Scintillation Camera Part 2

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Nov. 3, 2016

- RSNA/AAPM Physics Module 17.5 (Phys0309)
https://www.rsna.org/RSNA/AAPM_Online_Physics_Modules_.aspx
- Review of Radiologic Physics, W. Huda.
- The Essential Physics of Medical Imaging by Bushberg at al.
- Physics in Nuclear medicine, 3^{rd} ed. by Cherry et al.

17.5. Scintillation Camera

17.5.3. review -Collimator Characteristics (parallel hole)

Sensitivity, Resolution & camera components

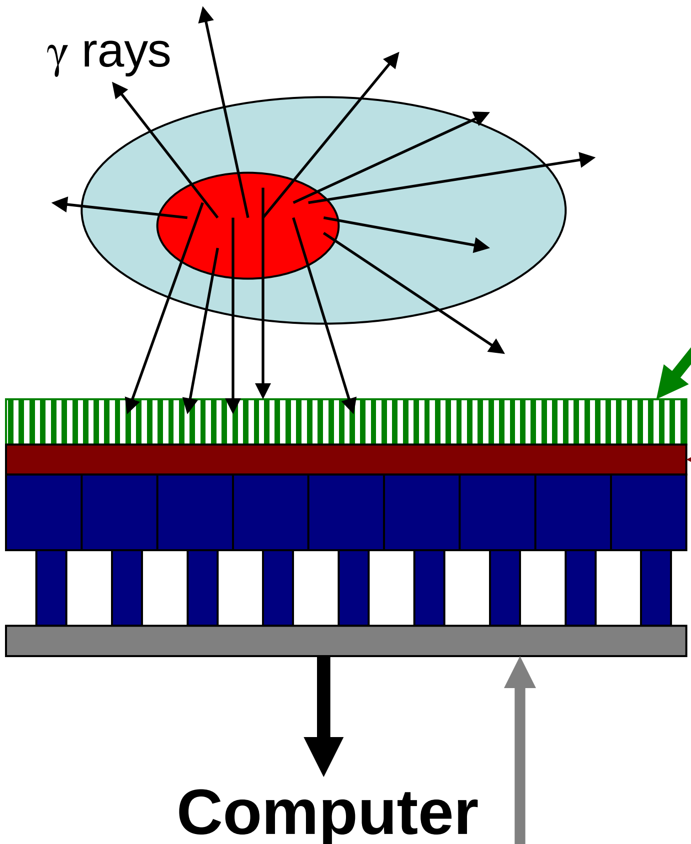
17.5.5 Image Acquisition

17.5.6 Image Processing

17.5.7 Measure of Performance

17.5.8 Artifacts

Summary of Gamma Camera



Collimator Define the direction of the detected γ rays. Major component affecting resolution and efficiency.

scintillation crystal γ ray detector. Emits light photons after deposition of high energy γ rays.

Photomultiplier tube (PMT) Each tube converts a light signal to an electrical signal and amplifies it.

Preamplifier, Positioning circuit & pulse height analyzer

Determines the location of each scintillation event.
Rejects non-photopeak events.

Summary of Collimator Characteristics

Collimator selection requires consideration of imaging object's location and size, energy of gamma rays, and desired resolution and sensitivity.

- Energy : low energy collimator (Tc-99m, Tl-201)
  medium energy collimator (Ga-67, In-111),
  high energy collimator (I-131)

  Thicker septa to reduce septal penetration

- Resolution : Low-energy high resolution (LEHR)
  Low-energy Ultra-high resolution (LEUHR)

- Sensitivity : Medium- or Low-energy general-purpose collimator (MEGP, LEGP) → poor resolution

1. Which is not correct way of increasing the useful counts for NM whole body images?
   a. Increase the administered activity
   b. Increase imaging time
   c. Move the patient closer to the gamma camera
   d. Use a higher sensitivity collimator

2. What is dynamic images?
   a. Image that is acquired for a preset time interval
   b. image that is acquired until total number of counts in the image reaches a preset number
   c. for a preset time per image, a series of images is acquired one after another
   d. A pair of images that are stored in a list

3. For an extrinsic gamma camera uniformity calibration, which of the following is TRUE?
   a. A Co-57 sheet source is used with collimator on
   b. A Co-57 sheet source is used with the collimator removed
   c. A Tc-99m point source is used in a syringe, at a distance more than 4 times the diameter of the detector with the collimator on
   d. A Tc-99m point source is used in a syringe, at a distance more than 4 times the diameter of the detector with the collimator removed.

4. Gamma camera intrinsic resolution and linearity are evaluated weekly using:
    a. A four-quadrant bar phantom
    b. A NEMA phantom
    c. A point source
    d. A wedge phantom
    e. Flask

5. How do we test whether the gamma camera accurately portrays the shapes of object or not?
    a. Uniformity
    b. Spatial linearity
    c. Multi energy spatial registration
    d. System efficiency

6. The intrinsic resolution of a gamma camera is 3mm FWHM and the collimator resolution measured for a point source at 10cm is 10mm FWHM. What is the system resolution in FWHM at 10cm?
    a. ~3 mm
    b. ~10 mm
    c. ~13 mm
    d. ~3.6 mm
    e. Need more information

$$R_{sys} = \sqrt{R_{int}^2 + R_{coll}^2} = \sqrt{10^2 + 3^3} = 10.4\text{mm}$$

7. Which of the following needs to be tested daily before patient imaging?
    a. Spatial resolution
    b. Uniformity
    c. Contrast resolution
    d. Sensitivity

8. Measures of performance of a gamma camera with the collimator attached are called "system measurements" (T/F)

9. PMT failure can produce a "HOT" defect. (T/F)

10. Images with off-peak energy window on the low side of photopeak contain more useful photons and improve image quality. (T/F)

11. Intrinsic resolution of gamma camera is measured without the collimator (T/F)

12. A narrower energy window can improve image contrast (T/F)

13. Common image format for planar NM images is 512x512 pixels. (T/F)

14. Sensitivity of a gamma camera equipped with a low-energy high-resolution (LEHR) collimator and a 3/8 inch thick detector is ~ 200 cpm/µCi. (T/F)

15. Resolution of a gamma camera is equivalent to that of CT. (T/F)

17.5.5 - Image Acquisition

Frame mode :

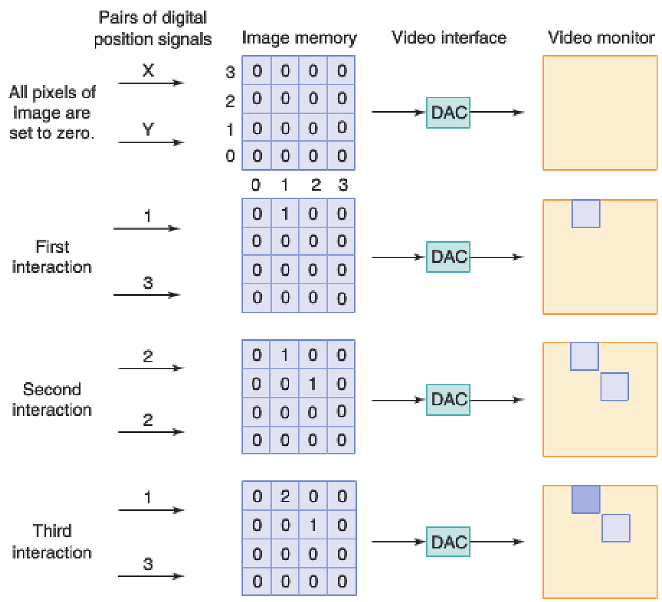
• a portion of the computer's memory is dedicated for the image.

