QC Protocols
Gamma Camera &
SPECT Systems

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Maywood, IL
1. **Gamma Camera Imaging**
   a. Brief overview of Gamma Camera Operation
   b. Brief overview of Camera Calibrations

2. **SPECT Phantom Imaging**
   a. Acquisition & Reconstruction
   b. Evaluation
   c. ACR & ICANL Accreditation Requirements

3. **Final Recommendations**
Gamma Camera Imaging of Radioactive Sources in Patients

Three major Components:

1. **Collimator** – channels the $\gamma$-rays and localizes the source in the patient
2. **NaI(Tl) Crystal** (single or multi-crystal) over width of patient stops the $\gamma$-rays.
3. **Array of PMT’s** – localizes $\gamma$-ray interaction in crystal
Localize $\gamma$-ray Hit in Crystal by Position Weighed Sum of PMT Pulses

$X = \frac{p_1 r_1 + p_2 r_2 + \ldots + p_7 r_7 + p_8 r_8}{p_1 + p_2 + \ldots + p_7 + p_8}$

- $p_i$ - PMT$_i$ pulse
- $r_i$ - positional weight
Components of Gamma Camera Spatial Resolution

- **Intrinsic Resolution**: Ability of the NaI(Tl) crystal and PMT combination to localize \(\gamma\)-ray interactions in the crystal.

- **Collimator Resolution**: Ability of the collimator to localize the \(\gamma\)-ray source in the patient.

- **Extrinsic Resolution**: Overall resolution combining collimator and intrinsic factors. Total resolution is quadratic sum of the two components.
Collimator Resolution

- **d** – hole diameter
- **l** – hole length
- **t** – septal thickness of lead
- **f** – collimator to source distance
- **c** – collimator to crystal center distance

Collimator Ratio – Resolving power of collimator

\[
\text{FWHM}_C \sim \left[ \frac{d}{l} \right] (l+f+c)
\]

Source to Crystal Distance
### Available Collimators

<table>
<thead>
<tr>
<th>Collimator Type</th>
<th>Hole Diameter (mm)</th>
<th>Hole Length (mm)</th>
<th>FWHM at 0 cm (mm)**</th>
<th>FWHM at 10 cm (mm)**</th>
<th>FWHM at 20 cm (mm)**</th>
<th>Sensitivity (CPM/μCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Energy All Purpose (LEAP or GAP)</td>
<td>1.43</td>
<td>23.6</td>
<td>4.4</td>
<td>9.1</td>
<td>15.3</td>
<td>360 (99mTc)</td>
</tr>
<tr>
<td>Low Energy High Resolution</td>
<td>1.11</td>
<td>23.6</td>
<td>4.2</td>
<td>7.5</td>
<td>12.3</td>
<td>230 (99mTc)</td>
</tr>
<tr>
<td>Low Energy Ultra-High Resolution</td>
<td>1.08</td>
<td>35.6</td>
<td>4.2</td>
<td>5.9</td>
<td>8.6</td>
<td>100 (99mTc)</td>
</tr>
<tr>
<td>Medium Energy</td>
<td>3.02</td>
<td>40.6</td>
<td>5.6</td>
<td>12.1</td>
<td>19.7</td>
<td>288 (67Ga)</td>
</tr>
<tr>
<td>High Energy</td>
<td>4.32</td>
<td>62.8</td>
<td>6.6</td>
<td>13.8</td>
<td>22.0</td>
<td>176 (131I)</td>
</tr>
<tr>
<td>Ultra-High Energy</td>
<td>3.4</td>
<td>75.0</td>
<td>6.0</td>
<td>10.4</td>
<td>~20.0</td>
<td>60 (18F)</td>
</tr>
</tbody>
</table>

** Siemens Orbiter Gamma Camera System with intrinsic resolution of 3.9 mm FWHM
Gamma Camera Quality Control

- Basic Planar QC Procedures
Intrinsic Spatial Resolution Measurement

4-Quadrant bar phantom replaces the collimator – The image is the shadow of the lead bars on the crystal.

