Quality Assurance Testing of Gamma Camera and SPECT Systems

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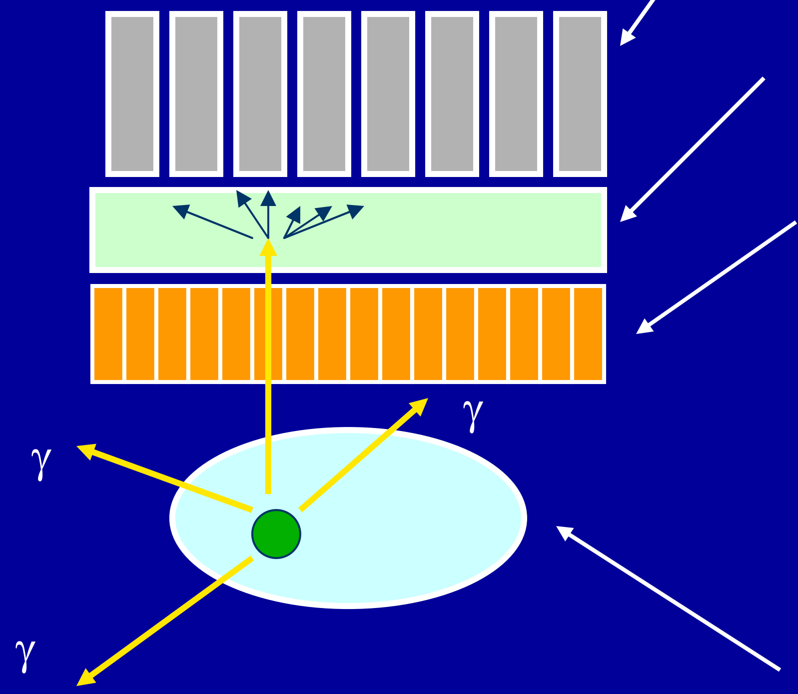
Disclaimers

Gamma camera images and photographs of equipment are not intended to advertise or endorse any particular manufacturer or vendor.

Outline

- Basics of Gamma Camera Operation
- Gamma Camera Calibrations
- Routine QC Tests
- SPECT Phantom Imaging
- Annual Physics Tests

Gamma Camera Operation



Array of Photomultiplier Tubes (PMTs):
Localizes the position where the gamma ray interacts in the crystal

Sodium Iodide crystal:
A gamma ray from the patient interacts and produces visible light photons

Collimator:
Forms a projection image by allowing only gamma rays traveling in certain directions to reach crystal (for a parallel hole collimator, gamma rays approximately perpendicular to crystal pass through).

Gamma rays emitted from patient

Position Determination

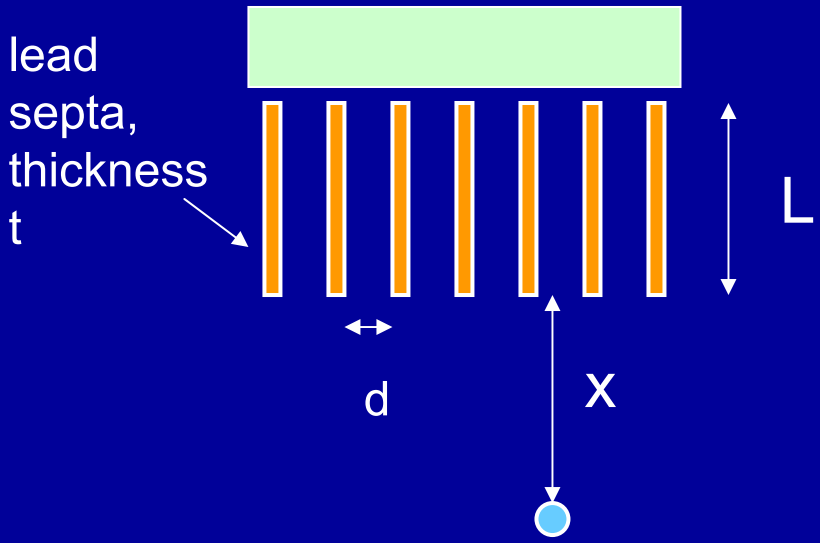
- The point where the gamma ray hits the crystal is determined by a weighted average of the signals from the group of PMTs receiving light from that event.
- The collimator localizes the origin of the gamma ray as somewhere along a specific line through the patient, since only gamma rays traveling parallel to the holes will go through. (Except for occasional septal penetration.)

Spatial Resolution

- Intrinsic resolution (R_{int}) refers to how well the crystal and PMT system localize an interaction in the crystal. Affected by crystal thickness, gamma ray energy, scatter in crystal.
- Collimator resolution (R_{coll}) refers to how well the collimator localizes the gamma ray source in the patient, affected by hole diameter and length, distance from collimator to patient.
- System resolution (R_{sys}) is combination of intrinsic and collimator resolution:

$$R_{sys} = \sqrt{R_{\text{int}}^2 + R_{coll}^2}$$

Collimator Resolution



d = hole diameter
L = hole length
X = distance from collimator
to source

Collimator Resolution

$$R_{coll} \approx \frac{d}{L}(L + x)$$

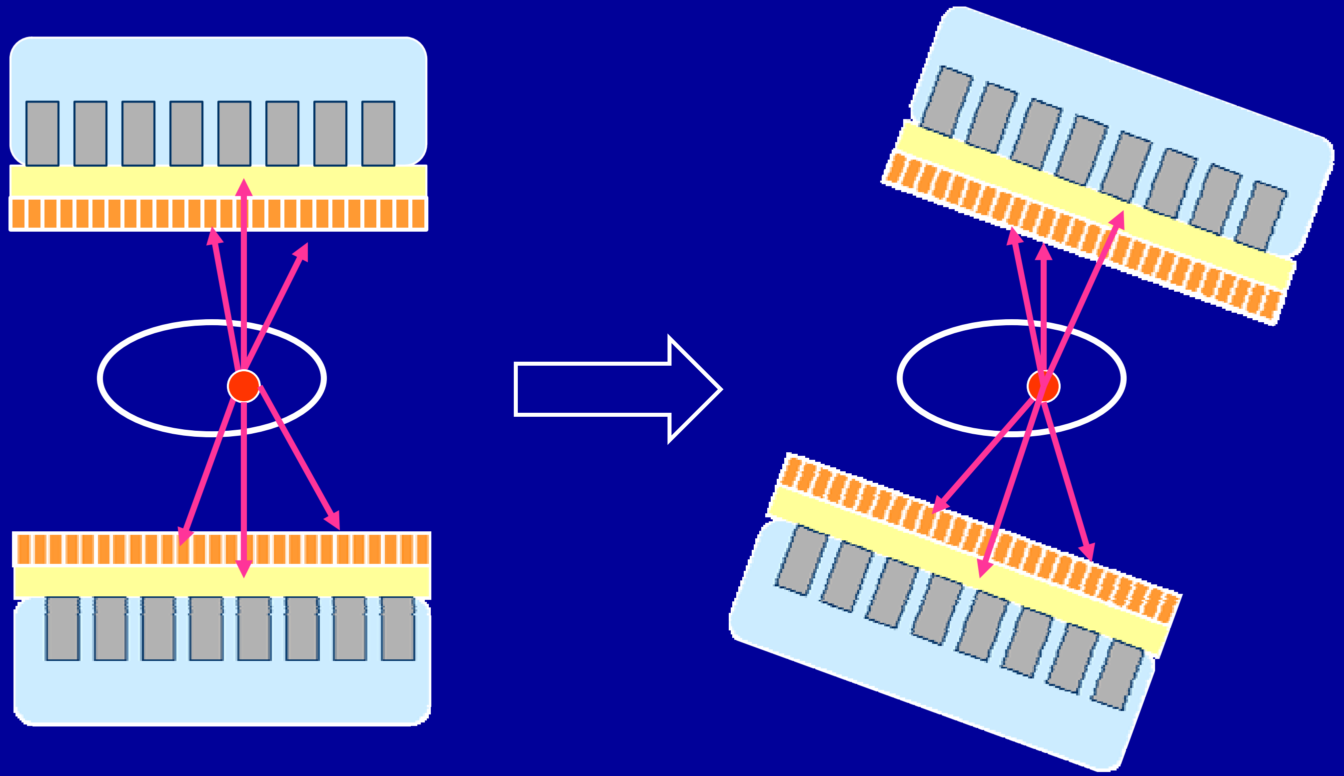
Collimators

- Parallel hole collimators used the most
- Different collimators available for different energy radionuclides – medium energy for ^{111}In and ^{67}Ga, high energy for ^{131}I
- Also have different choices for favoring high resolution vs. high sensitivity

Collimator Specifications

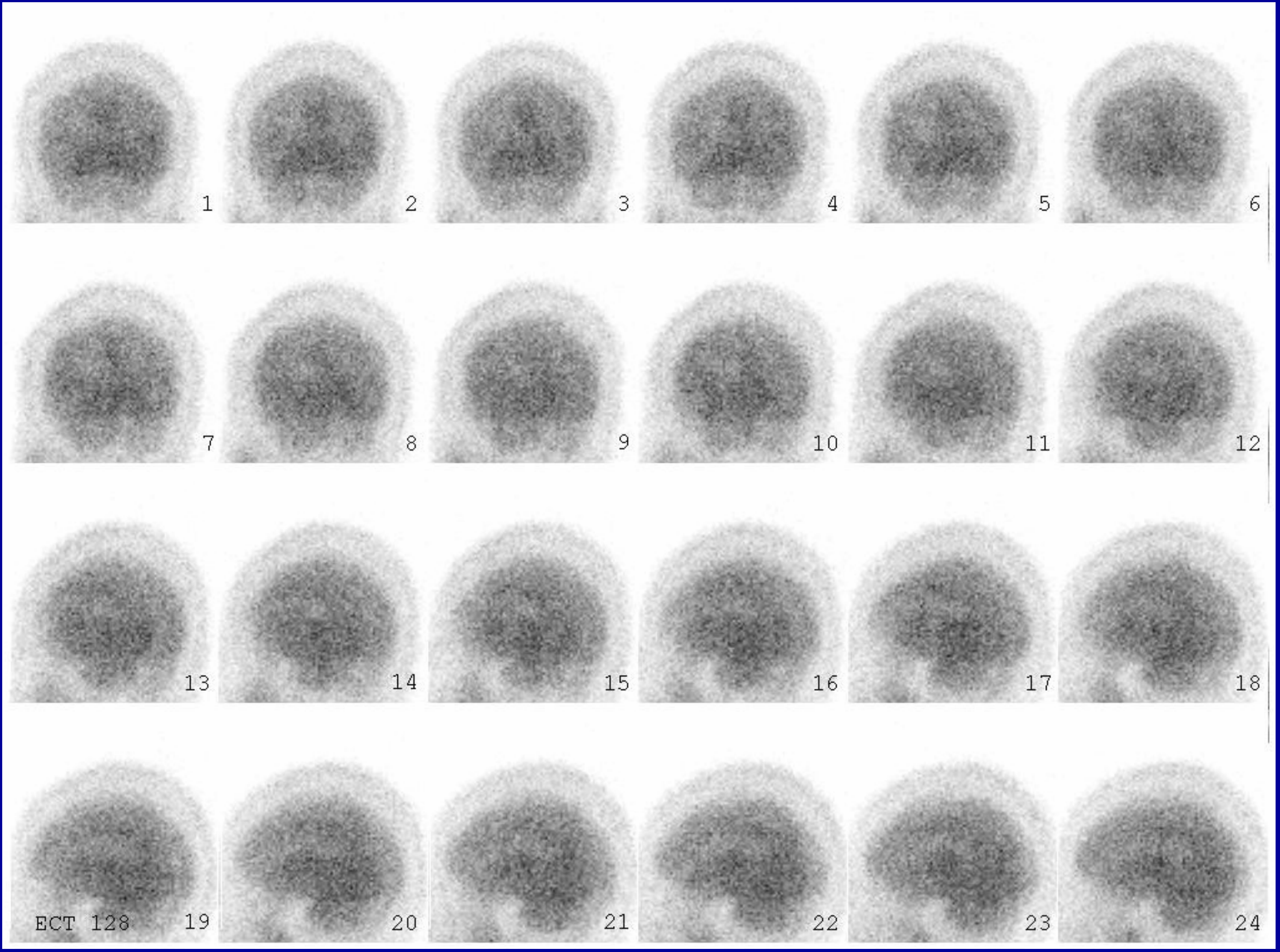
Type	Hole Diameter (mm)	Septal Thickness (mm)	Hole Length (mm)	Coll. Res. At 10 cm (mm)	System Res at 10 cm (mm) 9.5 mm crystal
LEGP	1.40	0.180	24.7	8.0	8.8
LEHR	1.40	0.152	32.8	6.3	7.4
MEGP	2.95	1.143	48.0	10.7	11.3
HEGP	3.81	1.727	60.0	12.0	12.5
HEHR	3.06	1.95	60.0	9.6	10.4

SPECT Operation

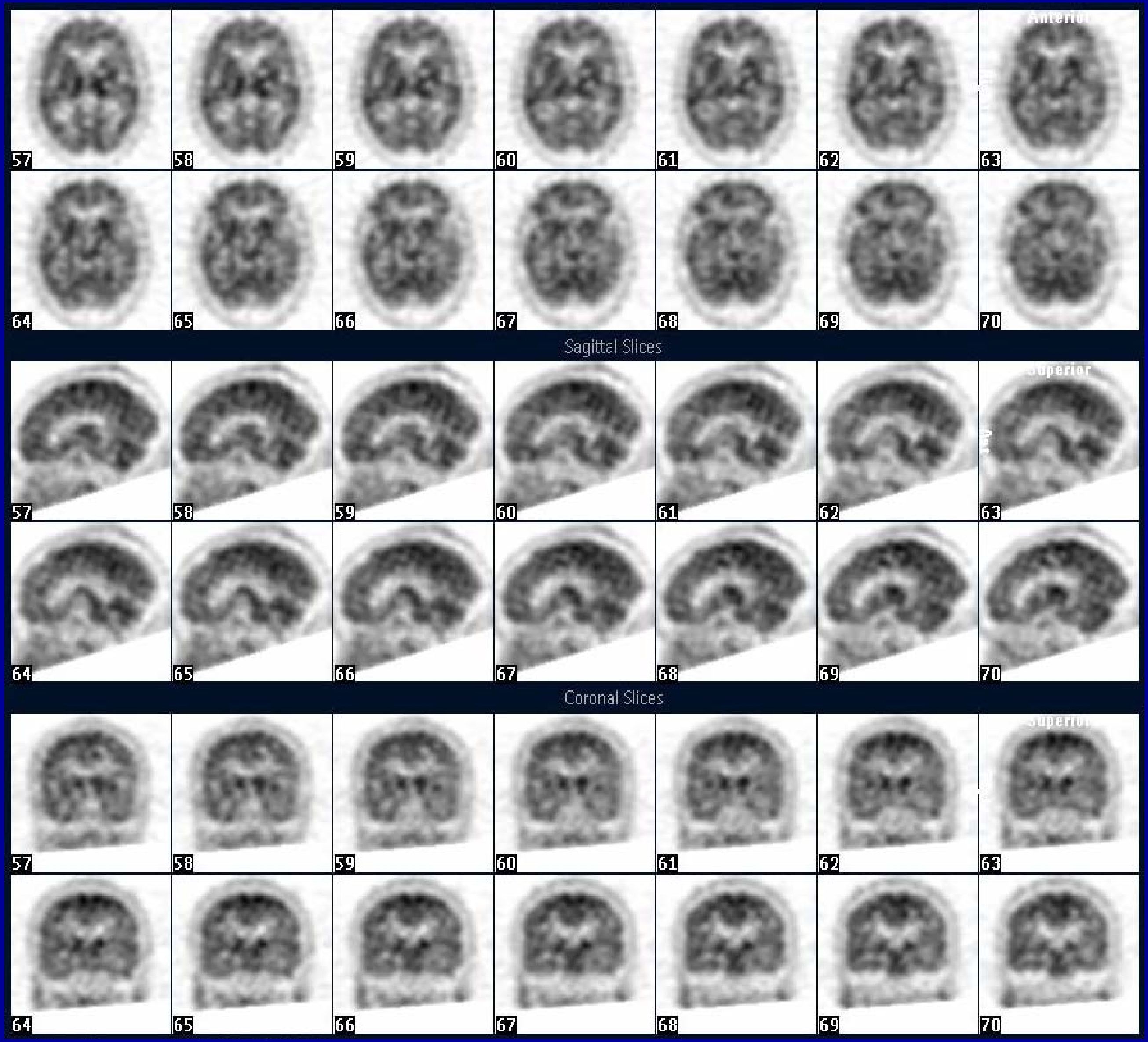


Camera heads rotate around patient, acquiring a set of projection images that are reconstructed into slices

SPECT Brain Projection Images



SPECT Brain Reconstructed Slices

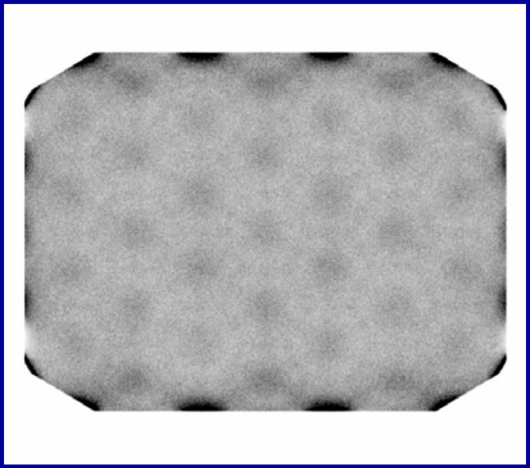


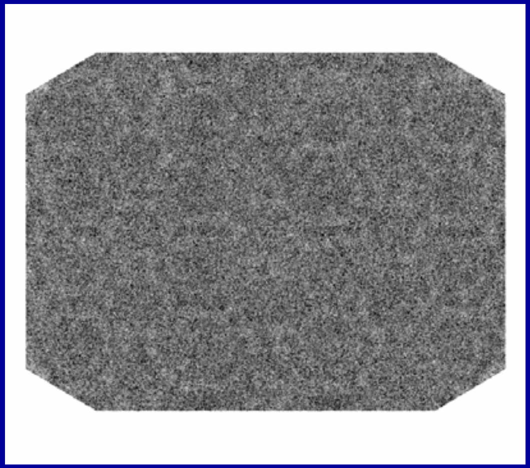
Gamma Camera Calibrations

- PMT gains must be balanced
- Correction Tables:
  - Energy
  - Linearity
  - Uniformity (Flood)
- Center of Rotation (COR) offset calibration for SPECT-capable cameras.