(form images directly as part of the acquisition)

Listmode :

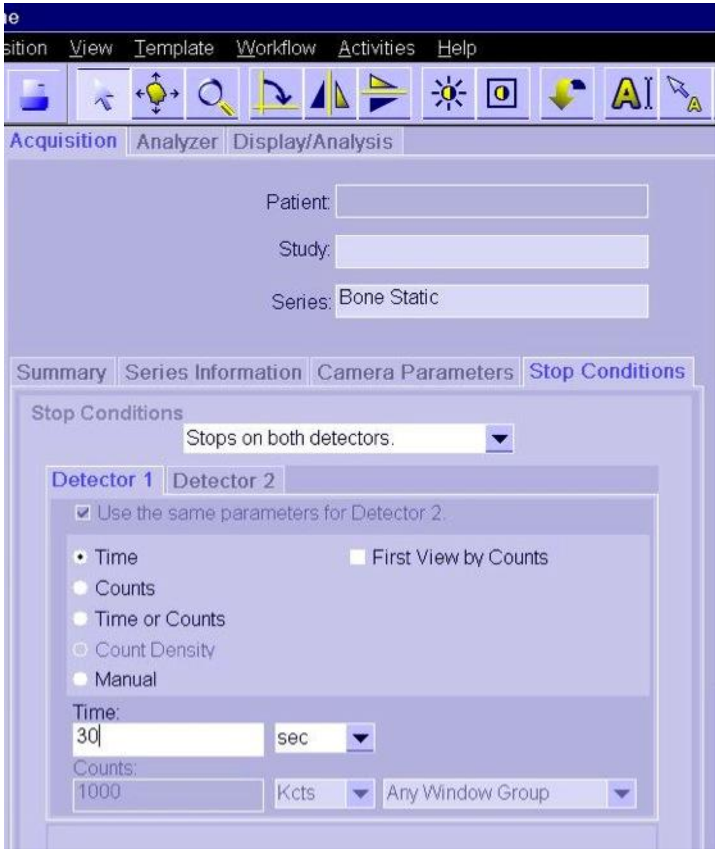
- the pair of (x,y) values are stored in a list, instead of being immediately formed into an image,
- and then replayed to create images

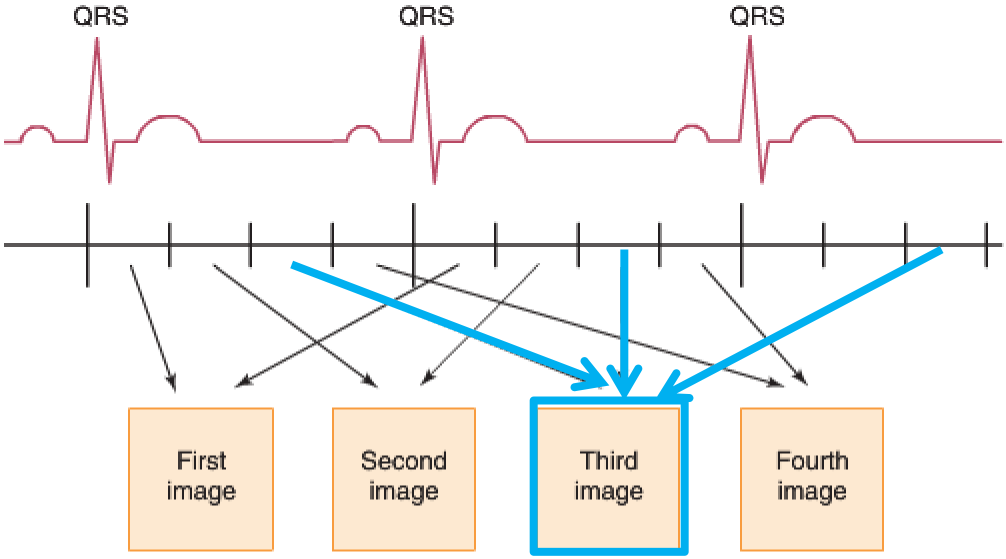
Frame mode



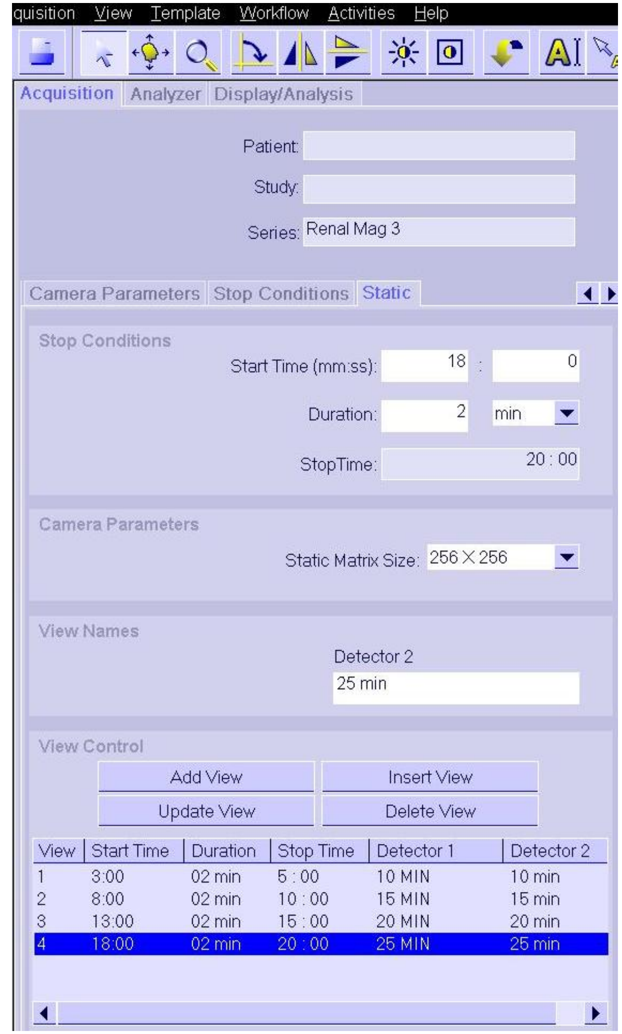
17.5.5 - Image Acquisition : Frame mode

- **static** : a single image is acquired for either a preset time interval or until total number of counts in the image reaches a preset number.
- **Dynamic** : a series of images is acquired one after another, for a preset time per image.
- **Gated** : for a repetitive dynamic process. Used for evaluating cardiac or for respiratory motion correction





17.5.5 - Image Acquisition (static & dynamic)

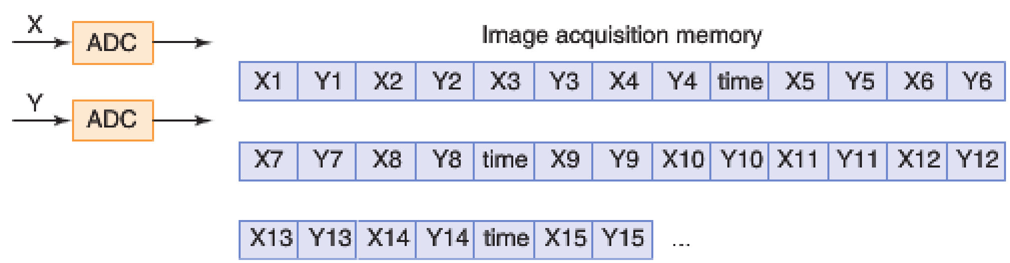


17.5.5 - Image Acquisition : Listmode

Listmode :

- After acquisition is completed, data are reformatted into conventional images for display
- Periodic timing marks are included in the list, e.g. physiologic monitor trigger mark

List mode



17.5.6 - Image processing

Region of Interest (ROI)

•closed boundary that is superimposed on the image.