4-Quad Bar Phantom

$^{99m}\text{Tc}$ Point Source (400 – 800 uCi)

Gamma Camera
Extrinsic Spatial Resolution Measurement

Planar Flood Source
(10 mCi $^{99m}$Tc or $^{57}$Co)
4-Quadrant Bar Phantom

Gamma Camera
Collimator
Planar Sheet Sources

$^{57}$Co Shhet Source – $T_{1/2}$ 270 days; 122 keV $\gamma$; 10-15 mCi at time of purchase.

$^{99m}$Tc Sheet Source (water filled) – $T_{1/2}$ 6 hrs.; 140 keV $\gamma$; 10-15 mCi at time of filling.
Measure Spatial Linearity with PLES Phantom

Images of PLES (parallel line equal spacing) phantom with $^{99m}$Tc source

Deviation from straight line of less than 1.0 mm for UFOV.
Measure Linearity with 4-Quadrant Bar Phantom

Note wavey/curve-linear appearance of lead bars throughout the image.
Measuring Intrinsic Uniformity

Gamma Camera

Point Source 400-800 uCi

5 UFOV Diameter distance

No Collimator

5-15 Million Counts 1-3 min.

Edge Packing (higher sensitivity) at edge

Flood Image

Statistical Variation:
- 3 Mcts. ~ 1600 ct/cm² (± 2.5%)
- 15 Mcts. ~ 4800 ct/cm² (± 1.4%)
Measuring Extrinsic Uniformity

Planar Sheet Source
10-15 mCi of $^{57}\text{Co}$ or $^{99\text{mTc}}$

5-15 Million Counts
3-15 min.

Edge Packing shielded by collimator ring.
Gamma Camera Calibrations

1. PMT Gains
2. Energy
3. Linearity
4. Uniformity
PMT & Energy Calibrations

First
PMT Gain
By FSE

Second
Energy Correction
By FSE
Linearity & Uniformity Calibrations

Third Linearity Correction By FSE

Fourth Uniformity Correction By Tech.
Quality Control Practices

1. **Photopeak** – Daily ensure isotope energy level centered over photopeak.

2. **Uniformity** - Flood images of 5-15 million counts each day of use, before imaging begins.
   a) Extrinsic flood image is preferred and tests heavily used collimators.
   b) Intrinsic flood image to test detector only, especially at the periphery of the FOV. Acquired at least one per week.

3. **Resolution** - Intrinsic (preferred) or extrinsic images of 5-10 million counts of four-quadrant bar phantom once per week.

4. **Linearity** - Intrinsic (preferred) or extrinsic images of 5-10 million counts with PLES or four-quadrant bar phantom once per week.

5. **Uniformity Correction Matrix** – Corrects residual non-uniformities. Flood images of 100 Mcts once per month for each isotope used.
Quantitate Daily Floods

Full Report of Uniformity Analysis
NAME: 3-04-97 ID: INTR FLD DATE:

UFOV

<table>
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<th>Integral Uniformity = 2.87%</th>
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<tr>
<td>Counts Location</td>
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<td>Minimum 7132 (34, 33)</td>
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<td>Maximum 7554 (46, 32)</td>
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Row Differential Uniformity = 1.69%
Column Differential Uniformity = 1.55%

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<td>251 (42, 32)</td>
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CFOV

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Plot IU for UFOV or CFOV daily
Pre-Assigned Action Levels

I. Good – no further evaluation needed
II. Marginal – repeat flood once; if still marginal next day/week contact Physicist or supervisor to determine status; a re-calibration may be necessary.
III. Unacceptable – repeat flood once; if still unacceptable contact Physicist or supervisor to determine status; a re-calibration may be necessary