Correction Tables

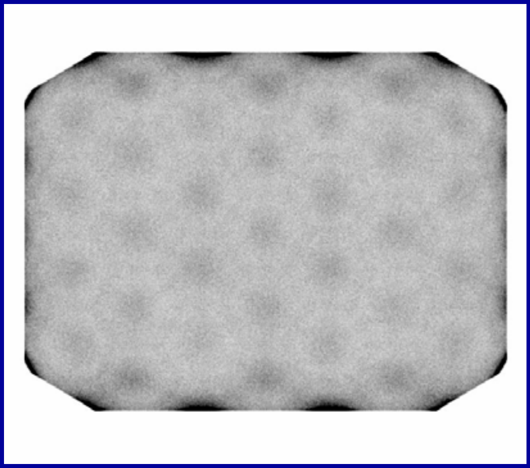
No corrections

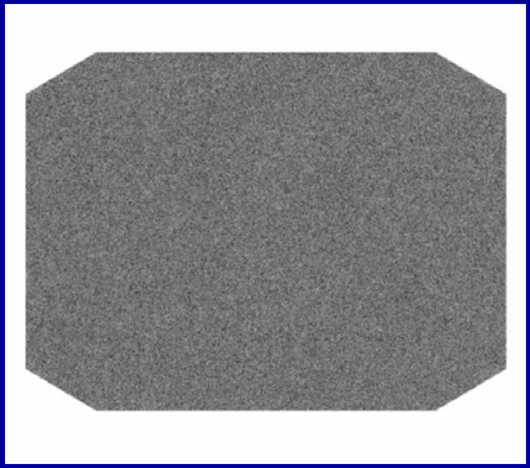




Energy And Linearity

Energy only



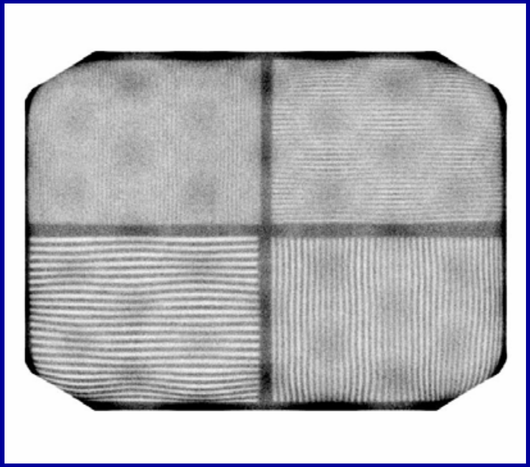


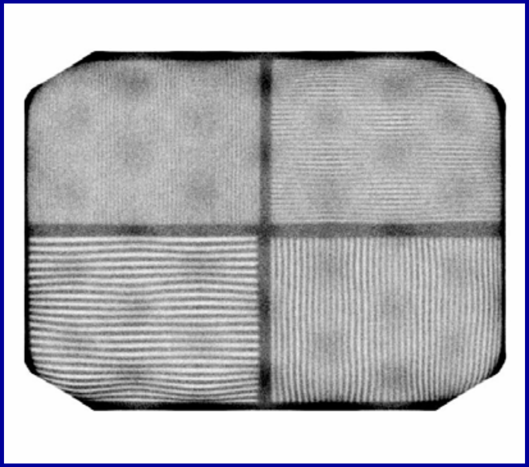
Energy, Linearity, Uniformity (all corrections)

^{99m}Tc Intrinsic Flood Images

Correction Tables

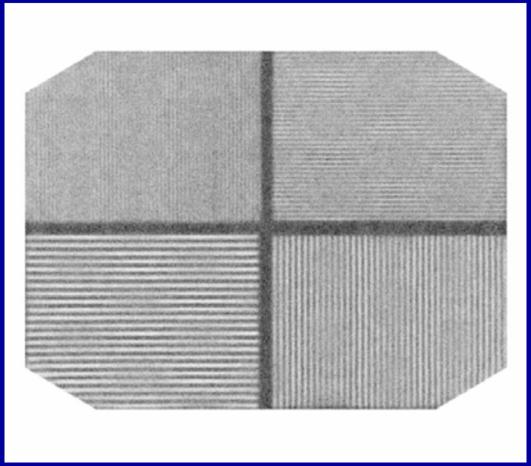
Energy only

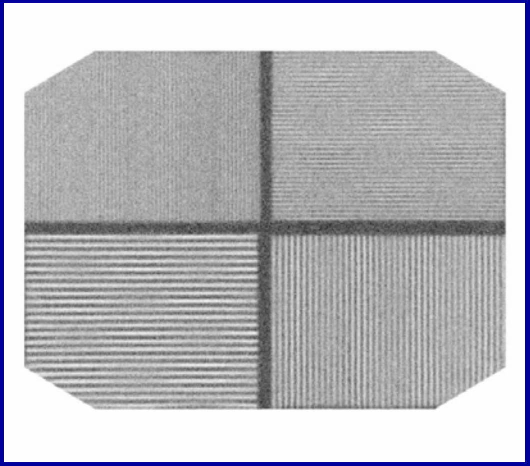




Energy and Uniformity, No Linearity Correction

Energy And Linearity Only

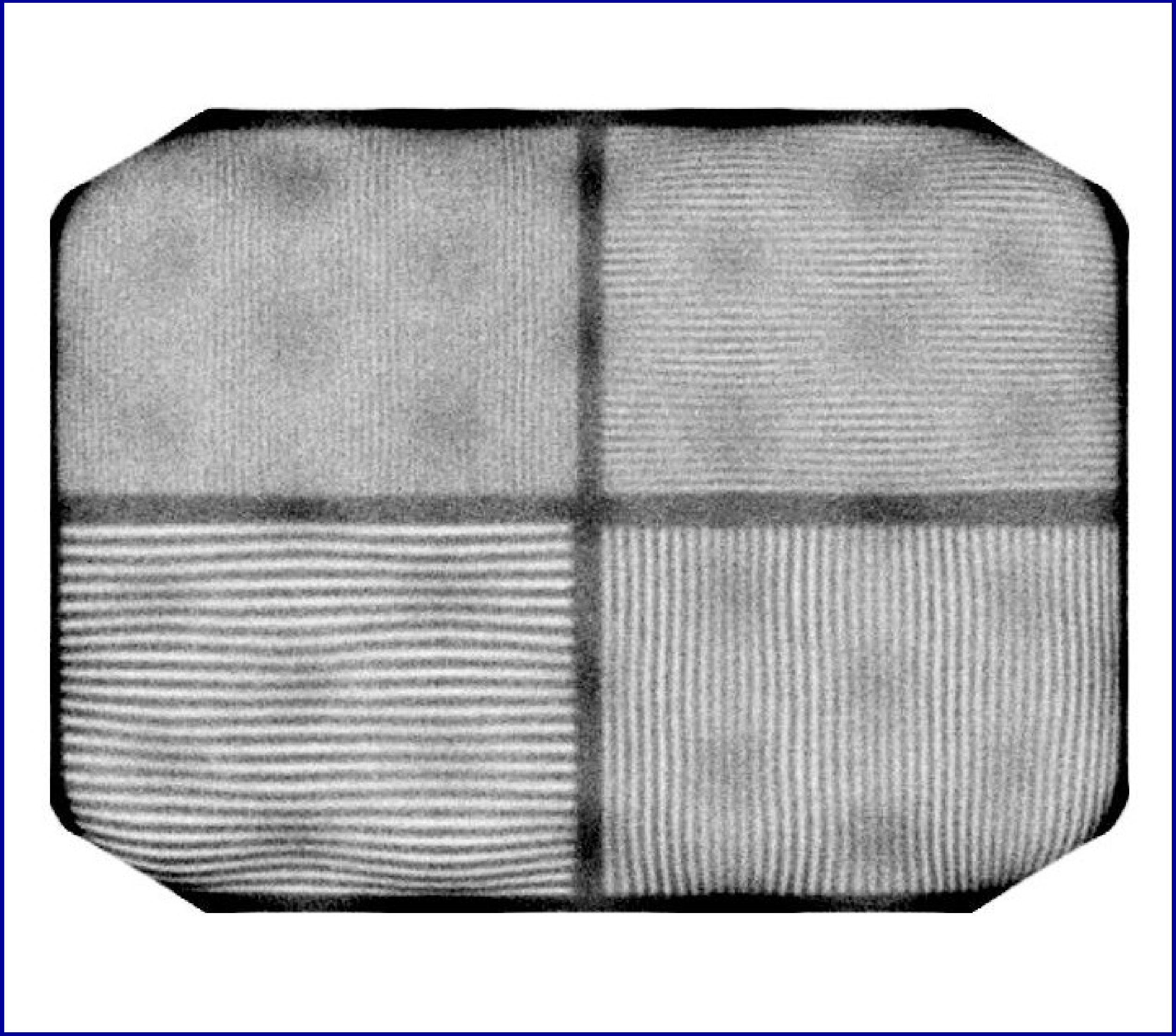




All Corrections On

^{99m}Tc Intrinsic

Intrinsic Bars – Linearity Correction Off



Routine QC Tests

- Uniformity - daily
- Spatial Resolution and Linearity - weekly
- Photopeak energy - daily
- Center of Rotation offset if camera used for SPECT – monthly or as recommended by manufacturer

Routine QC - Uniformity

- Uniformity must be checked every day that gamma camera is used, before the first patient
- Uniformity flood image may be acquired with collimator on for system (extrinsic) uniformity or collimator off for intrinsic uniformity
- 5 million counts is adequate for daily QC for large FOV camera
- Check that photopeak is centered in energy window

System Uniformity

With collimator on, use planar sheet source:

^{57}Co sheet source
10-15 mCi when new
122 keV γ
Half life 270 days

Water filled sheet source
Add 10-15 mCi ^{99m}Tc
140 keV γ
Half life 6 hours

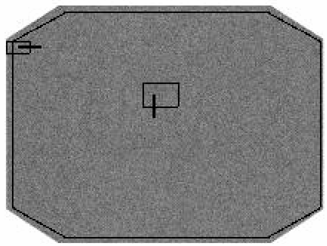
Intrinsic Uniformity

- General method – use ~ 500 μCi ^{99m}Tc point source, placed at a distance of five times the length of the camera field of view
- Some cameras have a special source holder and vendor specific procedure

Flood Images

Uniformity - Quantification

QC 1 13 09 ARGUS



FLOOD

UFOV

CFOV

Full Report of Uniformity Analysis
NAME: QC 1 13 09 ARGUS ID: DK DATE: 13Jan2009

UFOV

Integral Uniformity = 4.49%

	Counts	Location
Minimum	2331	(6, 18)
Maximum	2550	(30, 26)

Row Differential Uniformity = 3.28%
Column Differential Uniformity = 2.41%

	Diff.	Location
Max Row	158	(6, 18)
Max Col	120	(29, 26)

CFOV

Integral Uniformity = 3.70%

	Counts	Location
Minimum	2368	(31, 44)
Maximum	2550	(30, 26)

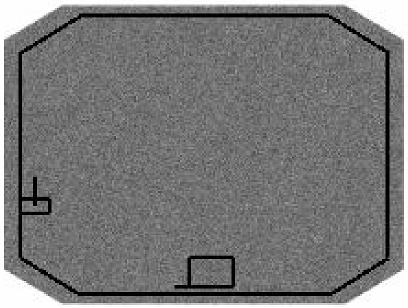
Row Differential Uniformity = 2.81%
Column Differential Uniformity = 2.41%

	Diff.	Location
Max Row	138	(26, 27)
Max Col	120	(29, 26)

Integral Uniformity should be < 5% for 5M count extrinsic flood for camera following NEMA method for calculation. Refer to vendor specifications.

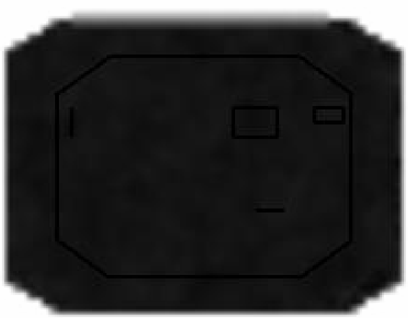
Uniformity Quantification

PHYSICS FORTE2, SLW



DET 1 LO INTR

UFOV



CFOV

Full Report of Uniformity Analysis
NAME: PHYSICS FORTE2, SLW ID: 1132009SW DATE: 13Jan2009

UFOV

Integral Uniformity = 2.76%

	Counts	Location
Minimum	2273	(8, 38)
Maximum	2402	(32, 47)

Row Differential Uniformity = 2.15%
Column Differential Uniformity = 2.36%

	Diff.	Location
Max Row	100	(27, 49)
Max Col	110	(8, 34)

CFOV

Integral Uniformity = 2.55%

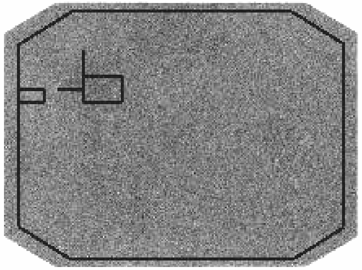
	Counts	Location
Minimum	2273	(48, 24)
Maximum	2392	(38, 25)

Row Differential Uniformity = 1.89%
Column Differential Uniformity = 2.23%

	Diff.	Location
Max Row	88	(38, 37)
Max Col	104	(13, 23)

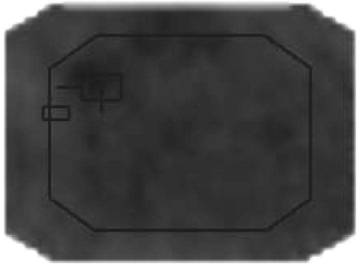
Uniformity – Not so Good

QC 7 8 09 FORTE 3



FLOOD HD1

UFOV



CFOV

Full Report of Uniformity Analysis
NAME: QC 7 8 09 FORTE 3 ID: - DATE: 08Jul2009

UFOV

Integral Uniformity = 7.16%

	Counts	Location
Minimum	2167	(8, 25)
Maximum	2501	(19, 24)

Row Differential Uniformity = 4.39%
Column Differential Uniformity = 4.03%

	Diff.	Location
Max Row	207	(12, 24)
Max Col	192	(16, 18)

