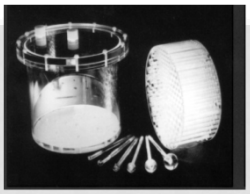
- Peak daily for ^{57}Co, ^{99m}Tc, & other isotopes to be used that day (Tech.)
- Uniformity - Flood images of 5-15 million counts each day of use, before imaging begins (Tech.)
  - Extrinsic flood image is preferred and tests heavily used collimators.
  - Intrinsic flood image to test detector only, especially at the periphery of the FOV. Acquired at least one per week.
- Resolution - Intrinsic (preferred) or extrinsic images of 5-10 million counts of four-quadrant bar phantom once per week (Tech.)
- Linearity - Intrinsic (preferred) or extrinsic images of 5-10 million counts with PLES or four-quadrant bar phantom once per week Tech.)
- Uniformity Correction Matrix – Flood images of 100 Mcts or more once per month for each isotope used (Physicist or Tech.).

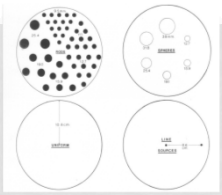
SPECT TESTS

Test of Image Quality with a SPECT Phantom

- **The ACR SPECT phantom is the phantom of choice** following the ACR acquisition and reconstruction protocol.
- **Performed at least semi-annual, at annual survey, and at acceptance testing.**
- **Use a scoring scheme** similar to ACR accreditation criteria
- **Evaluate COR and multiple detector volume registration**, by reviewing sinogram and linogram images of projection images. Manufacturer COR tests done by technologist.
- Perform NEMA tomographic resolution and head alignment by the line source method at acceptance testing.
- Use multiple detector sensitivity measurements obtained during planar testing.
- Test of rotational energy stability to be optional to explain loss of performance.

SPECT PHANTOM IMAGING





Jaszczak Deluxe:

- **Cold Rods – 12.7, 11.1, 9.5, 7.9, 6.4, 4.8 mm**
- **Cold Spheres – 31.8, 25.4, 19.1, 15.9, 12.7, 9.5 mm**

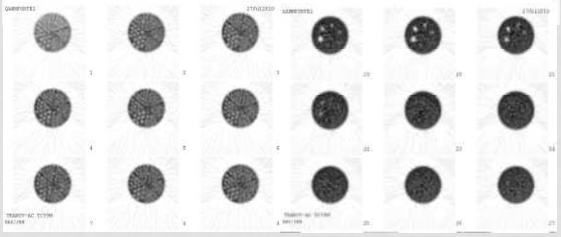
ACR SPECT PHANTOM PROTOCOL

- Acquire 120/128 images in 128 matrix over 360 arc with zoom to achieve 3 mm pixels.
- Acquire studies with 24 million total counts (new 32 million) with high resolution clinical collimator.
- Reconstruct by FBP with Butterworth filter optimized for phantom. Adjust cutoff to optimize sphere contrast and best spatial resolution in the rod section.
- Apply Chang attenuation correction with 0.12/cm for Tc-99m and 0.09 for Tl-201 or Ga-67.
- Save images at 6 mm/slice or 9 mm/sice for Tl-201 or Ga-67.
- Evaluate images for uniformity, contrast and spatial resolution.

ACR SPECIFICATIONS FOR SPECT IMAGING – THREE OR MORE ISOTOPES

- Submit complete SPECT phantom study images for two isotopes as before (Tc-99m, and Tl-201 or Ga-67/In-111)
- For each additional isotope submit for each detector head
  - planar uniformity images
  - Planar spatial resolution images with a four-quadrant bar phantom

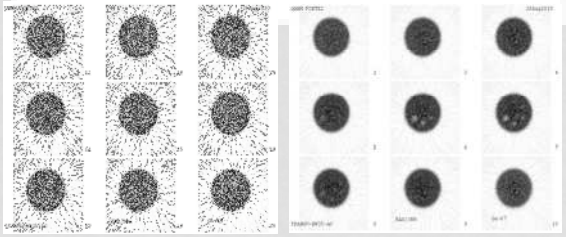
TC99M SLICE FORMATTING – 6 MM/SLICE



ACR Scoring:

- **Uniformity: Satisfactory**
- **Rods: 9.5 mm smallest observed (11.1 mm satisfactory)**
- **Contrast: 15.9 mm smallest observed (19.1 mm satisfactory**

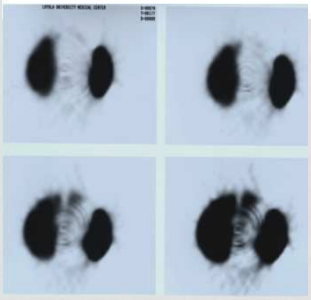
GA67 SLICE FORMATTING – 9 MM/SLICE



ACR Scoring:

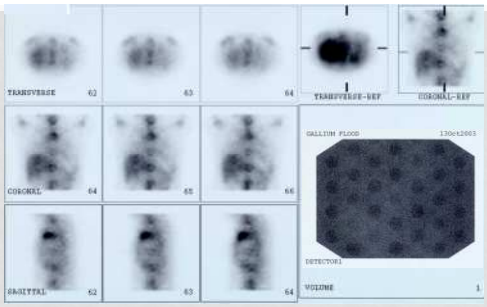
- **Uniformity: Satisfactory?**
- **Rods: 12.7 mm smallest observed (12.7 mm satisfactory)**
- **Contrast: 19.1 mm smallest observed (19.1 mm satisfactory)**

BULLSEYE/RING ARTIFACTS



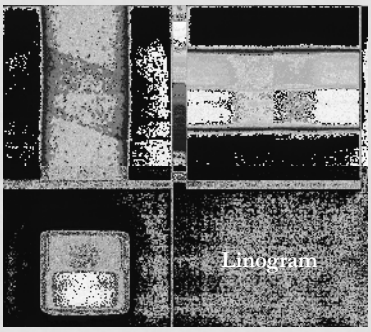
- Concentric rings of alternating high and low count densities appear in the transaxial images.
- May be caused by one or both camera heads.
- A new uniformity calibration is required.

SERIAL RING ARTIFACTS



Uniformity calibration may be necessary for other isotopes

NON-ALIGNED DETECTORS IN Y



SPECT QUALITY CONTROL PRACTICES

- Perform Gamma QC for each head (technologist)
- Uniformity Correction Matrix – Flood images of 100 Mcts or more once per month for each isotope used and recommended by the vendor (Physicist or Tech.).
- COR validation monthly (technologist)
- COR calibration as needed (Physicist)
- SPECT phantom once every six months (technologist)

SPECT/CT

Test of Image Quality with a SPECT Phantom with CT attenuation correction

- Performed semi-annual and during acceptance testing.
- The same acquisition protocol as for SPECT only, but apply CT attenuation correction. Evaluate image quality as before.
- Added to the SPECT phantom at one end are Co-57 button sources to test for SPECT and CT volume alignment.
- Refer to diagnostic CT test procedures to evaluate CT number accuracy and linearity
- Refer to diagnostic CT test procedures to measure CTDI.

ACR SPECT PHANTOM WITH CO BUTTON SOURCES

CONCLUSIONS

- Practically, performance tests of the gamma camera and SPECT systems must be limited so that they can be completed timely.
  - Acceptance tests completed in one full day
  - Annual reviews completed in ½ day
- It is necessary to involve the technologist in the testing. Trained technologists may perform some of annual tests. Must be review by physicist on site.

NEWLY PURCHASED CO-57 SHEET SOURCES NEED TO BE EVALUATED PRIOR TO PLACING INTO ROUTINE USE BECAUSE:

0% 1. they contain short-lived radioactive contaminants that have high energy gamma emissions.
0% 2. leakage of the radioactive Co-57 may be present.
0% 3. the dead-time count losses are not yet optimal.
0% 4. the dose rate from these sources are too high for personnel to handle.
5. the NRC mandates an evaluation that includes x-raying the source.

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THE RECOMMENDED FREQUENCY FOR MEASURING ENERGY RESOLUTION OF A GAMMA CAMERA DETECTOR IS

0% 1. daily.
0% 2. monthly.
0% 3. annually.
0% 4. at acceptance testing.
0% 5. none.

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THE SINOGRAM OF SPECT PHANTOM PROJECTION IMAGES IS USED TO

0% 1. correct for attenuation.
0% 2. record phantom and imaging table motions.
0% 3. observe the accuracy of the center-of-rotation calibration.
0% 4. reconstruct coronal slices.
0% 5. provide uniformity correction.

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A RING ARTIFACT OBSERVED IN RECONSTRUCTED SPECT IMAGES ARISES FROM

0% 1. a low count rate during acquisition.
0% 2. a non-uniformity in a gamma camera detector.
0% 3. insufficient mixing of the isotope inside the phantom.
0% 4. center-of-rotation calibration error.
0% 5. differential attenuation in the slices.

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CO-57 BUTTON SOURCES INCLUDED IN SPECT/CT PHANTOM ACQUISITIONS IN ORDER TO

0% 1. measure the quantitative accuracy of reconstructed images.
0% 2. measure the attenuation correction accuracy by CT.
0% 3. localize the CT scan range.
0% 4. measure the accuracy of registration between the SPECT and CT volumes.
5. measure the energy resolution of the gamma camera detector.

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