•May be drawn manually or automatically by the computer

•Sum, max, min, mean, standard deviation …

Time-activity curve (TAC)

- For a given ROI on a dynamic (or gated) image sequence, the counts within ROI are plotted as a function of time.

Blood TAC
Organ/Tissue TAC

17.5.6 - Image processing

- Example : Renal scintigraphy using Tc-99m MAG-3 images
- Dynamic acquisition, e.g.15 sec x 80 frames
- Used for evaluation of renal function including effective renal plasma flow (ERPF),

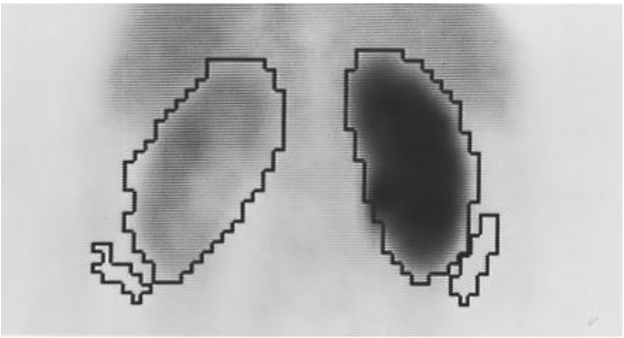
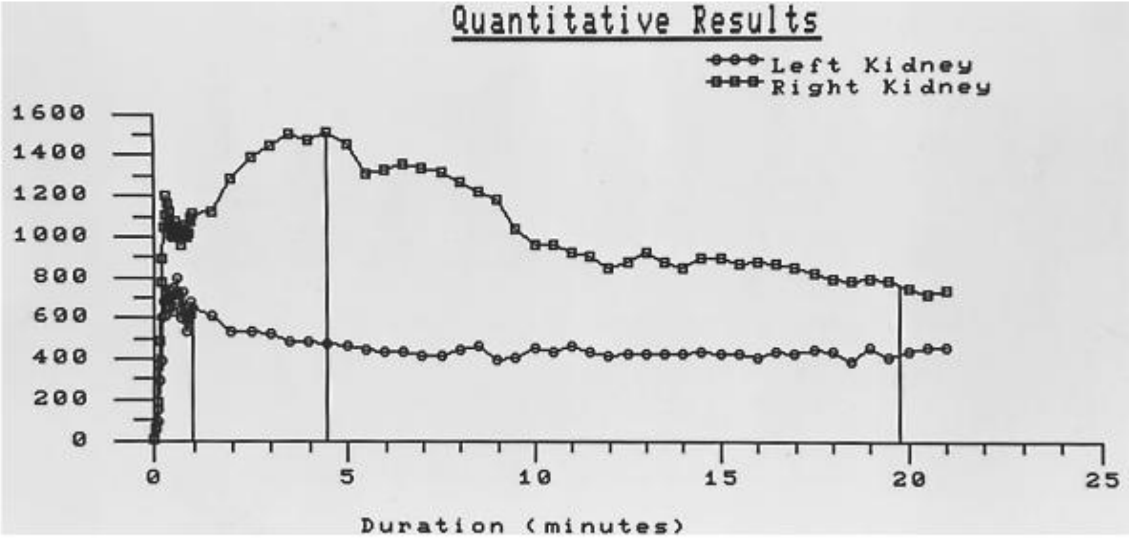


FIGURE 18-21 Regions of interest (**bottom**) and time-activity curves (**top**).