CFOV

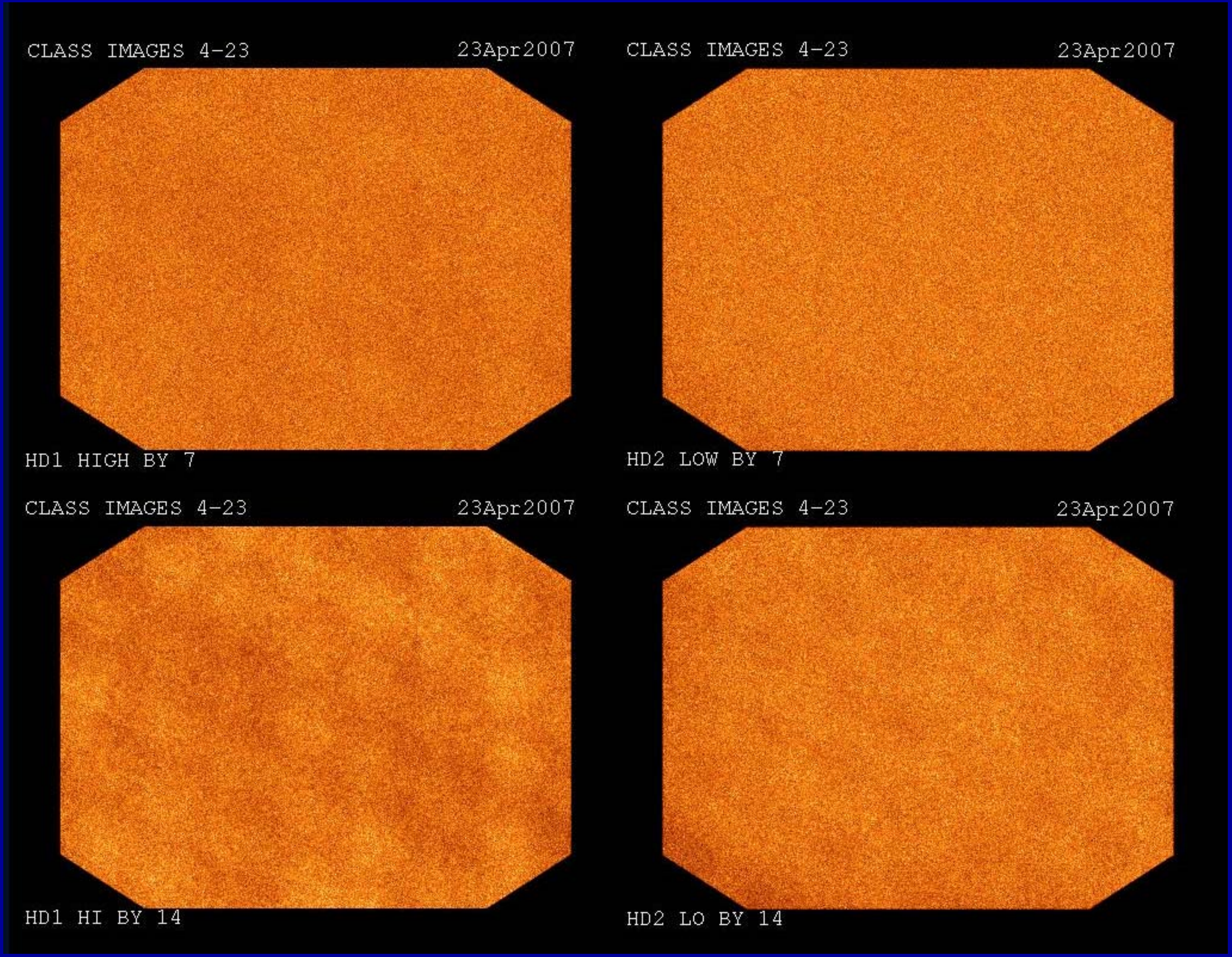
Integral Uniformity = 5.64%

	Counts	Location
Minimum	2234	(12, 28)
Maximum	2501	(19, 24)

Row Differential Uniformity = 4.39%
Column Differential Uniformity = 2.73%

	Diff.	Location
Max Row	207	(12, 24)
Max Col	133	(19, 24)

Flood Images – Off Peak

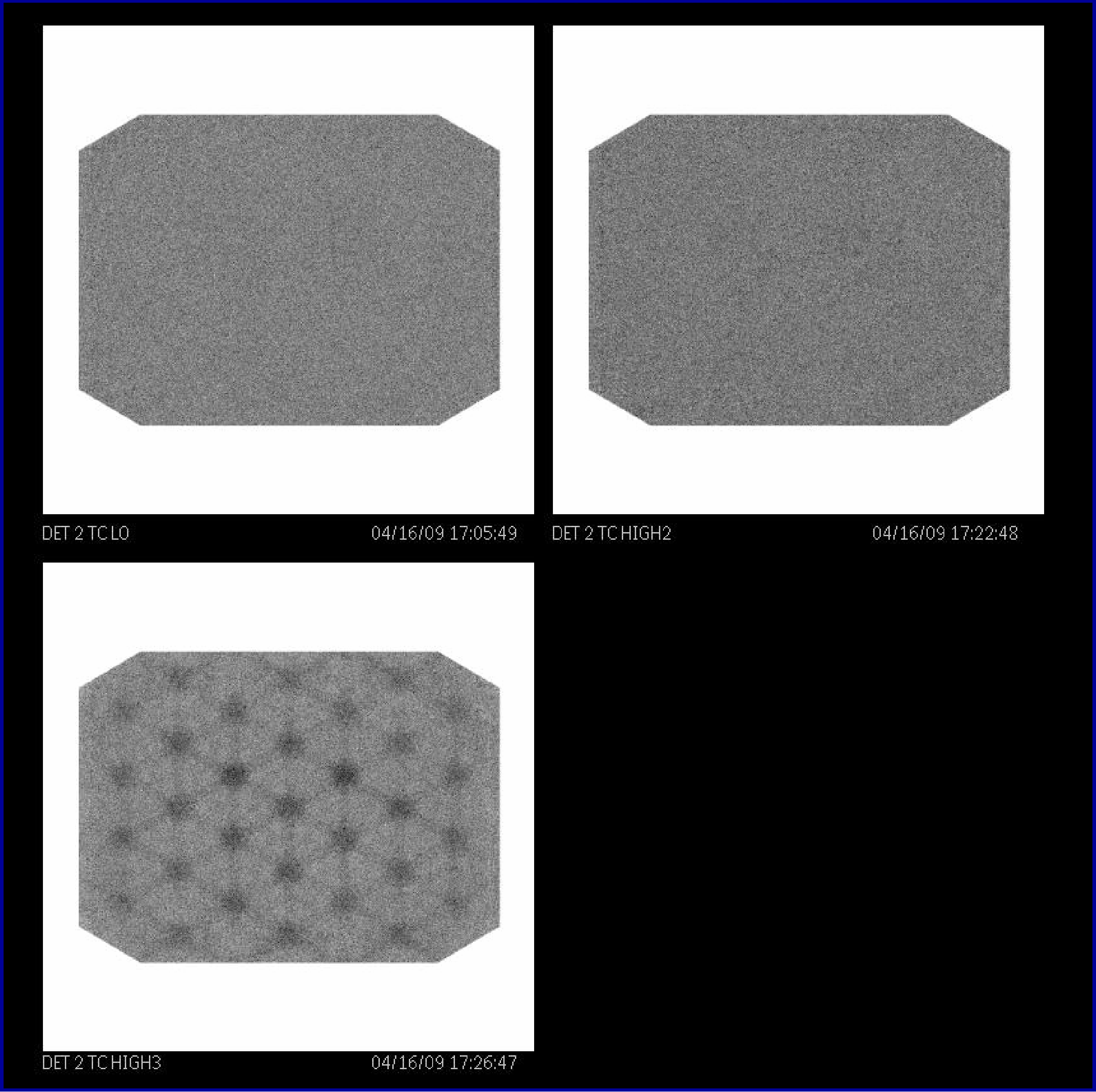


Low to High Count Rate Intrinsic Floods

19 kcps

79 kcps

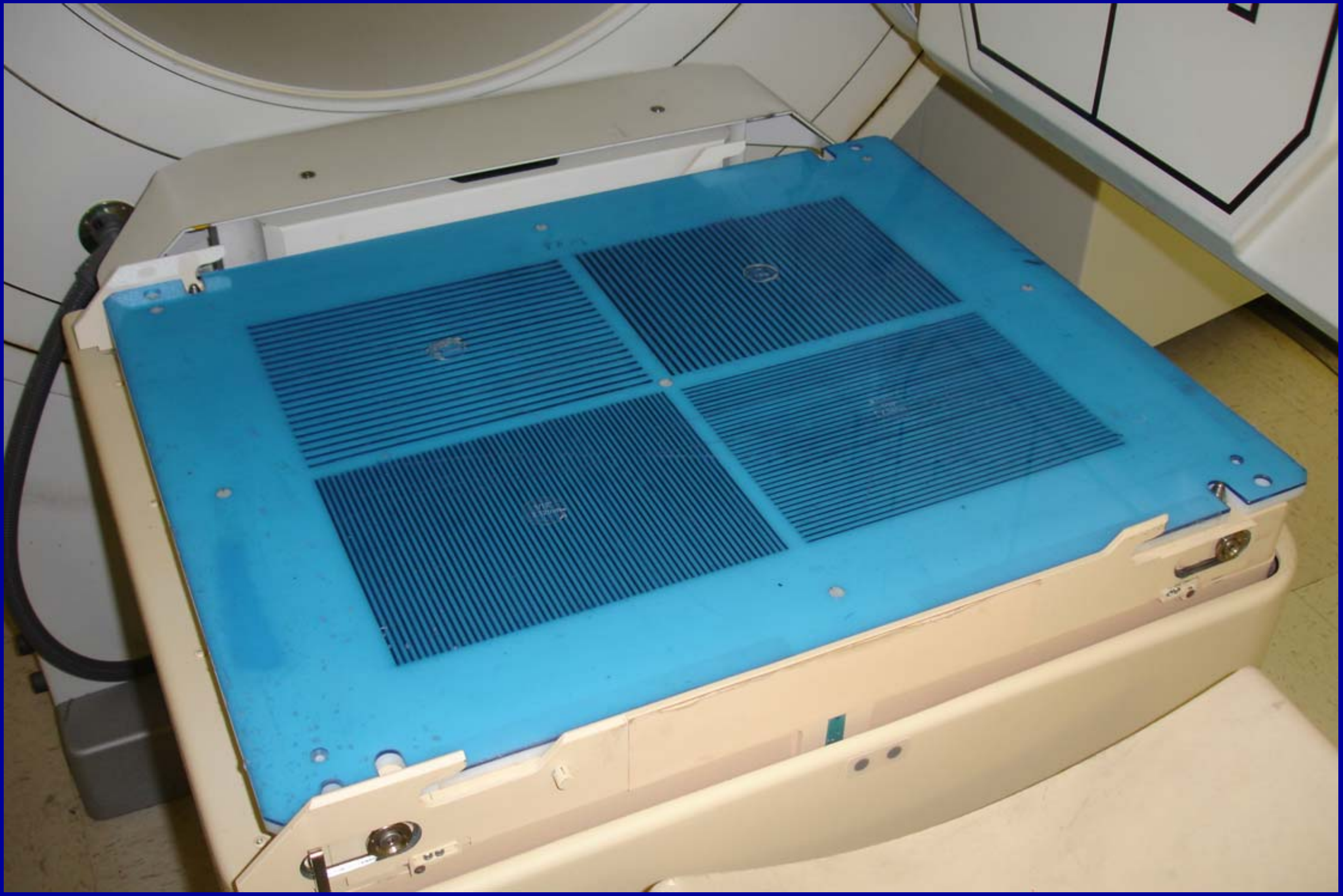
109 kcps
(too high)



Routine QC – Spatial Resolution and Linearity

- Image bar pattern at least weekly to check spatial resolution and linearity
- May be done extrinsically using ^{57}Co or ^{99m}Tc sheet source and bar pattern placed on top of collimator
- May be done intrinsically using ^{99m}Tc point source at a distance, with bar pattern placed on top of crystal.
- 2.5 million counts adequate for routine QC

Spatial Resolution – Four Quadrant Bar Pattern



Intrinsic Spatial Resolution

Point Source ^{99m}Tc, 400-800 μCi

Collimator off, bar pattern on top of crystal

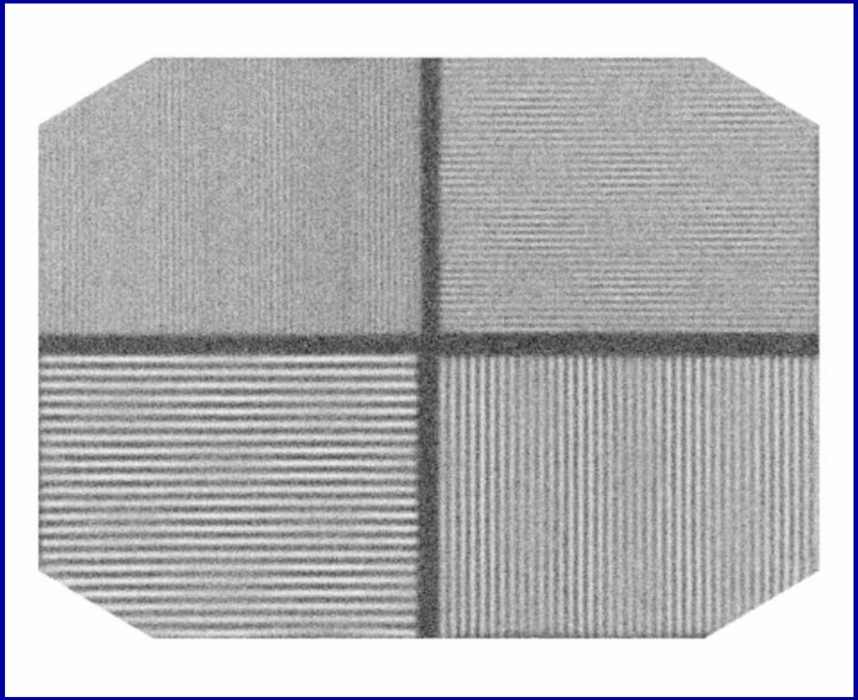
Extrinsic Spatial Resolution

Bar pattern on top of collimator, sheet source on top of bars

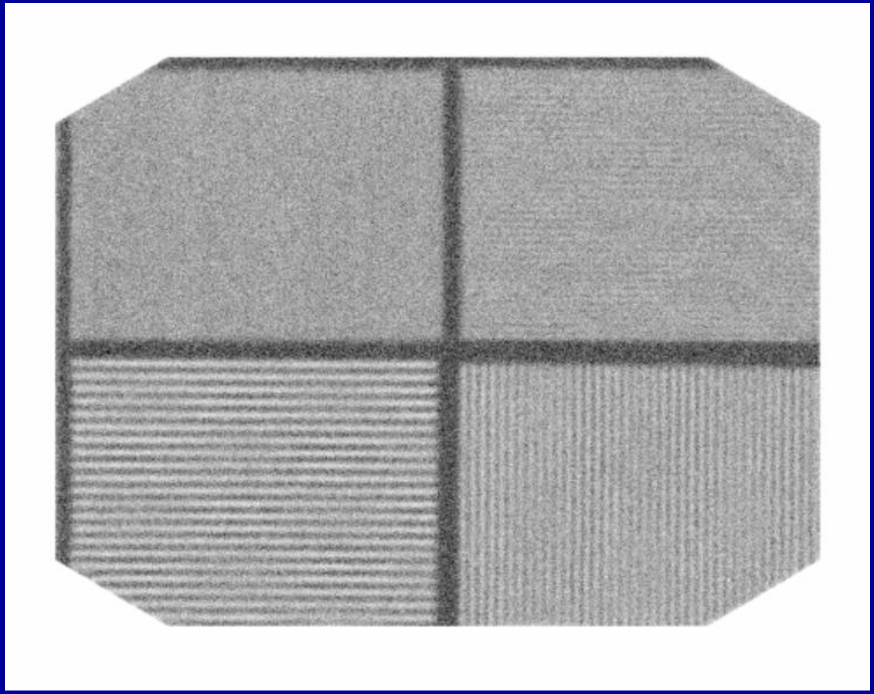
Routine QC – Spatial Resolution and Linearity

- Resolution - check that smallest resolvable bar pattern remains the same, no abrupt changes
- Linearity – check that lines on bar pattern do not appear significantly wavy and that there is no abrupt change