<table>
<thead>
<tr>
<th>Gamma Camera</th>
<th>Intrinsic Uniformity – IU in UFOV</th>
<th>Extrinsic Uniformity – IU in UFOV</th>
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<tbody>
<tr>
<td>Vertex</td>
<td>I – below 3.5</td>
<td>I – below 5.0</td>
</tr>
<tr>
<td></td>
<td>II – 3.5 – 5.0</td>
<td>II – 5.0 – 6.0</td>
</tr>
<tr>
<td></td>
<td>III – above 5.0</td>
<td>III – above 6.0</td>
</tr>
<tr>
<td>Forte I</td>
<td>I – below 3.5</td>
<td>I – below 5.0</td>
</tr>
<tr>
<td></td>
<td>II – 3.5 – 5.0</td>
<td>II – 5.0 – 6.0</td>
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<td></td>
<td>III – above 5.0</td>
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<tr>
<td>Forte II</td>
<td>I – below 3.5</td>
<td>I – below 5.0</td>
</tr>
<tr>
<td></td>
<td>II – 3.5 – 5.0</td>
<td>II – 5.0 – 6.0</td>
</tr>
<tr>
<td></td>
<td>III – above 5.0</td>
<td>III – above 6.0</td>
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Irregardless of IU, if a single tube is visible in the flood image, contact Physicist or supervisor to determine status.
Intrinsic and/or Extrinsic Floods?

Det 1 – Co-57

Det 2 – Co-57

Det 1 – Tc-99m

Det 2 - Tc-99m
Routine Bar Pattern Images - Why?

90 Deg. Rotation
Intrinsic and/or Extrinsic Bars?

Tc-99m Intrinsic

Co-57 Extrinsic
Intrinsic Bars - Better Assess X/Y Resolution

Tc-99m
Intrinsic Bars - Better Assess Linearity

Note - wavy bars wrapped around PMT’s
Rotating Gamma Camera SPECT
SPECT Acquisition

Whole Body Planar Bone

- 256x1024 image
- 20 min.
- 2.3 million counts

Bone SPECT

- 120 128x128 images
- 3° step & shoot rotation over 360°
- 30 sec/image/head
- 32 min. total acq.
- 60,000 cts/image
Reconstructed Bone SPECT Images

Each line across the image corresponds to one transaxial slice in the tomographic volume.

- 4 mm slice thickness for 128 matrix over 50 cm field-of-view.
FPB vs. Iterative Reconstructions

Iterative - OSEM

FBP
Gamma Camera SPECT QC

- Uniformity Corrections
- COR Corrections
- SPECT Phantom Imaging
Concentric rings of alternating high and low count densities appear in the transaxial images due to insufficient gamma camera uniformity.
Uniformity Correction

Acquire High Count Flood Image

Generate Flood Correction Matrix

30-100 million count flood images, 10 times daily flood requirements
Uniformity Correction is a Calibration

- Uniformity correction applied to all patient images
- Both planar and SPECT imaging
Intrinsic Uniformity Calibration

1. Performed for Tc-99m and/or other isotope used clinically
2. Precise point source
3. Low background and scatter free
4. Correct count rate
5. Correct total counts
6. FOLLOW THE MANUAL
Fractured Point Sources?

- Isotope in 0.1 - 0.2 ml in hub of syringe or in end of the needle cap.
- Requires exchange of needle.
- Do not mishandle and fracture source.
Can this be used?

Acquired at 100 Kcps
Intrinsic Uniformity Correction - May Mask Underlying Problems!

Detector with intrinsic linearity problems
Extrinsic Uniformity Calibration

1. Ideally the best - Corrects for both collimator and intrinsic detector
2. Requires planar flood source
3. Ideally Tc-99m, Co-57 is only a surrogate
4. Required for each collimator
5. FOLLOW THE MANUAL
Extrinsic Uniformity Correction - May Mask Collimator Problems!

Damaged collimator with crushed lead septa
Extrinsic or Intrinsic Correction?