ROIs over both kidneys & background

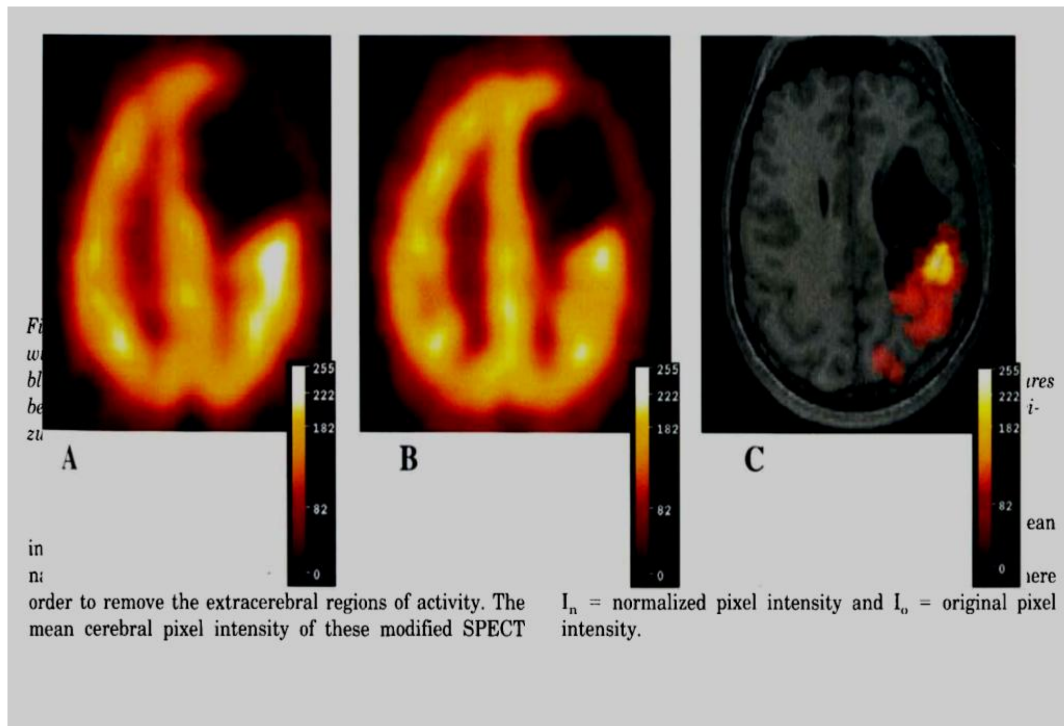


TACs describing the uptake and excretion of the radiopharmaceutical

Bushberg. p702

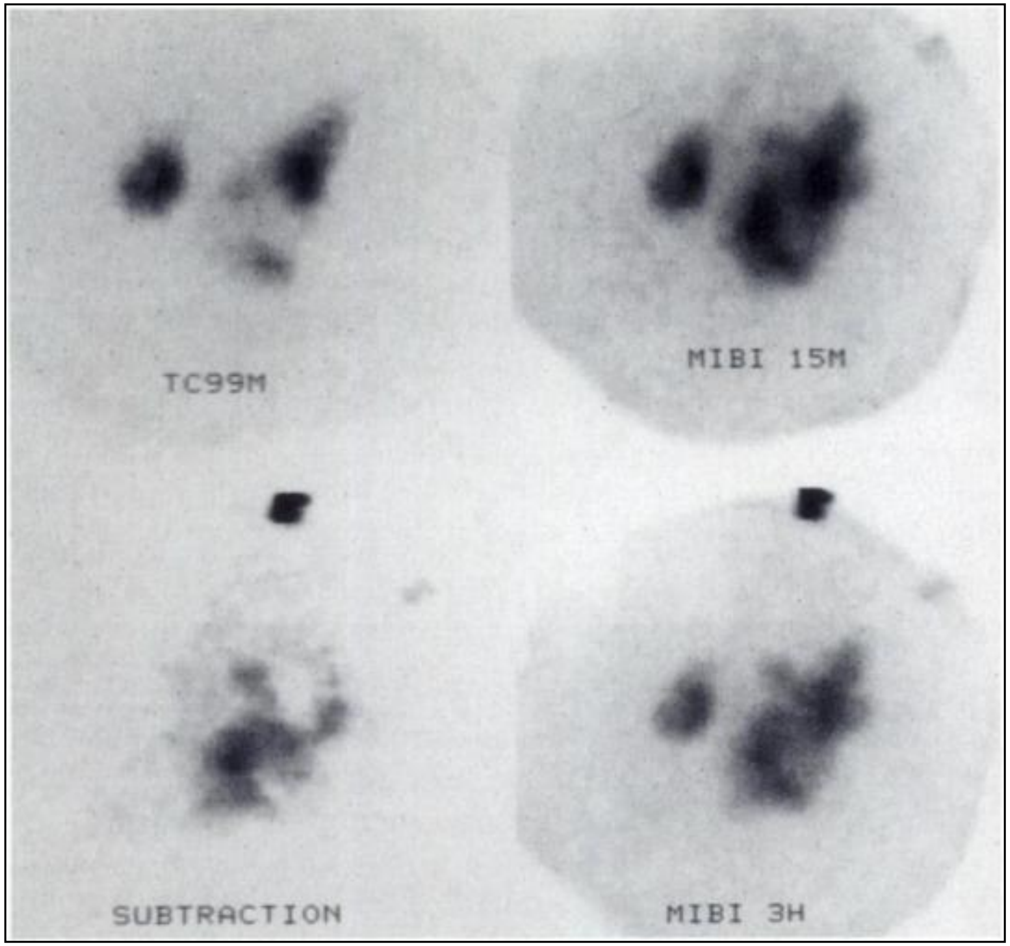
<u>Image Subtraction</u>

- One image is subtracted from another.
- The resultant image depicts the change in activity in the patient during the time interval between the acquisitions of the two images.
- E.g., Dual-phase, or dual-isotope scintigraphy/SPECT
- Qualitative or quantitative



NEUROLOGY
1998;50:445-454

17.5.6 - Image processing : Subtraction



If MIBI > Tc, considered positive for abnormal parathyroid tissue

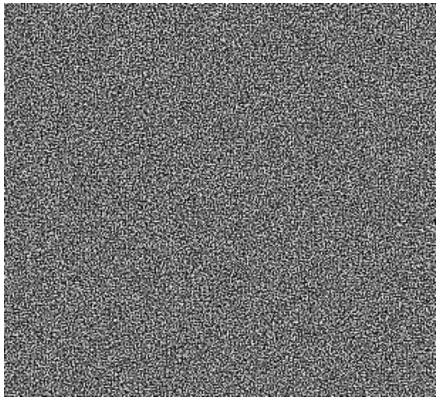
J. Nucl. Med 1997 28(6):834-839

Spatial Filtering

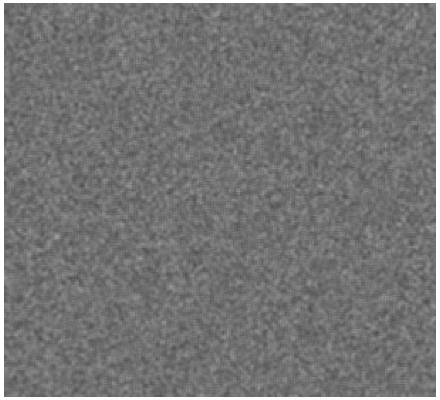
•Process of reducing a grainy appearance due to the statistical nature of the acquisition process

•"smoothing" → convolution filtering → reduces spatial resolution

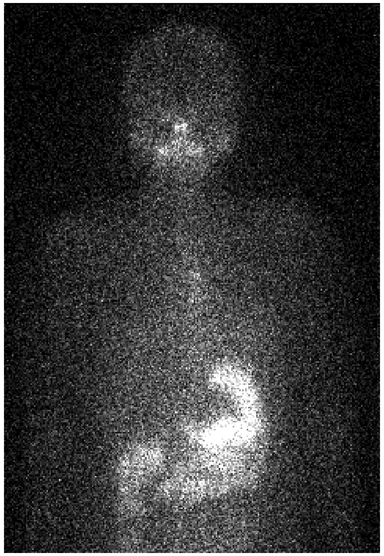
•Applied to both static and dynamic images



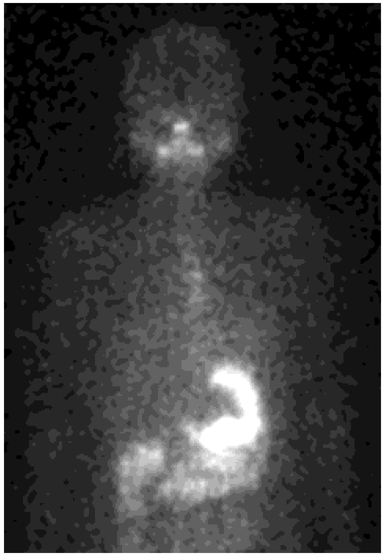
Mean = 18
Stdev = 12.3



Mean = 18
Stdev = 1.5



With filter



Temporal Filtering

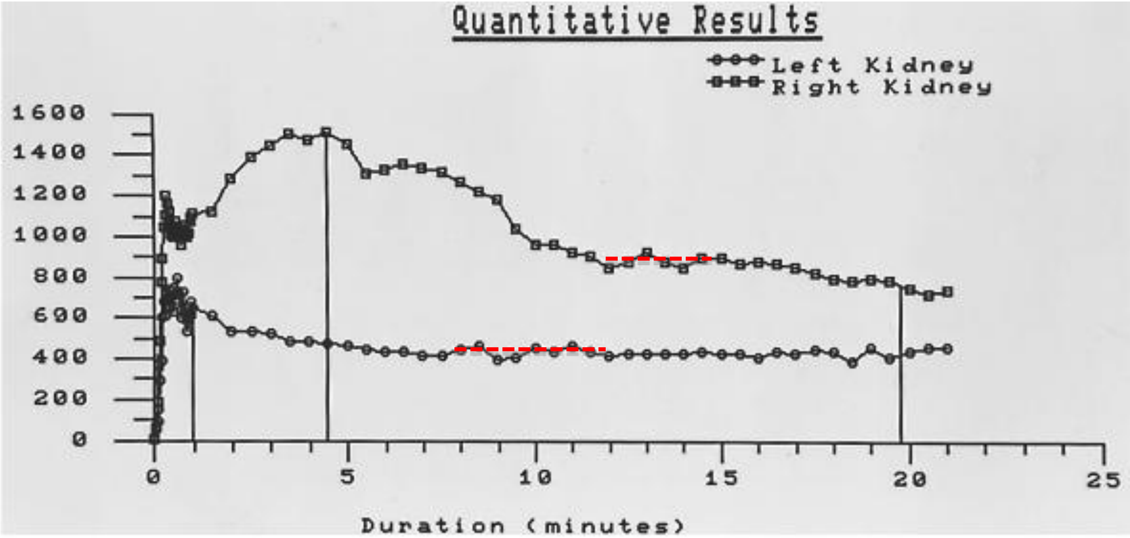
•Used on dynamic images

•To reduce the effects of statistical variation particularly in low count images.