Bar pattern – intrinsic vs. extrinsic

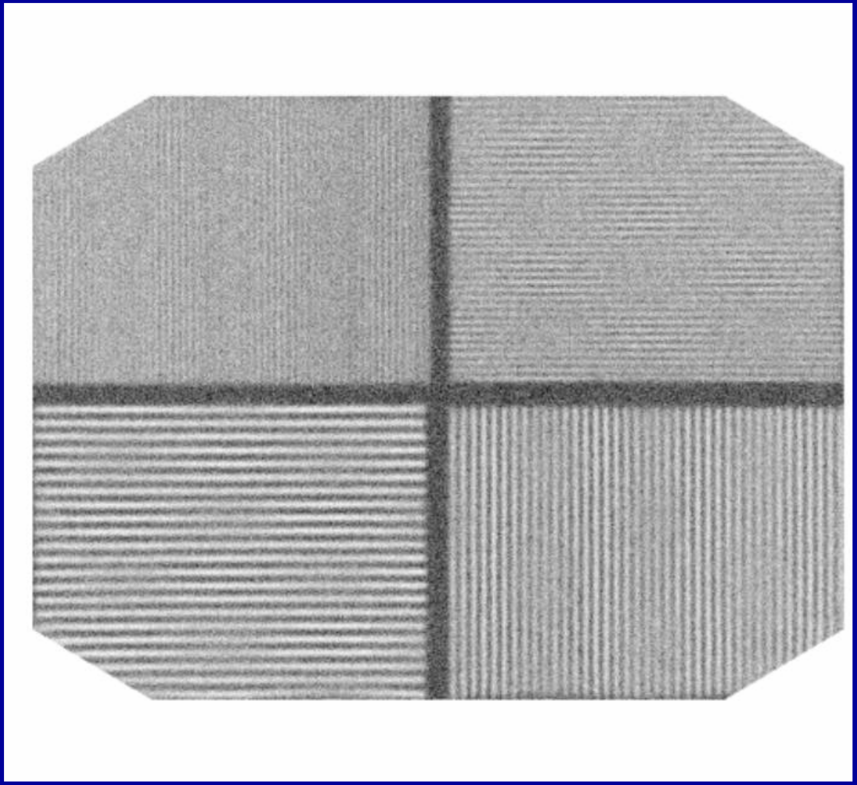


Intrinsic – better resolution than extrinsic

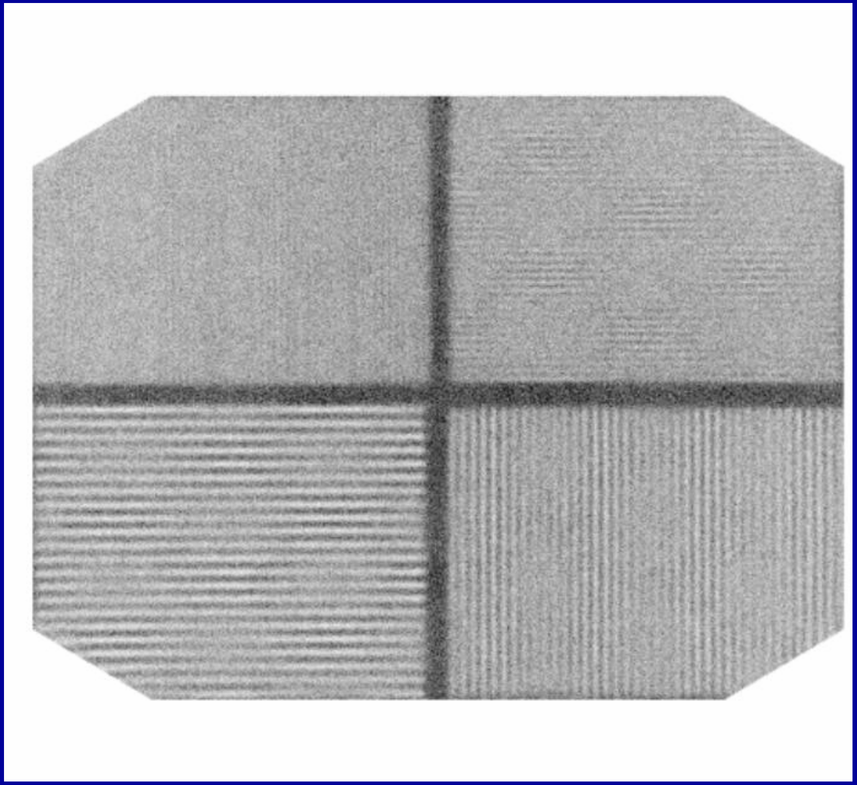


Extrinsic

Intrinsic Bar Pattern Tc and Thallium

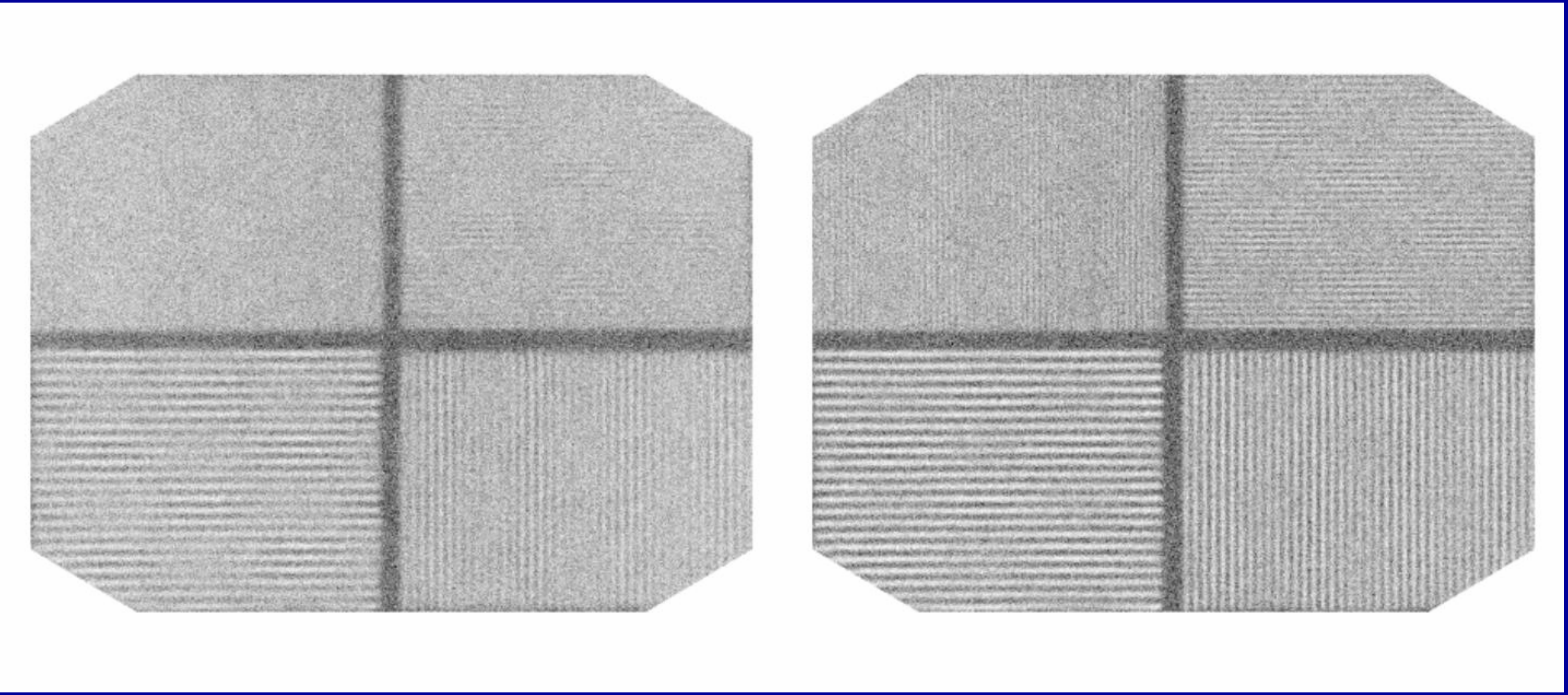


^{99m}Tc



^{201}Tl

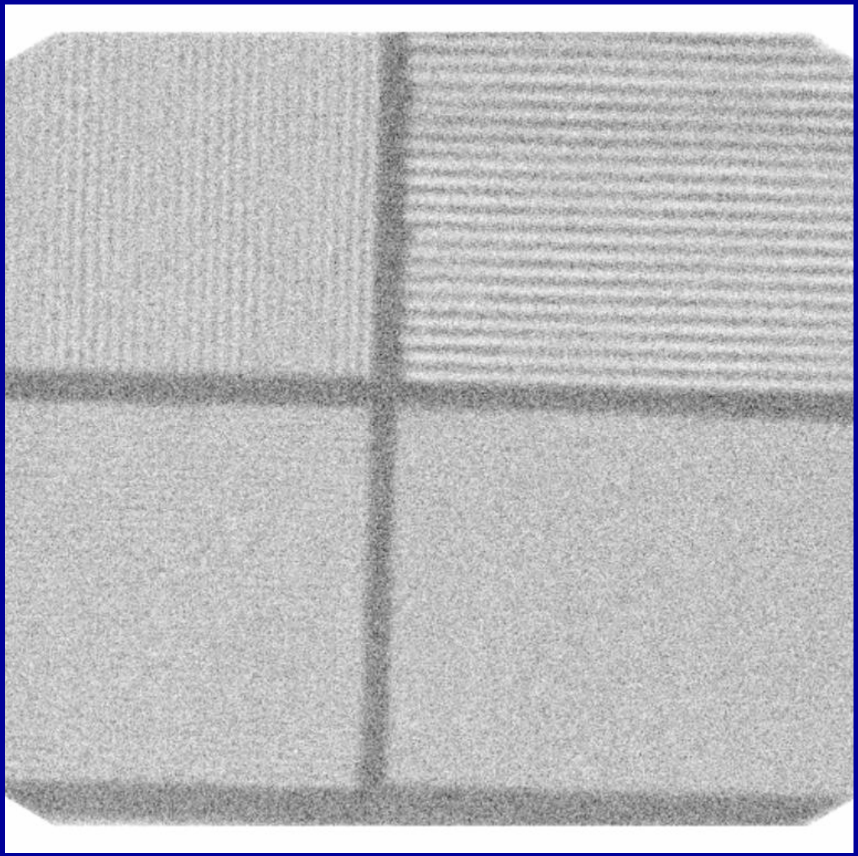
Intrinsic Thallium bar pattern, One Peak at a time