Tc-99m Intrinsic

Co-57 Extrinsic
The center of the gamma camera in all acquired images must be known.
SPECT CO R Acquisition is a Calibration

1. Used to correct patient images
2. Extrinsic calibration for both 180 and 90 degree detector separations
3. Must follow manufacturer recommendations regarding number and placement of sources
4. Sources must have sufficient activity
5. Completed monthly, or per manufacturer specifications
Jaszczak Phantom:
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
1. Determine smallest rod sections visible
2. Compare count rates - for multiple detectors, must be within 5% of one another (remember to decay correct for Tc-99m)
1. Acquire SPECT phantom studies with 2-3 times counts obtained clinically (24 million for ACR).
2. Reconstruct at highest resolution filter. Use FBP for ACR.
• Look for bullseye artifacts. If present, new intrinsic correction flood must be acquired.
• Spatial resolution – number of rod sections observed.
• Contrast – number of spheres observed.
180 Degree Orbit SPECT

SPECT Phantom Acquisitions for dual head SPECT system of fixed heads and 180 degree acquisition only.
Uniformity Problems!
<table>
<thead>
<tr>
<th>Phantom Reconstruction no AC</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
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Phantom Reconstruction & AC

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Note: The images are placeholders and should be replaced with actual images relevant to Phantom Reconstruction & AC.
ACR SPECT Phantom Formatting

Summing of Slices

Uniformity (3 slices)
Resolution (12 slices)
Contrast (2 slices)
Non-Aligned Detectors in X

Sinogram
Non-Aligned Detectors in Y

Linogram
ACR QC Guidelines - Technologist

1. **Intrinsic or System Uniformity** - each day of use

2. **Intrinsic or System Spatial Resolution** - weekly

3. **Center-of-Rotation** or Multiple Detector Registration Calibration/Test for SPECT Systems - monthly

4. **High-Count Floods For Uniformity Correction** for SPECT Systems - frequency as recommended by a qualified medical physicist

5. **Overall System Performance for SPECT Systems** - quarterly

   - SPECT Phantom; Tc-99m must be done at least semiannually;
   - other radionuclides may be tested on alternate quarters.

ACR Nuclear Medicine/ PET Accreditation Program Requirements 3/28/2008
ACR QC Guidelines - Annual Tests

1. Intrinsic Uniformity
2. Intrinsic or System Spatial Resolution
3. System Uniformity - check all collimators
4. Sensitivity - verify that count rate per unit activity is satisfactory
5. Energy Resolution
6. Count Rate Parameters
7. Overall System Performance for SPECT Systems - SPECT Phantom
8. Formatter/Video Display
9. System Interlocks
ICANL QC Guidelines

1. **Energy peaking** - Daily prior to use; documentation not required
2. **Intrinsic or extrinsic uniformity** - Daily prior to use; (approximately 2-5 million counts)
3. **Resolution and linearity** - Weekly bar phantoms
4. **Uniformity calibration** - Monthly or per manufacturer’s recommendations
5. **Center of rotation** (SPECT) - Monthly
6. **Collimator integrity** - Annually
7. **Preventive maintenance** - Every 6 months

The ICANL Standards for Nuclear Cardiology, Nuclear Medicine and PET Accreditation, 2007
Recommended QC Guidelines - Technologist

1. **Energy peaking** - Daily prior to use

2. **Intrinsic or extrinsic uniformity** - Daily prior to use; (4-10 million counts)

3. **Uniformity Calibration** - Monthly, or per manufacturer's recommendations:
   a. Intrinsic - Yes
   b. Extrinsic - only when necessary

4. **Intrinsic uniformity, resolution and linearity QC** - Quarterly

5. **SPECT Center of rotation** - Monthly, or per manufacturer's recommendations

6. **SPECT Phantom** (quarterly)

7. **Preventive maintenance** - semi-annual by FSE
Recommended - SPECT Phantom Imaging

1. Assesses intrinsic and collimator uniformity, altogether. If only Tc-99m intrinsic uniformity correction is applied and not ring artifacts - no collimator flood correction is needed.

2. Assesses sensitivity differences in detectors

3. Assesses adequacy of COR corrections observed in sinogram and linogram

4. Assesses overall SPECT resolution and contrast
Recommended - QC Guidelines Annually

1. Intrinsic uniformity, spatial resolution, & linearity

2. System uniformity - check all collimators

3. Sensitivity - verify that count rate per unit activity per detector is satisfactory

4. Detector energy resolution

5. Count rate parameters

6. Overall SPECT performance - SPECT Phantom and possibly for additional isotope

7. Formatter/Video display & system interlocks