•Involve a weighted averaging technique between each pixel on one images and the same pixel from the frames before and after.

•Causes a loss of spatial resolution, but allows a cine loop to be viewed without flicker.

•Usually both spatial and temporal filters are applied.



17.5.6 - Left-Ventricular Ejection Fraction (LVEF)

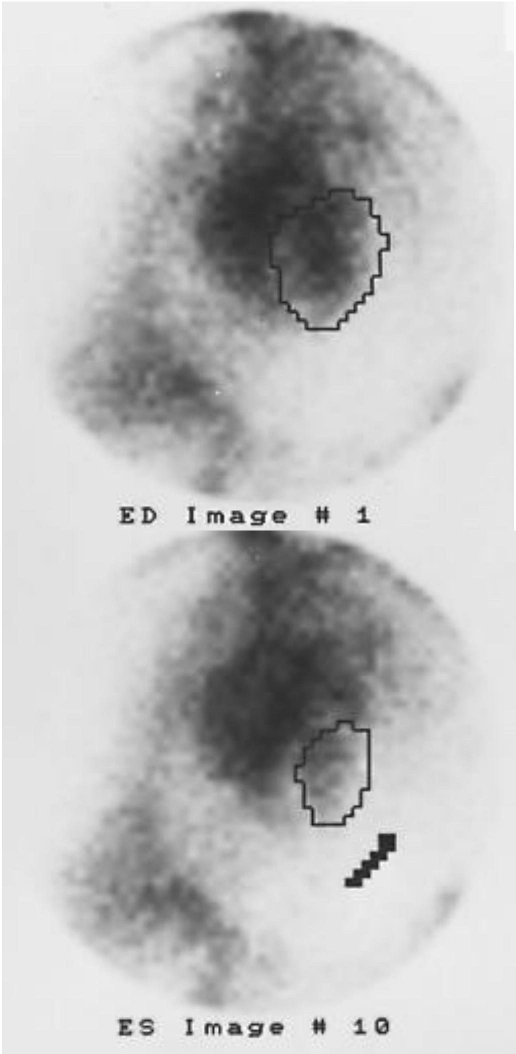
LVEF is a measure of the mechanical performance of the left ventricle of the heart.

$$LVEF = \frac{V_{ED} - V_{ES}}{V_{ED}}$$

V_{ED} : the end-diastolic volume
V_{ES} : the end-systolic volume

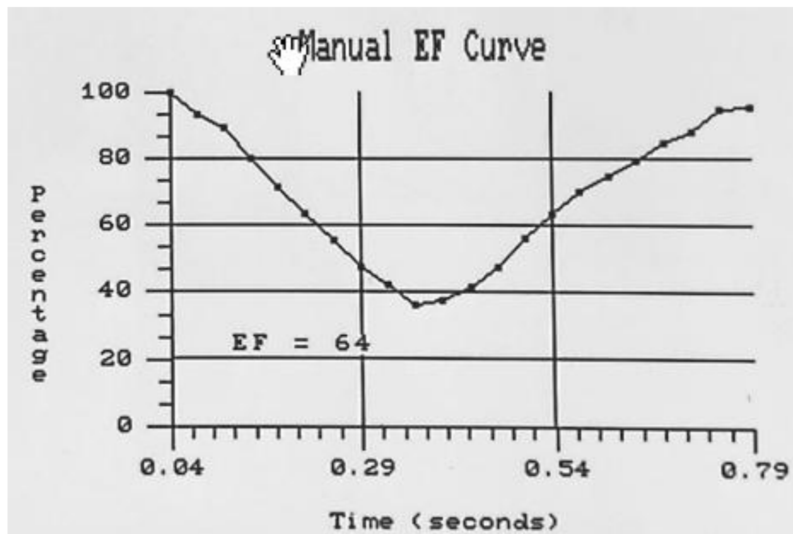
- **Gated blood pool image** sequence using Tc-99m red blood cells
- Left anterior oblique (LAO) projection at an angle demonstrating the best separation of the two ventricles.
- ~ 10min acquisition (~6M counts)
- <u>LV counts are proportional to LV volume throughout the cardiac cycle</u>
- Background counts need to be subtracted

17.5.6 - Left-Ventricular Ejection Fraction (LVEF)



EF Statistics

Total ED Counts:	21700
Net ED Counts:	16811
Total ES Counts:	8492
Net ES Counts:	6032
Avg Background Counts:	31
Heart Rate:	75



Bushberg. p703

$$LVEF = \frac{16811 - 6032}{16811} \times 100 = 64\ \%$$

17.5.7 - Measures of Performance

Important step for the highest image quality

- **Extrinsic (system)** : measures of the performance **with** the collimator
- **Intrinsic** : measures of the performance **without** the collimator

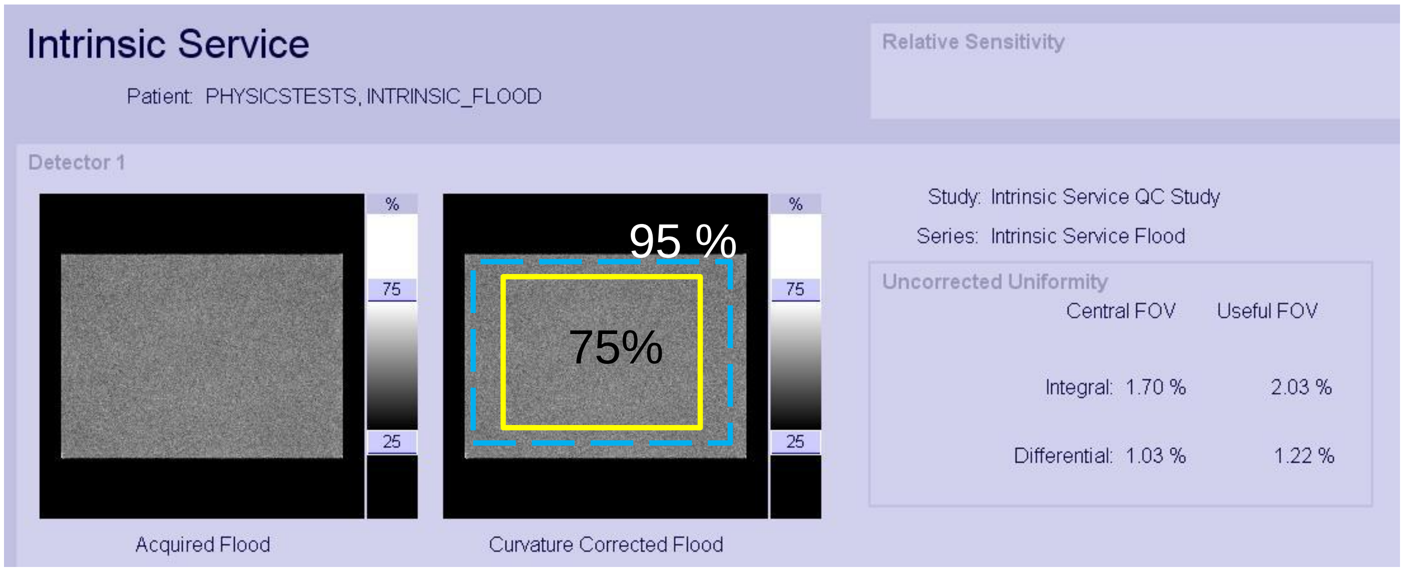
Intrinsic Uniformity

measure of camera response to uniform irradiation of the **detector surface**

A syringe source placed at 4-5 times the largest side of the detector (<100 μCi Tc-99m)