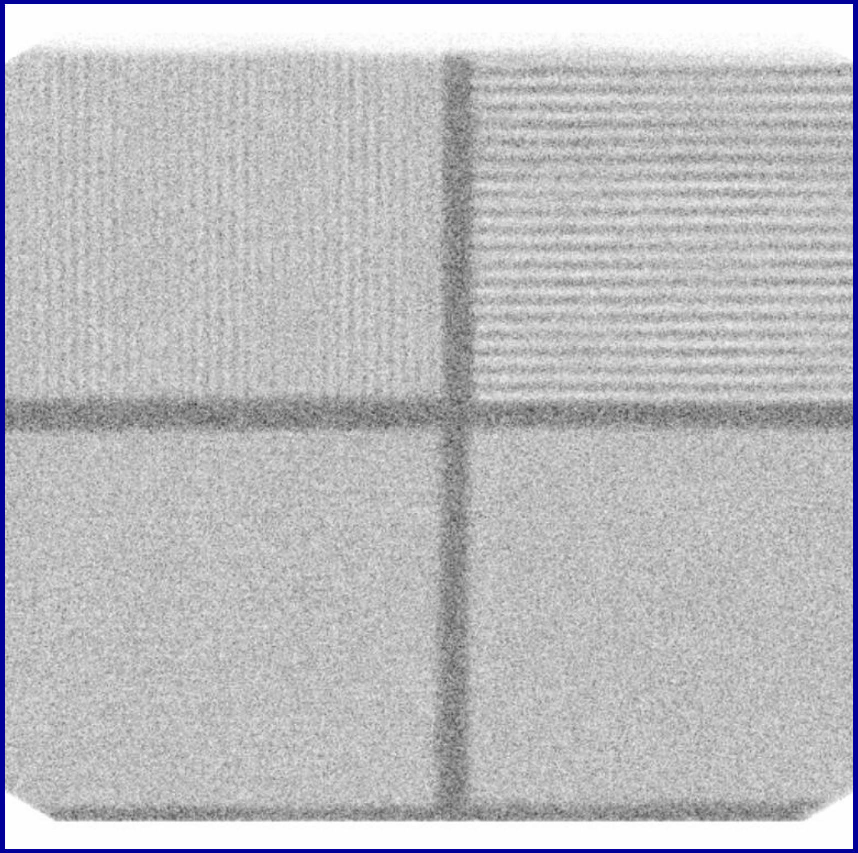
Lower energy peak only, 69 keV

Upper energy peak only, 167 keV – Better resolution at higher energy

Extrinsic Bars – ^{99m}Tc and ^{57}Co



^{99m}Tc 140 keV γ

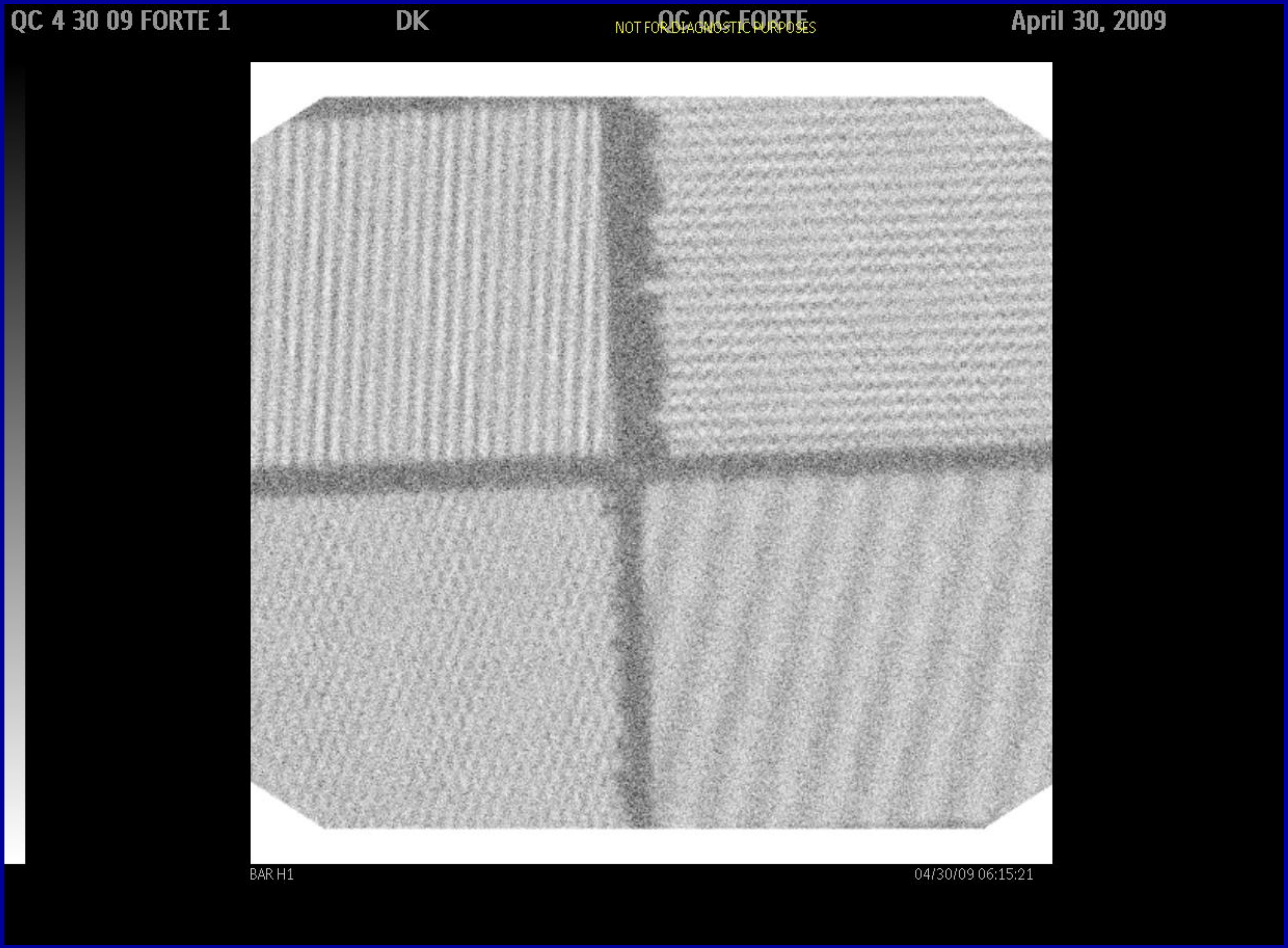


^{57}Co 122 keV γ

Tc resolution better due to higher energy gamma

Bar pattern – slight nonlinearity in corner

Bar Pattern with wrong collimator Medium Energy Collimator

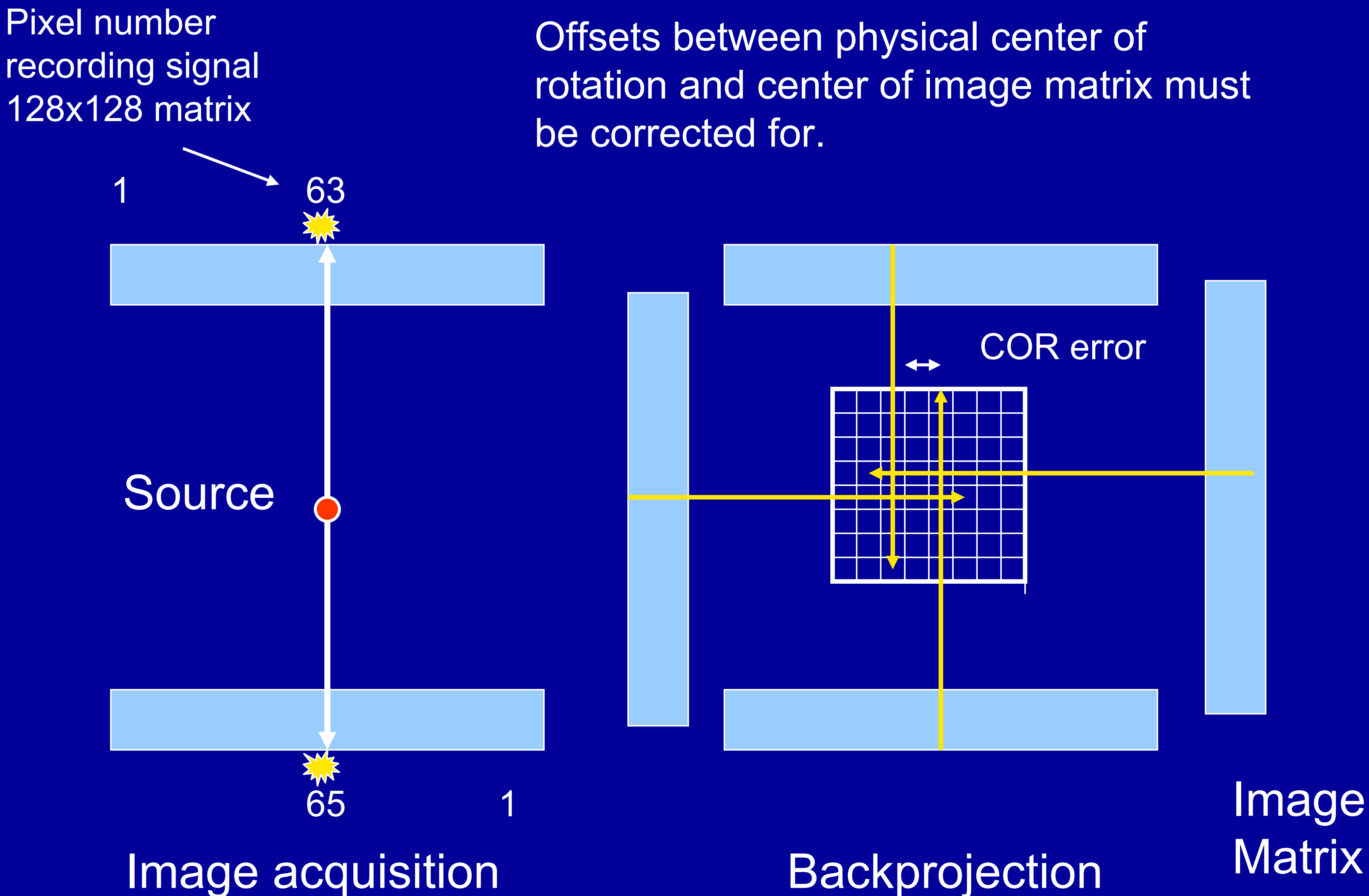


SPECT QC – Center of Rotation

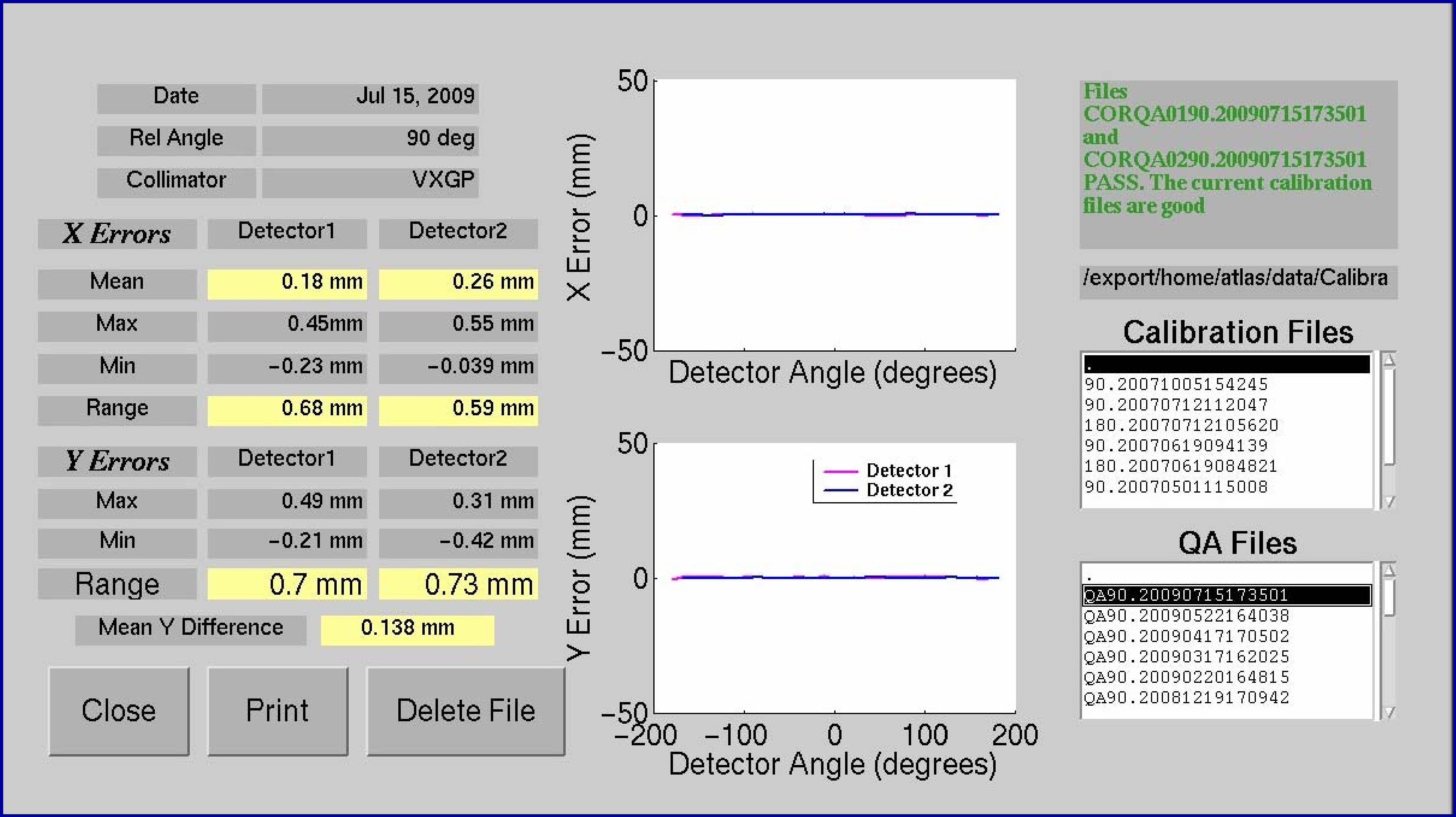
- Test or calibrate COR (center of rotation) corrections at least monthly
- Follow manufacturer's recommendations and instructions for testing/calibration procedures

Center of Rotation

Offsets between physical center of rotation and center of image matrix must be corrected for.



Center of Rotation



Summary of Routine QC

- Check photopeak daily and adjust as needed.
- Check uniformity daily and take action if uniformity unacceptable.
- Check bar pattern for resolution and linearity at least weekly.
- Check/calibrate COR at least monthly if camera used for SPECT.

Accrediting Bodies and QC Recommendations

- Accreditation is required by some insurance companies for full reimbursement
- Accreditation in nuclear medicine is offered by:

  American College of Radiology (ACR)

  and

  Intersocietal Commission for the Accreditation of Nuclear Medicine Laboratories (ICANL)

Accrediting Bodies and QC Recommendations

- ACR requires specific tests be done on a gamma camera and the images submitted for review by physicists
- ICANL does not require submission of physics tests or phantom images
- Both ACR and ICANL have recommendations for QC

Routine QC for Technologists – ACR Guidelines

- Intrinsic or System Uniformity – daily
- Intrinsic or System Resolution – weekly
- COR or Multiple Detector Registration Calibration/Test for SPECT systems – monthly
- High count floods for uniformity correction – as recommended by medical physicist
- Overall system performance for SPECT systems - quarterly SPECT phantom, ^{99m}Tc at least semiannually, other radionuclides on alternate quarters

ACR Nuclear Medicine/PET Accreditation Program Requirements 6/1/2009

ICANL Guidelines for Gamma Camera QC

- Energy peaking – daily
- Intrinsic or extrinsic uniformity – daily
- Resolution and linearity (bar pattern)- weekly
- High count floods (≥ 30 M counts) – monthly or per manufacturer's recommendation
- Center of rotation – monthly
- Collimator integrity – annually
- Uniformity calibration – monthly or per manufacturer's recommendations
- Preventative Maintenance – every 6 months

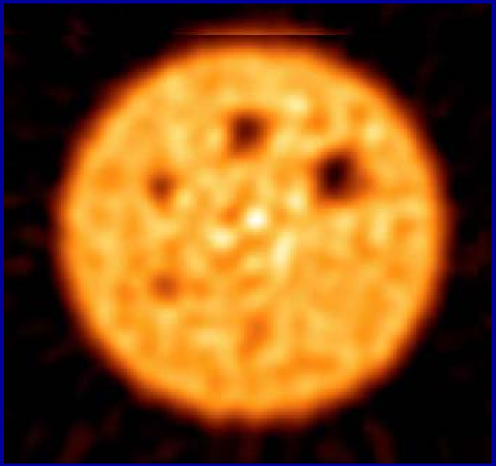
2008 ICANL Standards for Nuclear Cardiology, Nuclear Medicine and PET Accreditation

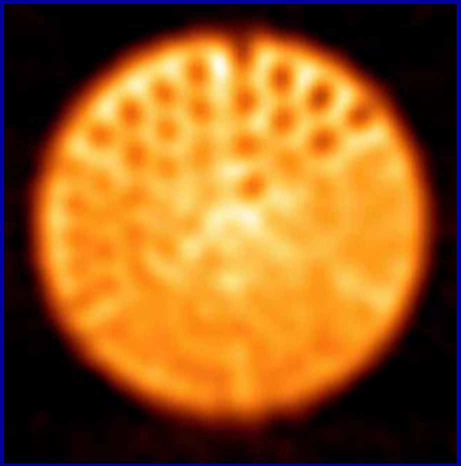
SPECT Phantom

- Jaszczak Phantom used for many years for SPECT quality control.
- This phantom is approved by ACR for SPECT ACR Accreditation images

SPECT Phantom Imaging

- Deluxe version has spheres of diameters: 31.8, 25.4, 19.1, 15.9, 12.7, 9.5 mm
- Rods of diameters: 12.7, 11.1, 9.5, 7.9, 6.4 and 4.8 mm





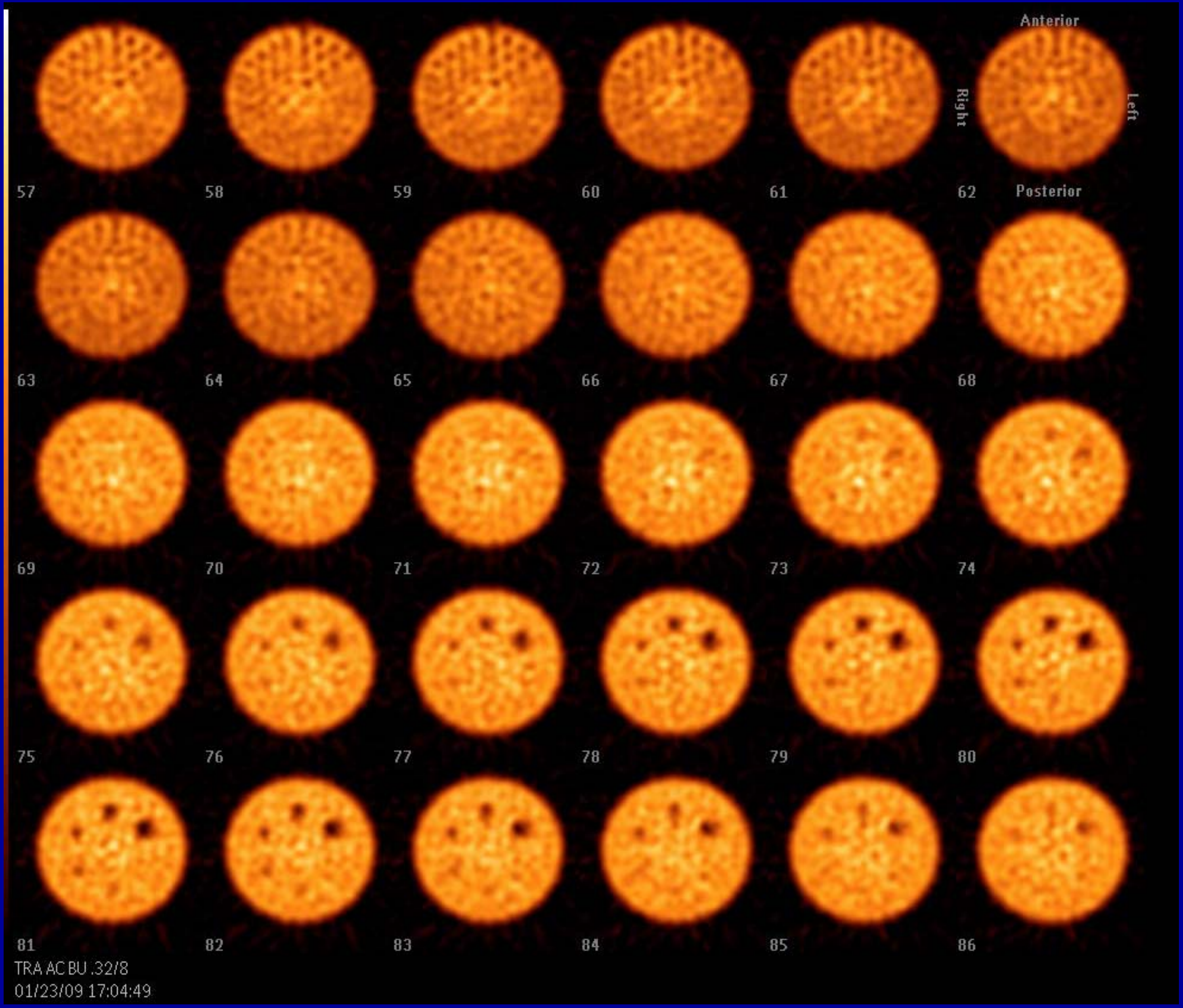
SPECT phantom imaging procedure

- Make sure largest sphere lined up with largest rod section (rotate if needed)
- Fill phantom with ~20-25 mCi ^{99m}Tc for high res collimator (too much activity causes excessively high count rate and possible artifacts. Too little activity takes a long time to image). Keep count rate < 30kcps
- Center phantom in field of view