17.5.7 - Uniformity

Intrinsic Uniformity	Daily verification : ~ 10M counts (before patient imaging) Monthly calibration : ~200M counts (used for data correction)



< 4-6 %

Monthly Uniformity correction

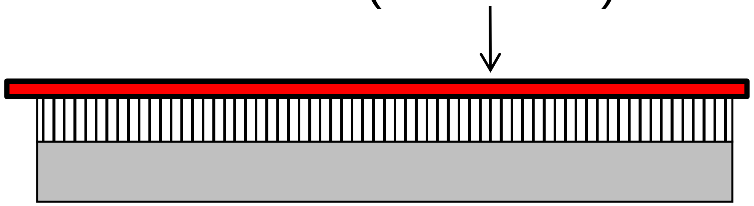
- Integral uniformity searches the entire flood to find the max and min pixel values
- Differential uniformity looks at changes in pixel values over short segments of the flood (find the highest & lowest pixel values within a five-pixel segment)

17.5.7 - Measures of Performance

Extrinsic Uniformity

- **Extrinsic Uniformity (system uniformity)** : measures of the performance **with** the collimator

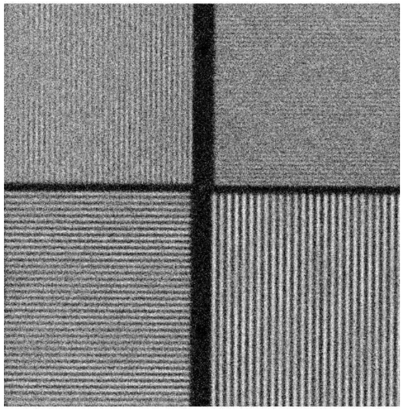
Co-57 planar source
(5 ~ 10mCi)



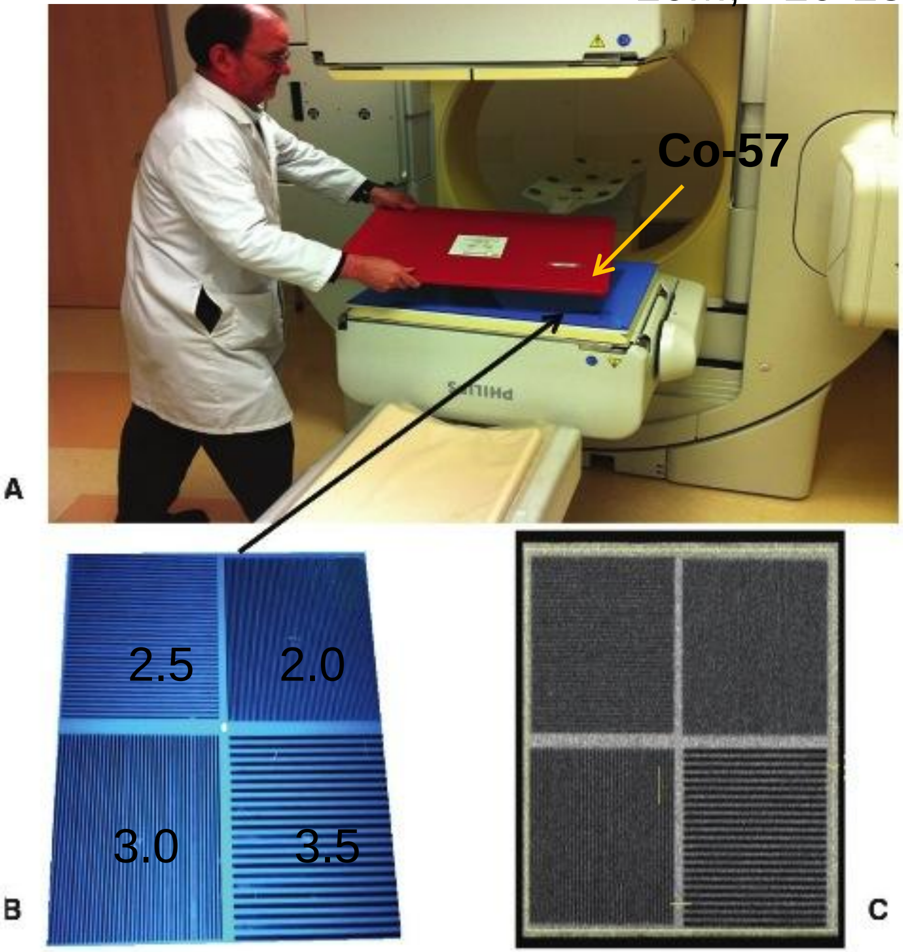
Co-57 : 123 keV
270 day halflife

17.5.7 Spatial resolution

Intrinsic



extrinsic 10M, ~10-15mi



Bar phantom Acquired image

3.0mm bars visible → 1.7 x 3.0 = 5.1 mm

Some of 2 mm bars visible → 1.7 x 2.2 = 3.7 mm

Weekly QC

System Resolution

System resolution determined the sharpness of images.

- intrinsic resolution
- Collimator resolution

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

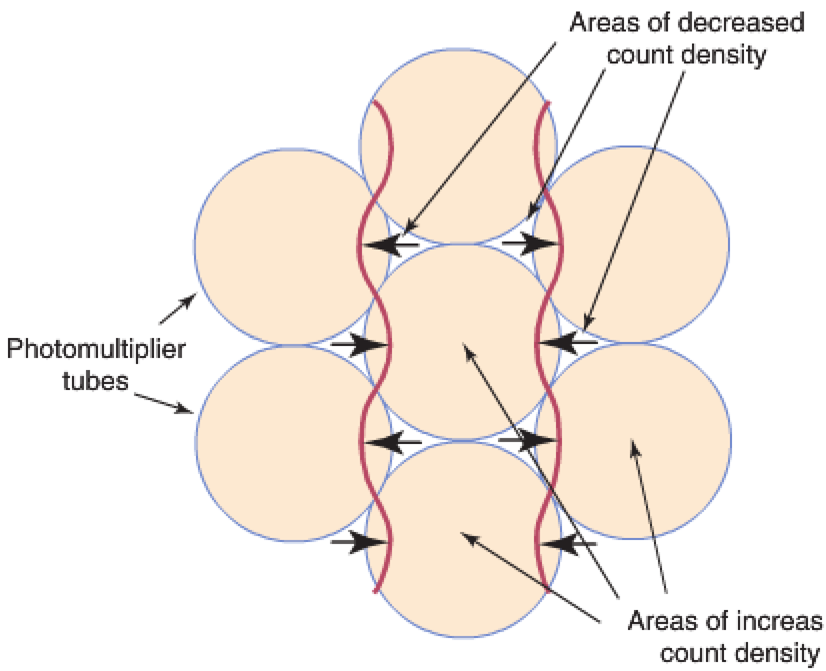
Example $\quad R_{coll}$ = 1 cm and R_{int} = 0.3cm

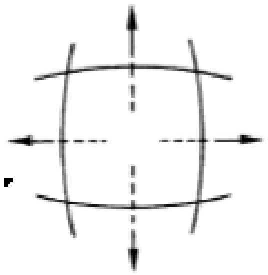
$$\mathrm{R_{sys}} = \sqrt{\mathrm{R_{int}^2} + \mathrm{R_{coll}^2}} = \sqrt{1.0^2 + 0.3^3} = 1.04\mathrm{cm}$$

determined primarily by collimator resolution

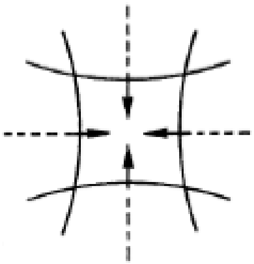
17.5.7 - Spatial linearity

- A measure of the camera ability to portray the shapes of objects accurately.
- Images of bar phantom
- Position circuit causes the locations of individual counts to be shifted toward the center of the nearest PMT.



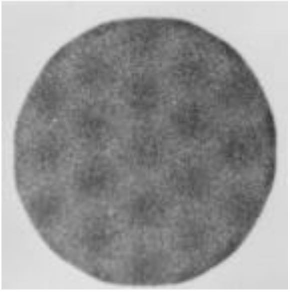


"Barrel" distortion

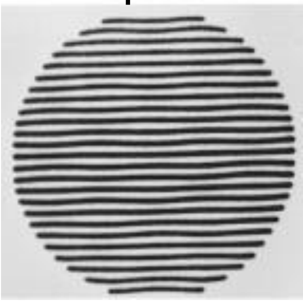


"Pincushion" distortion

Uniform Flood



Bar pattern



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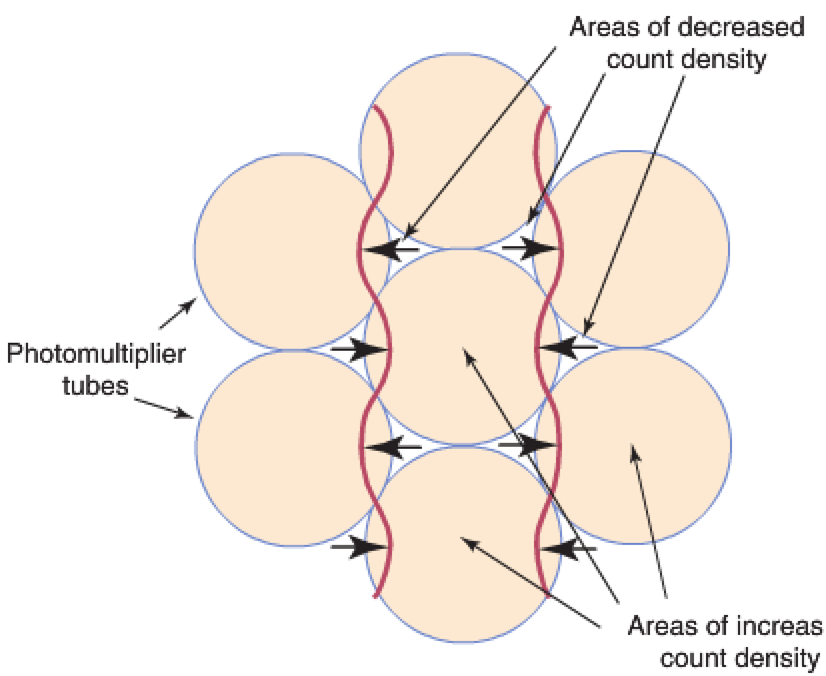
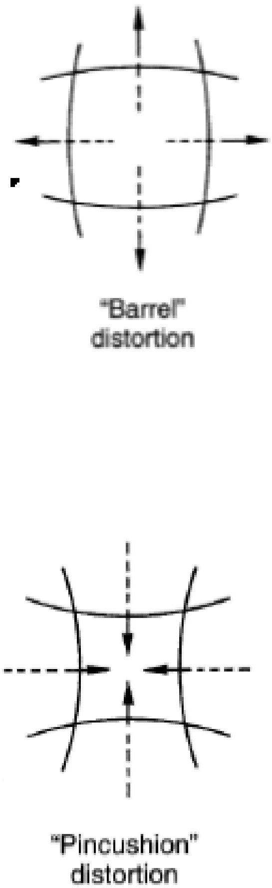
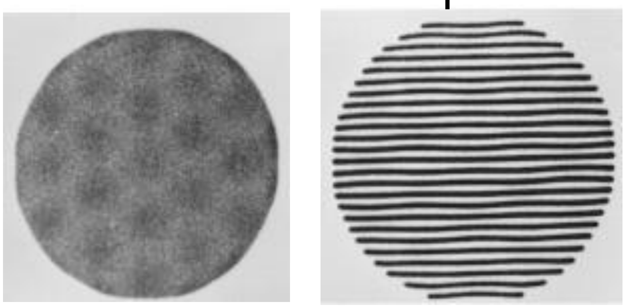
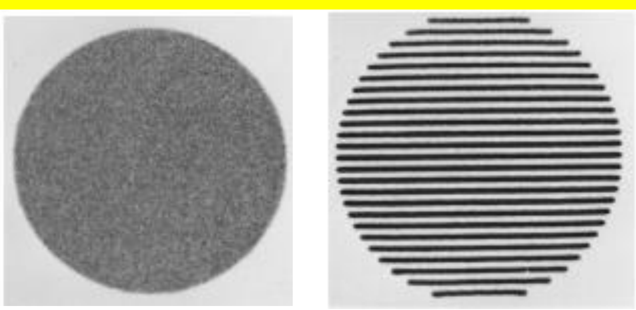




Uniform Flood   Bar pattern



After correction (tuned, uniformity)



17.5.7 - Measures of Performance

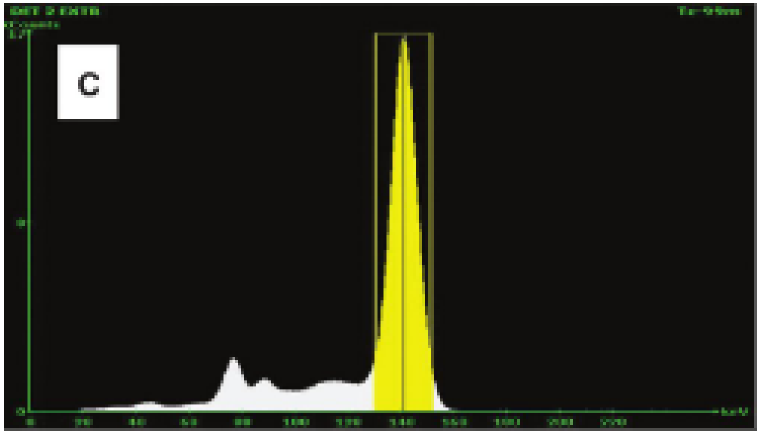
Multienergy (multiple window) spatial registration

- A measure of the camera's ability to maintain the same image regardless of the energies deposited in the crystal by the incident gamma rays.
- Position is independent of the deposited energy

  e.g. Ga-67 with 93keV (40%), 185keV (20%), & 300keV (22%)

Energy Resolution

- Ability to distinguish between interactions depositing different energies in crystal
- FWHM of photopeak divided by the energy. (%).