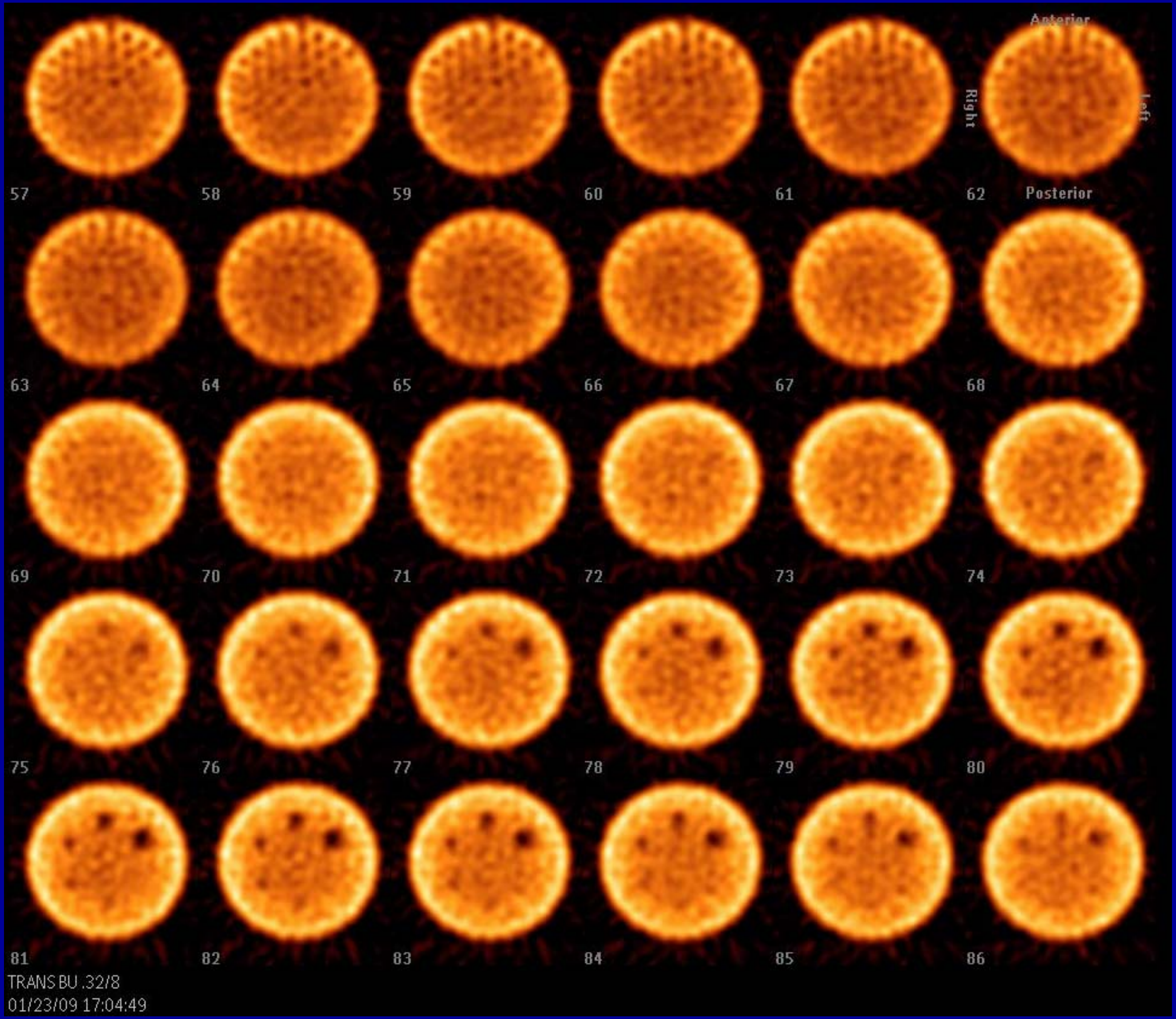
SPECT phantom imaging procedure

- ACR protocol is for 24 M total counts. Check count rate and adjust time per stop to achieve this
- Use 128 X 128 matrix, 120 or 128 views over 360 degrees
- Use a radius of rotation as close to 20 cm as possible
- For a large field of view camera, set the zoom between 1.33 and 1.46

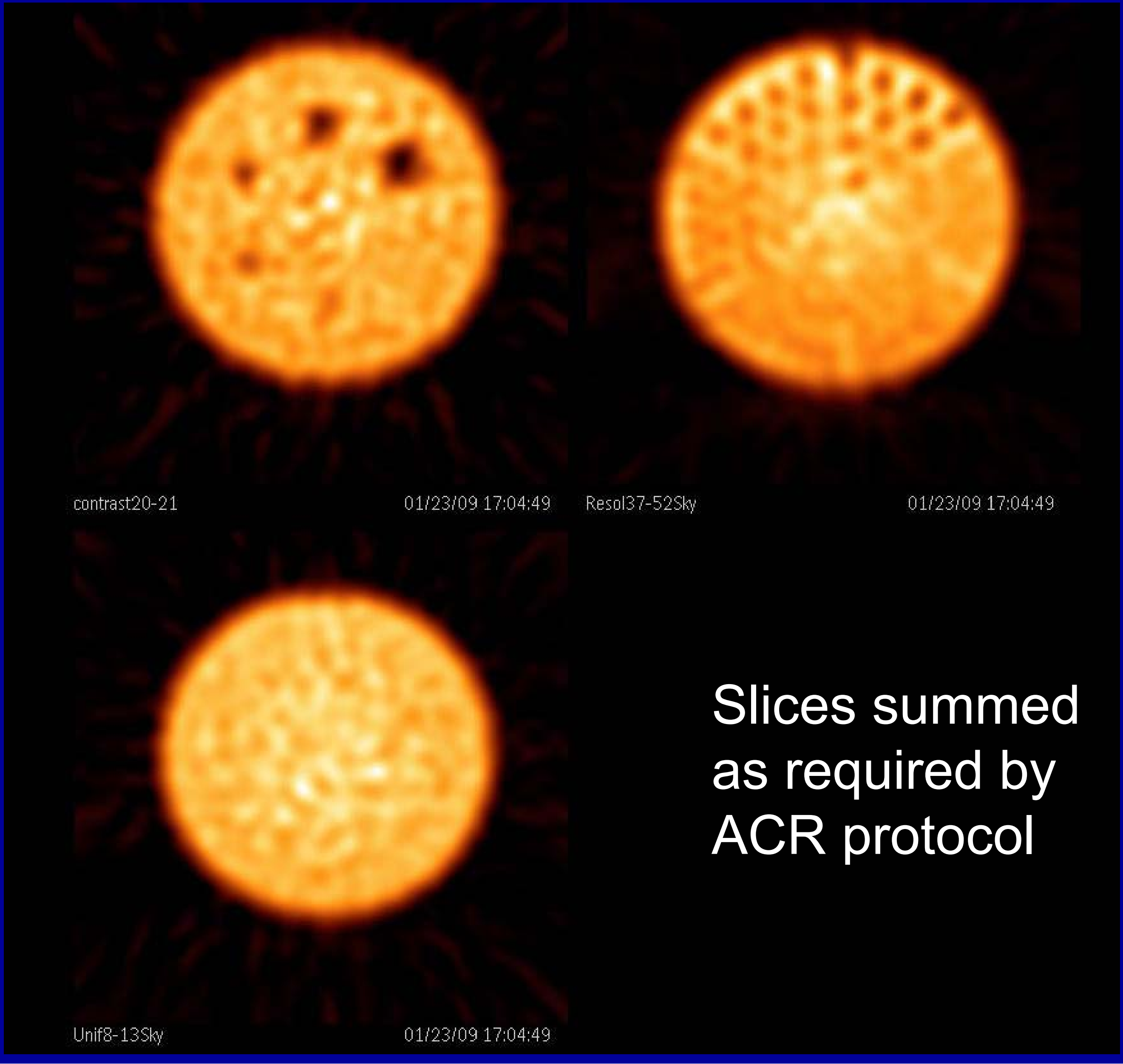
SPECT phantom reconstructed slices



SPECT phantom reconstructed slices – no attenuation correction



Summed Slices

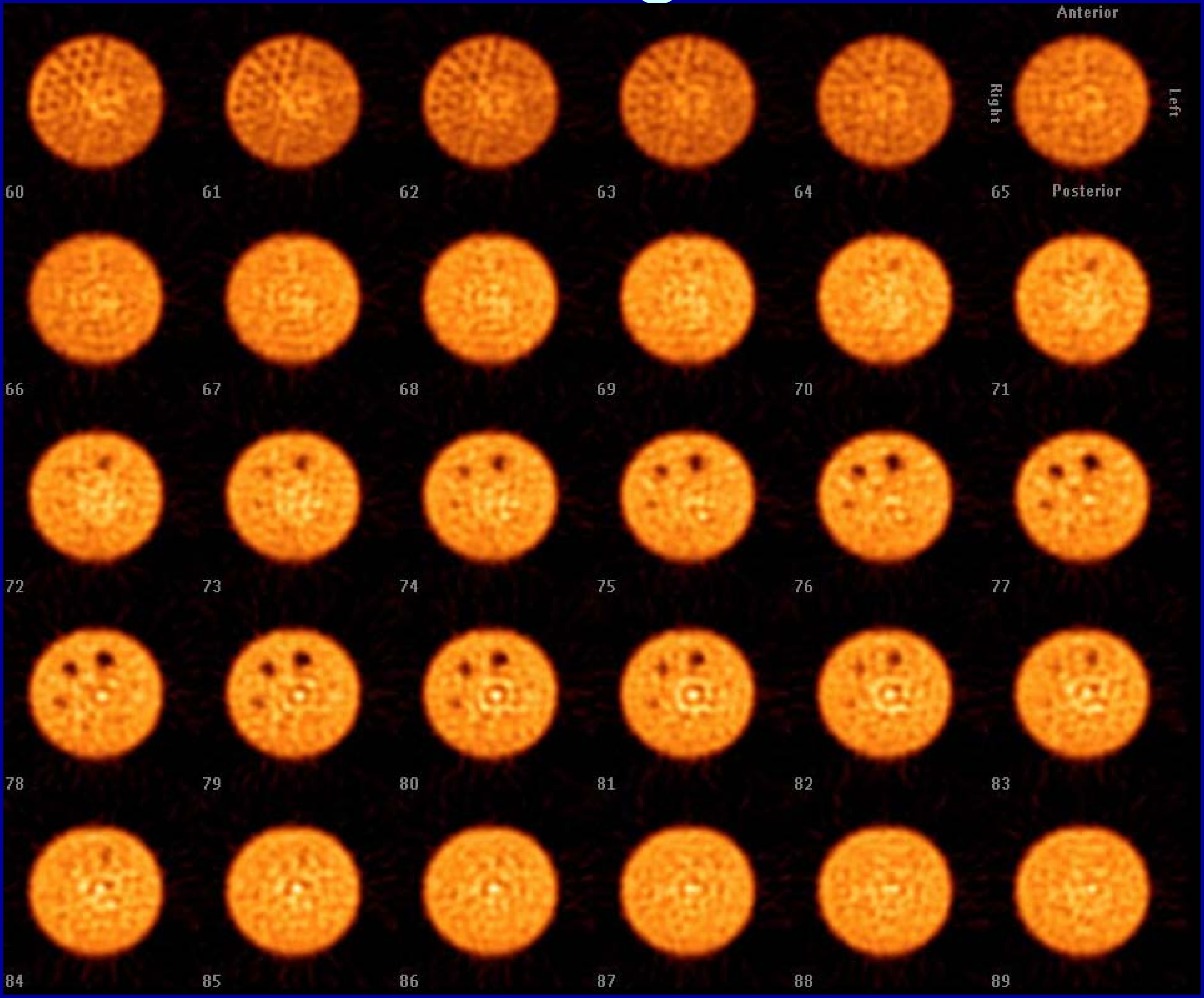


Slices summed as required by ACR protocol

ACR accreditation scoring criteria (from ACR website)

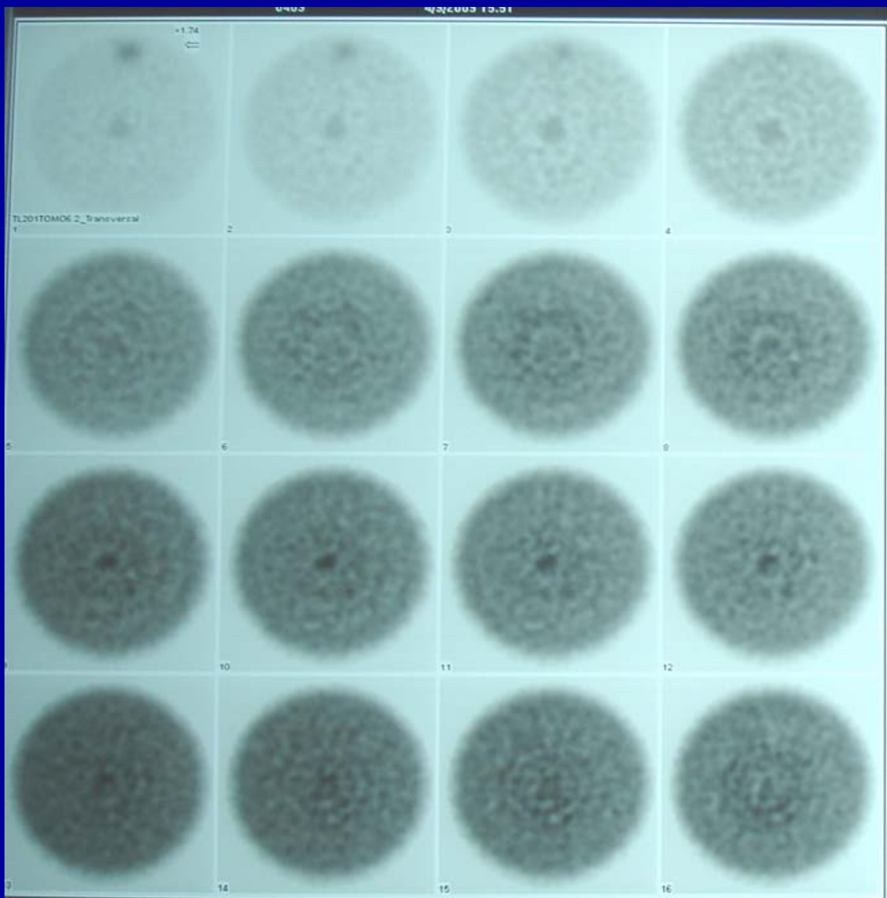
- Phantom images are scored for:
  - Resolution – smallest size of rods visible
  - Contrast – number of spheres visible
  - Uniformity – look for ring type artifacts or other artifacts
- For specifics, refer to ACR website, since criteria vary according to type of collimator and which radionuclide used

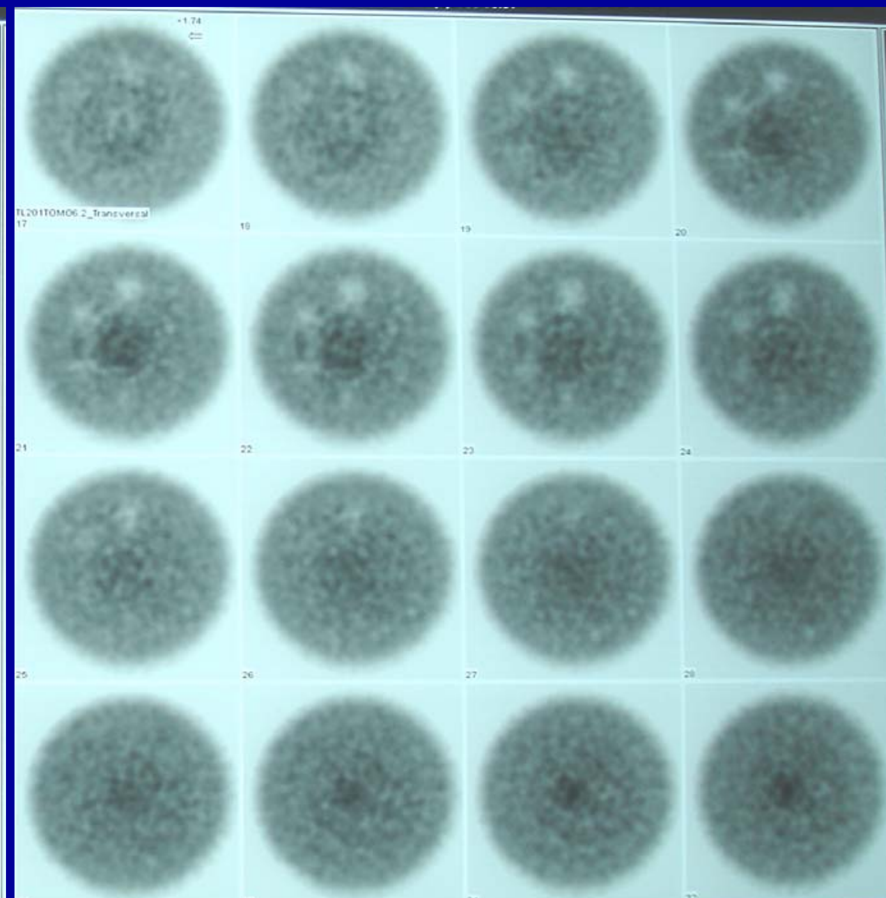
Ring Artifacts



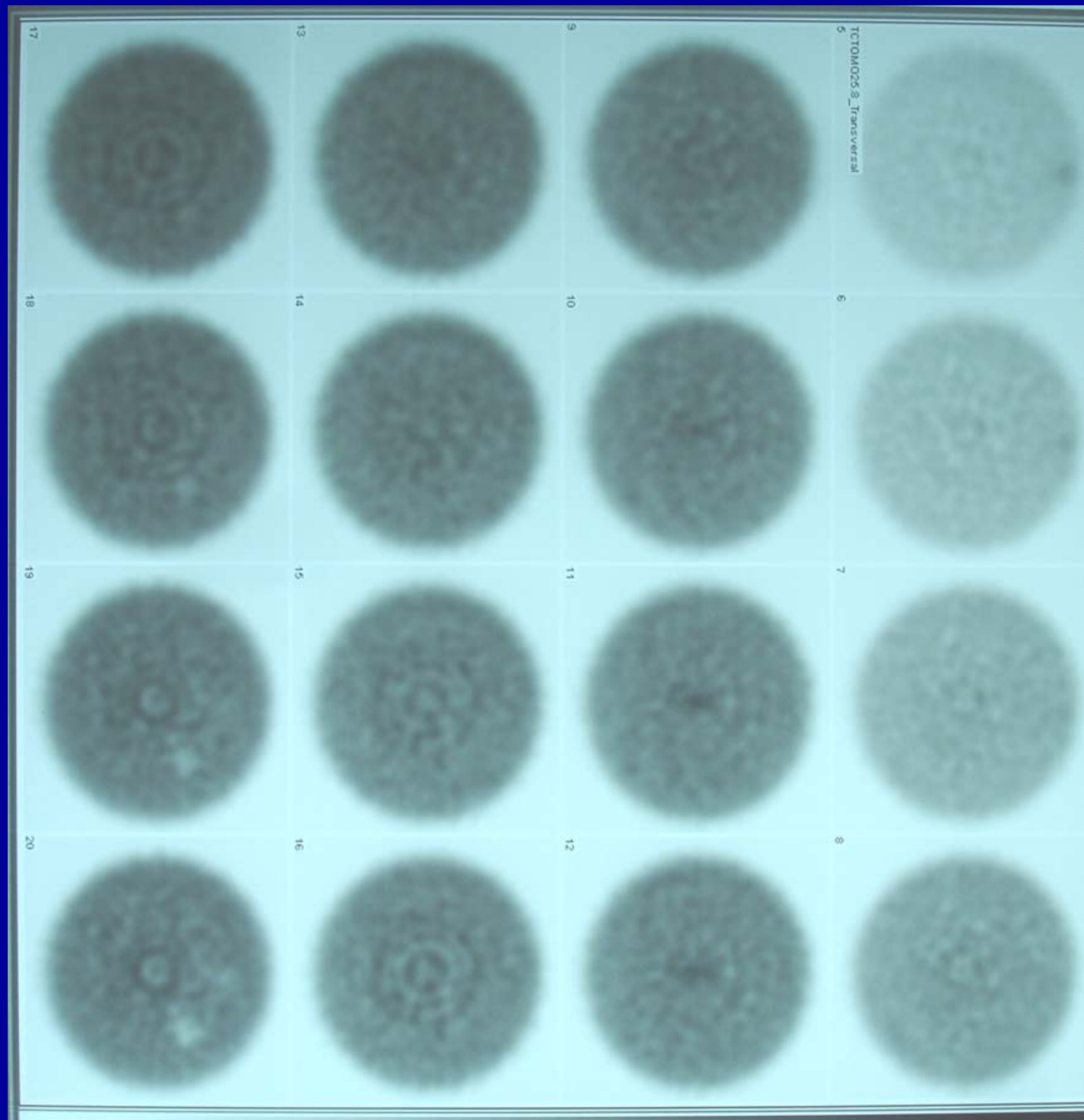
Ring artifacts visible

Ring Artifacts

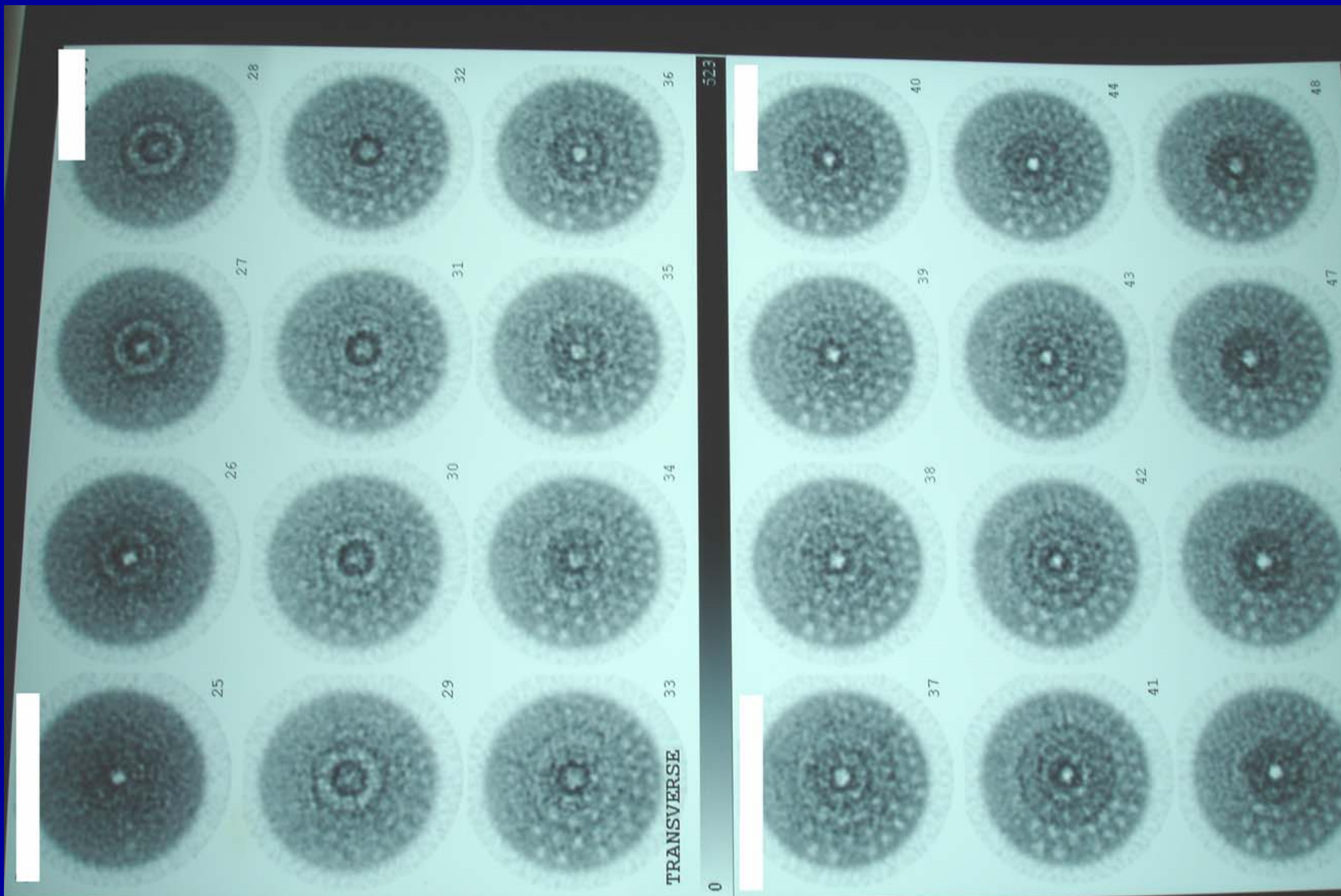




Ring Artifacts



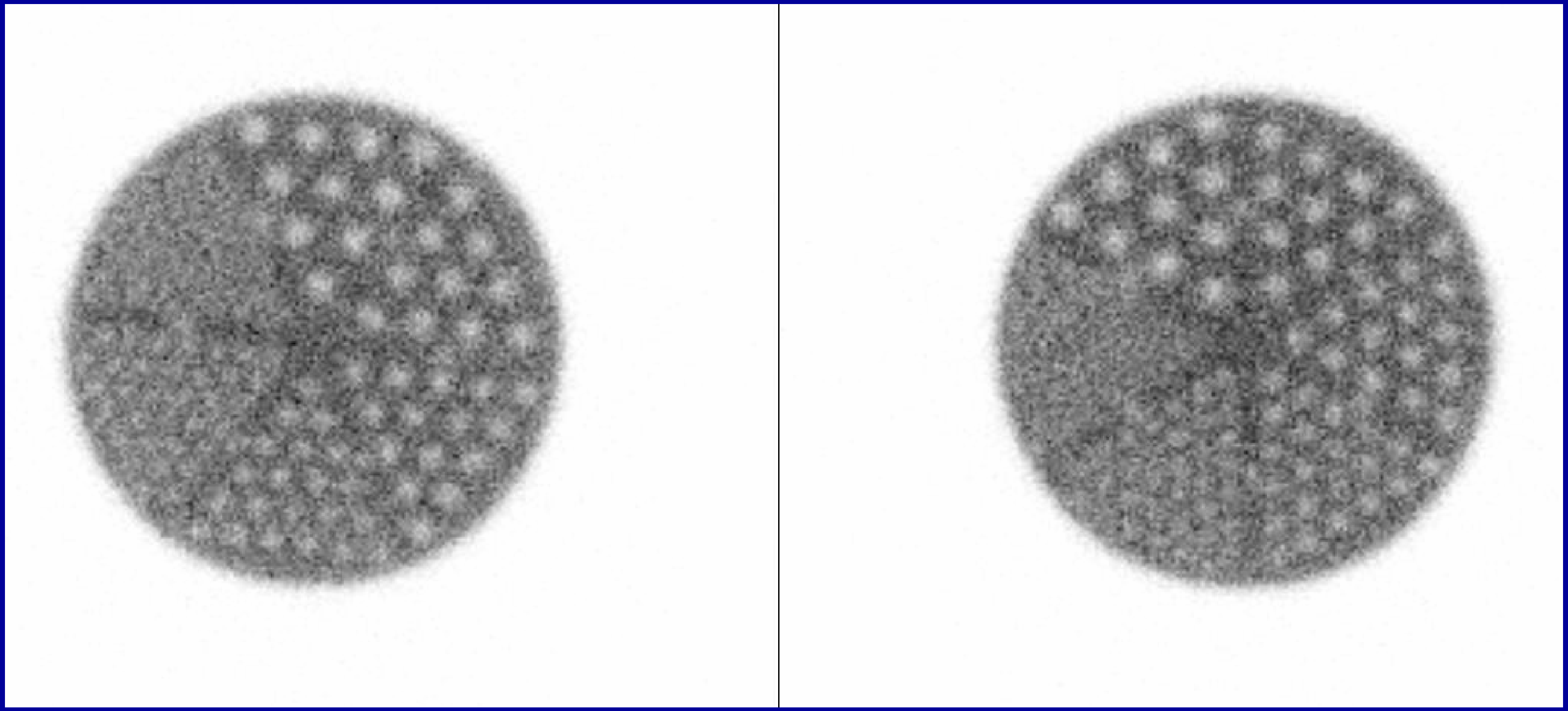
Severe Ring Artifacts



SPECT Ring Artifacts

- Caused by non-uniformities such as:
  - Visible non-uniformities in flood image due to camera being off peak, PMT gain imbalance, or need for new correction tables
  - Shift in photopeak as camera head rotates
  - Collimator defect or damage (not visible in intrinsic flood image)
- Even small non-uniformities can cause ring artifacts

SPECT phantom planar resolution images



Static images of SPECT phantom standing on end on top of collimator. Provides a measure of planar system resolution with scatter.

Annual Gamma Camera Tests – ACR Guidelines

- Intrinsic and system uniformity
- Energy resolution
- Intrinsic or system spatial resolution
- High count rate performance
- Sensitivity
- System interlocks
- If camera used for SPECT, SPECT phantom images to evaluate tomographic uniformity, contrast and spatial resolution

Annual Gamma Camera Tests – Suggested Procedures

Intrinsic Uniformity:

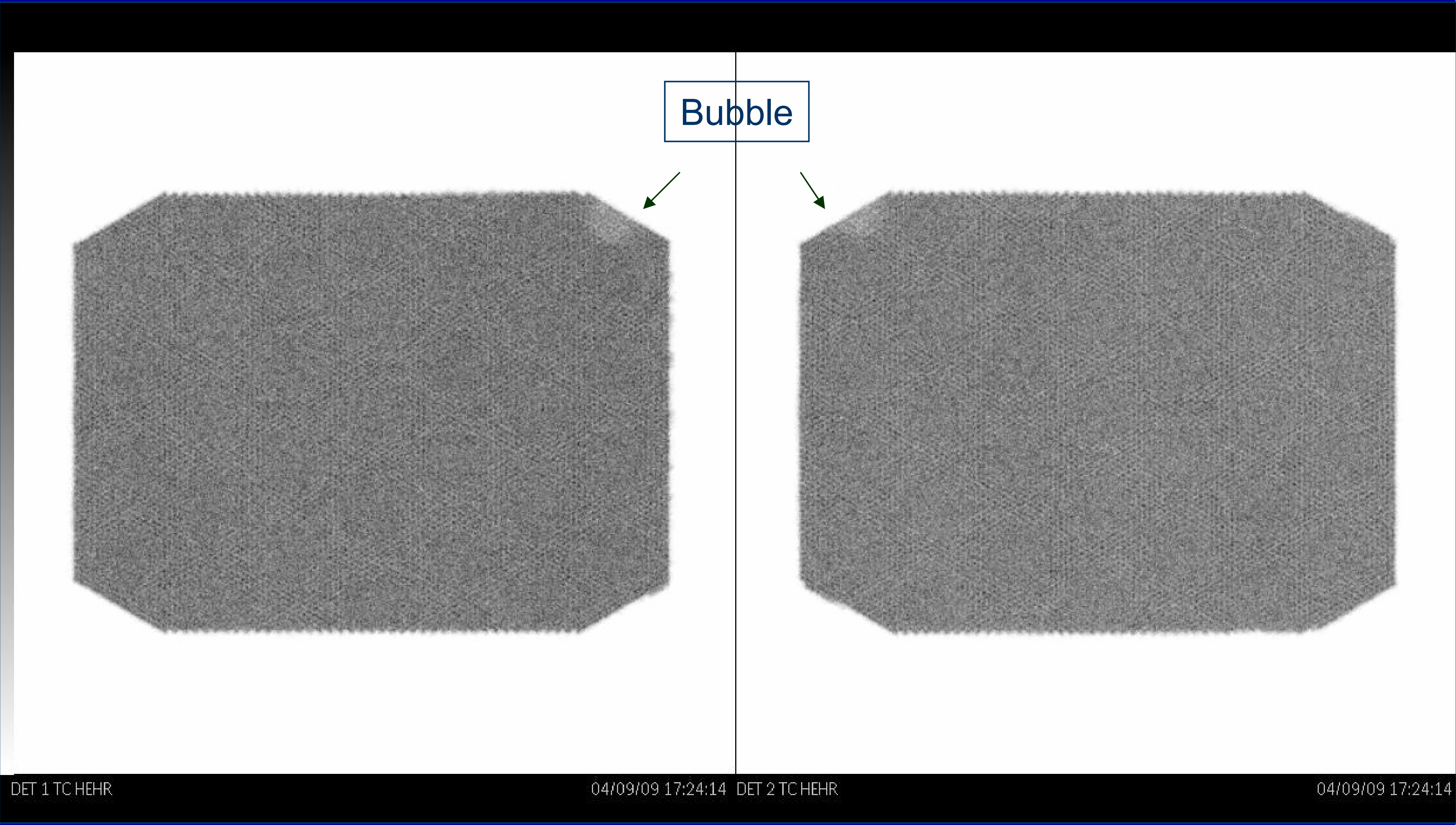
- Acquire flood images with at least 5 M total counts
- If Thallium is used routinely, acquire Thallium uniformity image as well as ^{99m}Tc
- Acquire a high count rate image to test performance at high count rates

Annual Gamma Camera Tests – Suggested Procedures

System Uniformity:

- Acquire images with at least 5 M total counts
- Use ^{99m}Tc or ^{57}Co Sheet source
- Check collimators for defects
- Can check medium or high energy collimators for defects with ^{99m}Tc or ^{57}Co sheet source.

High Energy Collimator with ^{99m}Tc Sheet Source



Annual Tests – Spatial Resolution

- Intrinsic spatial resolution should be checked, especially if not done routinely
- If four quadrant bar pattern used, rotate bar pattern to check smallest resolvable bars in both x and y direction

Annual Gamma Camera Tests – Suggested Procedures

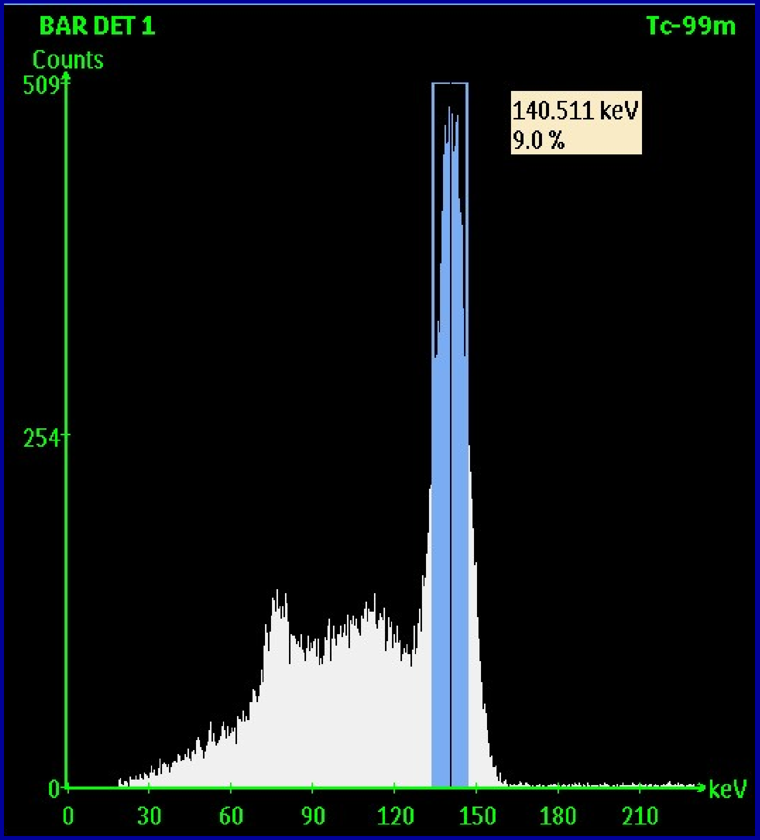
Energy Resolution:

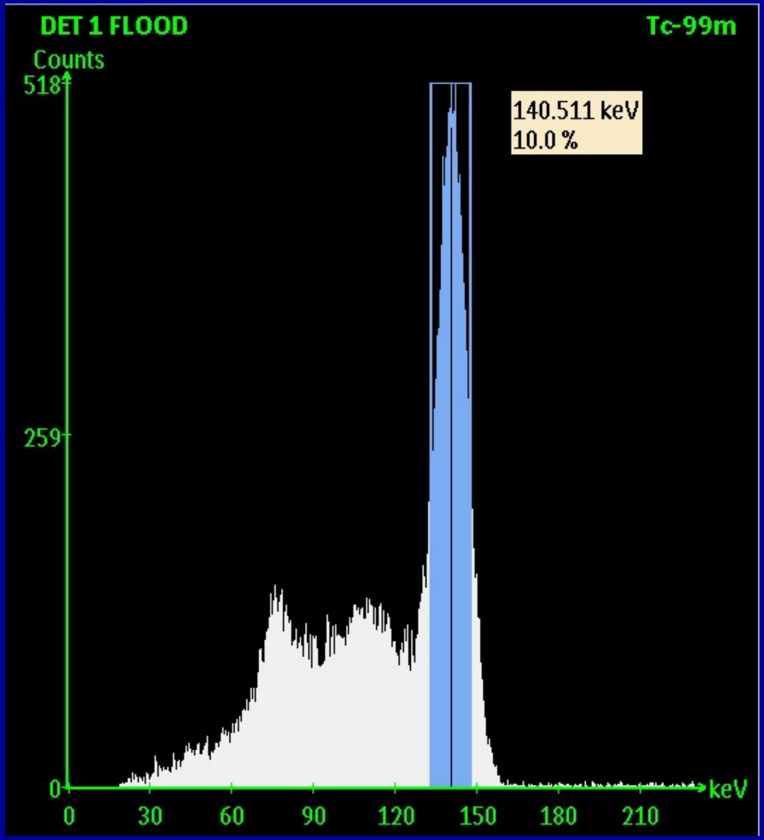
Defined as FWHM of photopeak divided by the mean energy.

Intrinsic energy resolution specified by manufacturer for ^{99m}Tc, typically 9-10%

Can estimate visually by observing photopeak and adjusting energy window

Energy Resolution





- Estimate ~ 9% energy resolution – photopeak width is approximate width of 9% window at half the peak height

Annual Gamma Camera Tests – Suggested Procedures

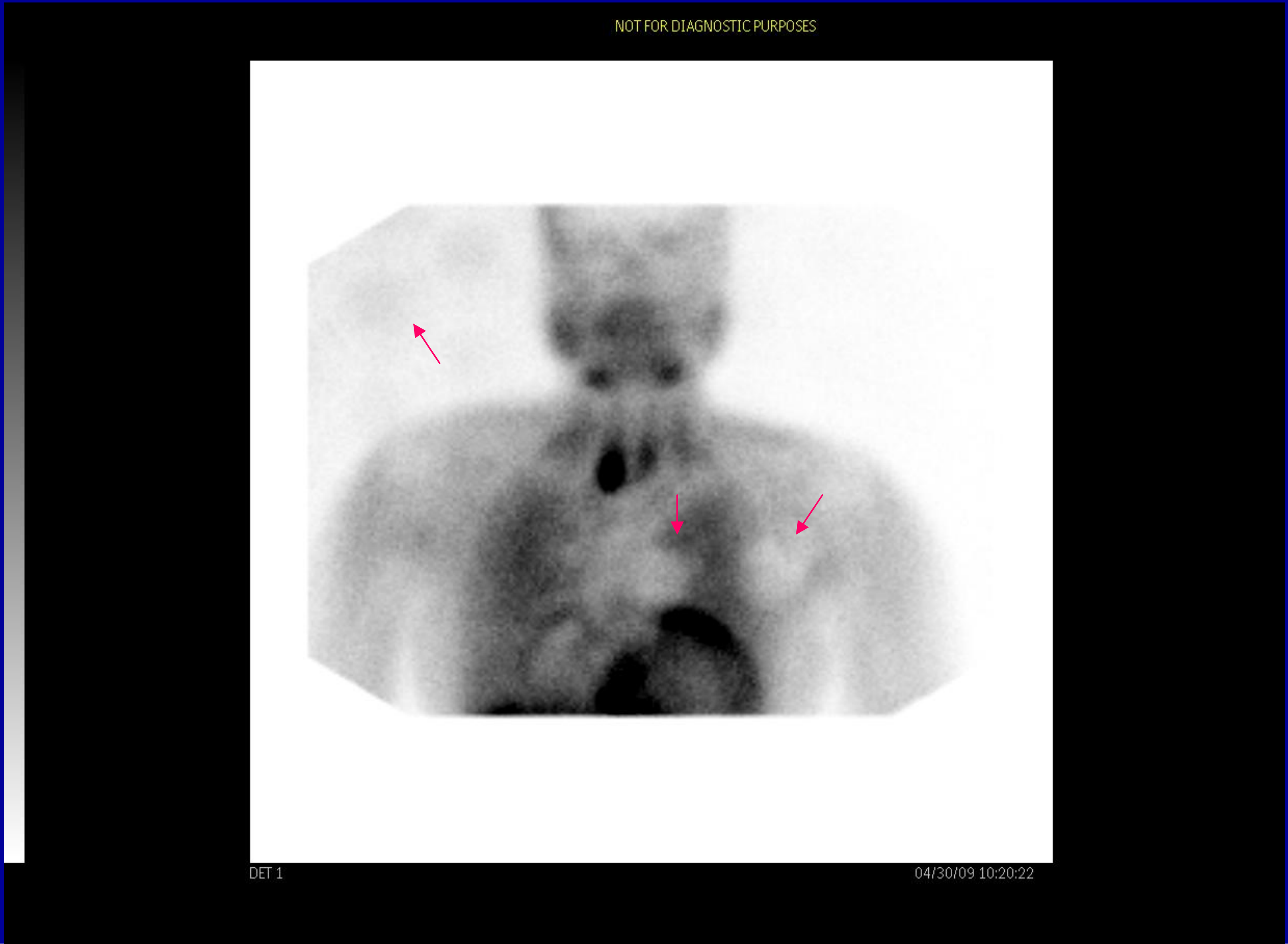
- Sensitivity:
  - Place ~1-2 mCi ^{99m}Tc and a small amount of water in a small plastic flat-bottomed vial. Record exact activity and time
  - Place on top of Styrofoam cup or similar object 10 cm from collimator face

Annual Gamma Camera Tests – Suggested Procedures

- Sensitivity:
  - Acquire 1 minute image, also a 1 min background image
  - Resulting counts/min per μCi can be compared with vender specification for the collimator used. Also if > 1 camera head, sensitivity should be similar for all heads.

Unusual Artifacts

Tube-like Artifacts visible in Parathyroid study



Cause: ^{99m}Tc Aerosol from previous patient pulled into camera head by fans

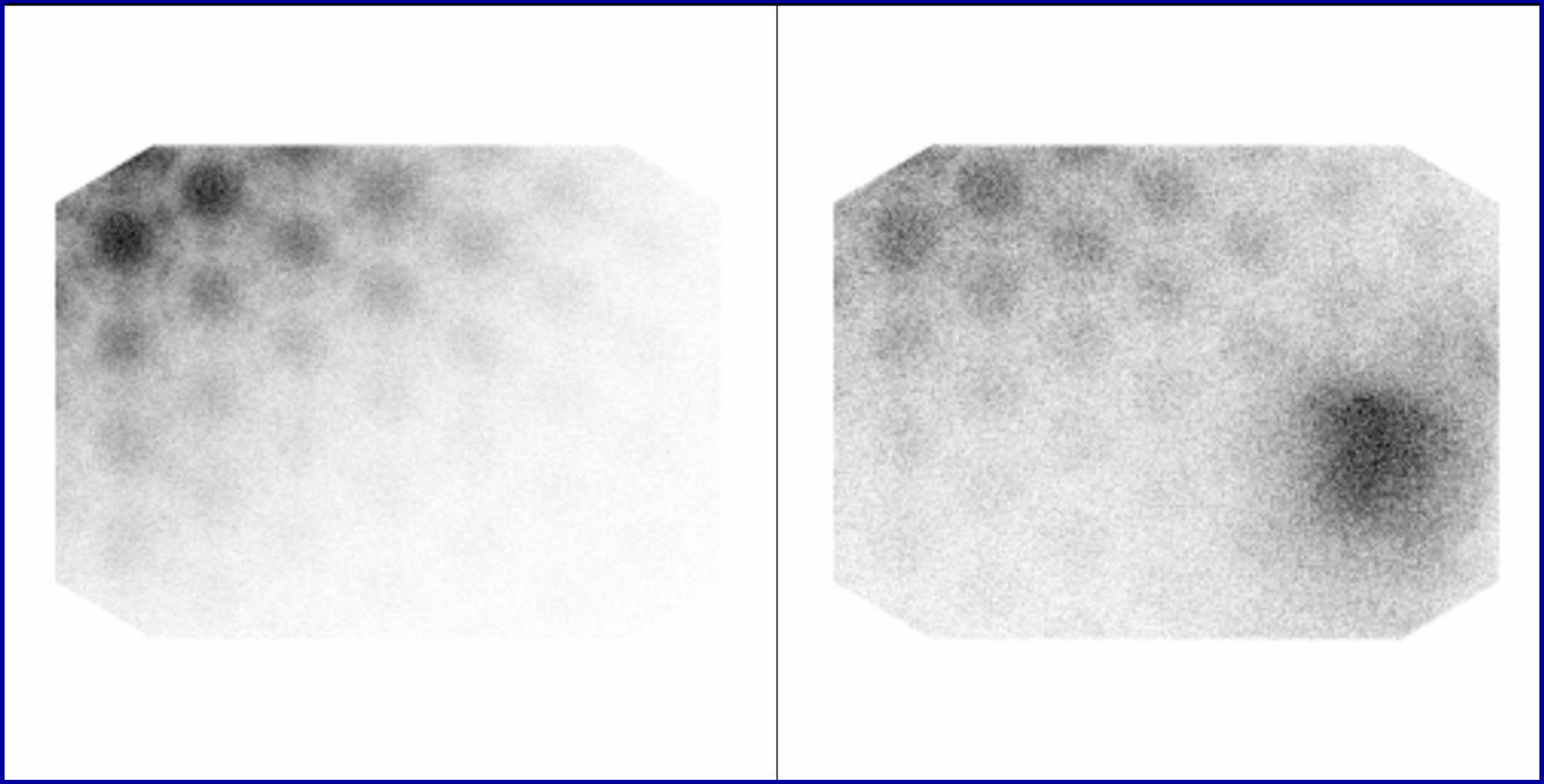
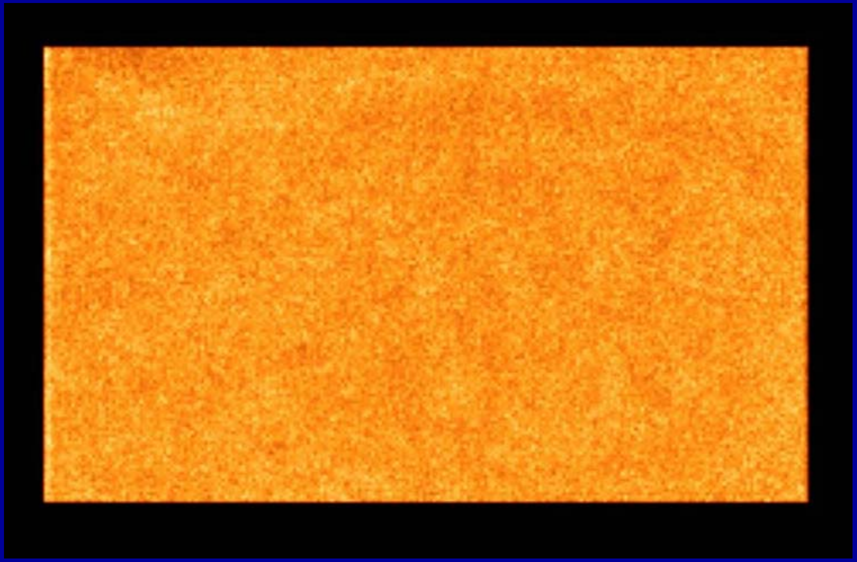


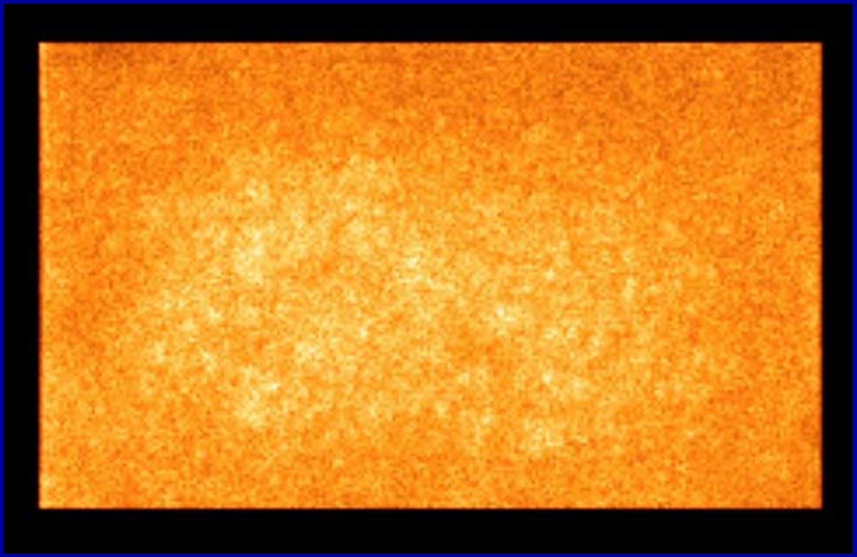
Image made with no other source other than aerosol pulled into camera heads. Tc present behind the crystal. Patient breathed aerosol close to camera heads and leakage occurred around breathing apparatus.

Daily QC – Water filled sheet source with ^{99m}Tc MAA added

Morning QC looked bad



QC repeated with same source later in afternoon



Note “clumping” effect caused by using MAA.
^{99m}Tc MAA (normally used for lung perfusion imaging) was used by mistake. Should use ^{99m}Tc pertechnetate.
Sheet source had to be emptied and rinsed

The End