~ 10 % for Tc-99m

17.5.7 - Sensitivity (efficiency)

Fraction of gamma rays emitted by a source that produces counts in the image

System efficiency (Es) = (Ec) * (Ei) * (f)

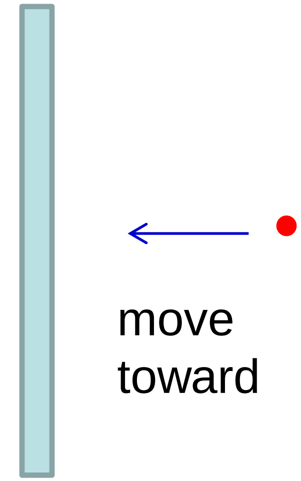
Ec : collimator efficiency (~ 0.02%)
Ei : intrinsic efficiency (~80-90%)
f : fraction of accepted by the energy discrimination circuits (0~1)

- 150-200 µCi Tc-99m layer in flask.
- Acquire for 2min and obtain the total counts (after background subtraction)

~200 CPM / µCi per detector (LEHR, Tc-99m)

17.5.7 - Count-rate performance

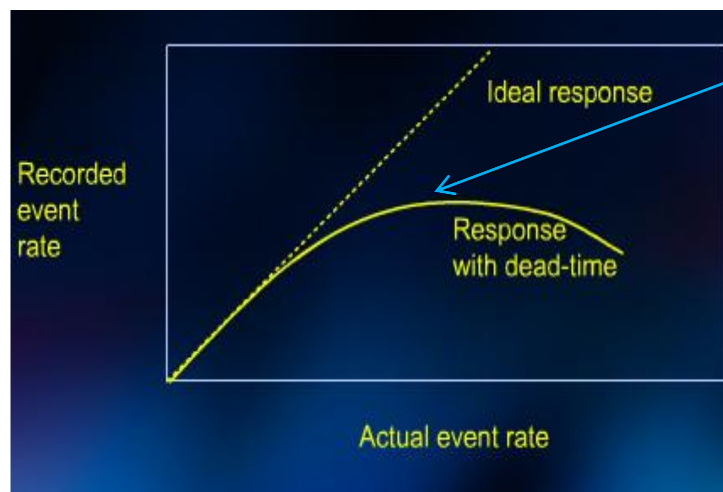
- Determine the maximum count rate above which paralyzing dead-time effect
- Measured intrinsically (remove collimator)
- Use ~500 μCi Tc-99m
- Move the source toward the detector. → the count rate will increase
- The count rate will increase to a maximum and then fall as the source near the detector.
- Determine the maximum count rate (decrease if camera system performance degrades)



Typical max count rate > 300 kcps

Dead-time

Ratio of recorded count rate and actual count rate is dead-time



max

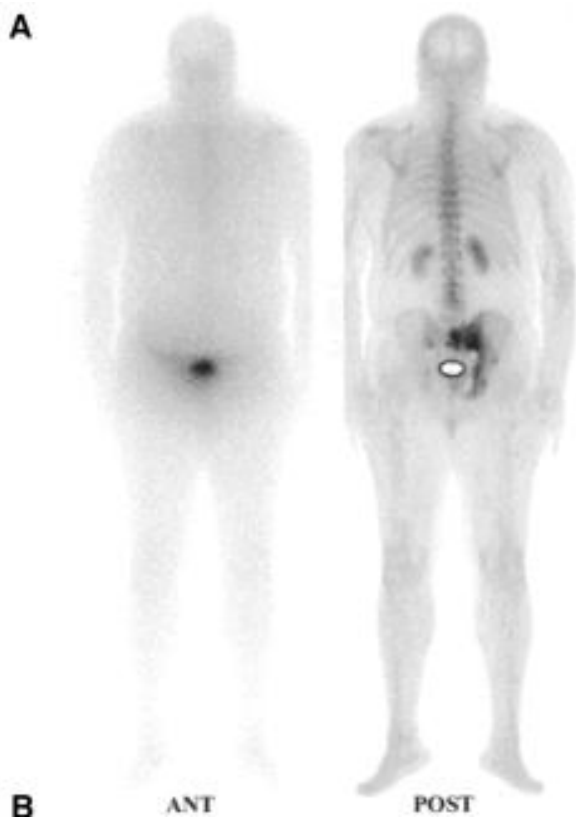
17.5.7 - Artifacts

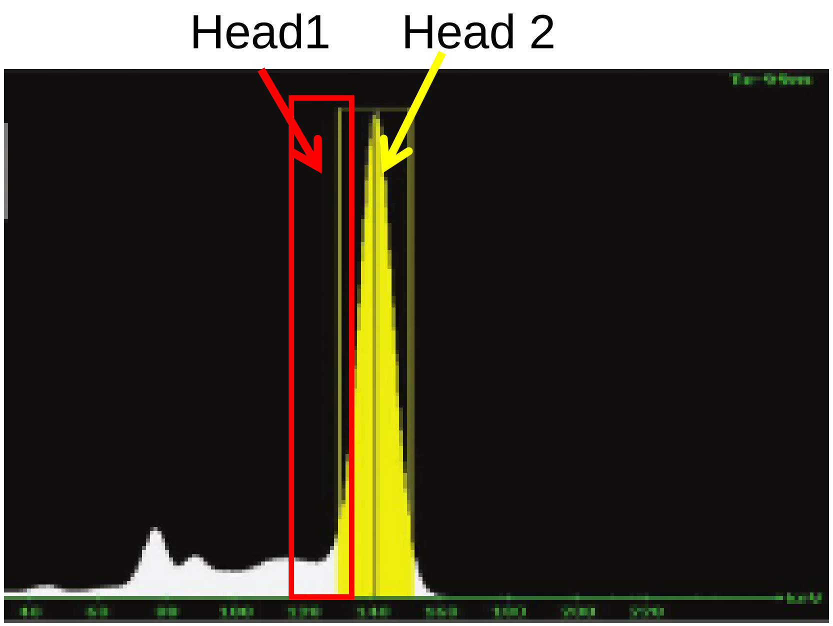
- Damaged or Broken Crystal
- Non-uniformity
- Bad PMT
- Improper Energy peaking
- Mechanical separation of coupling elements
- Damaged collimators

- Wrong collimator selection
- Motion : patient motion, respiratory and cardiac motion.
- Dual isotope : all QCs should be done for both radionuclides

Off-peak artifact (improper energy window)

Tc-99m MDP WB bone scan





Head I was found to be off-peak (secondary to malfunction of a PMT)

→The malfunctioning PMT was replaced

1.J. Nucl. Med. Technol.**September 1, 2003** vol. 31 no. 3 **165-169**

17.5.7 - Cracked crystal

What happens if your crystal gets cracked?

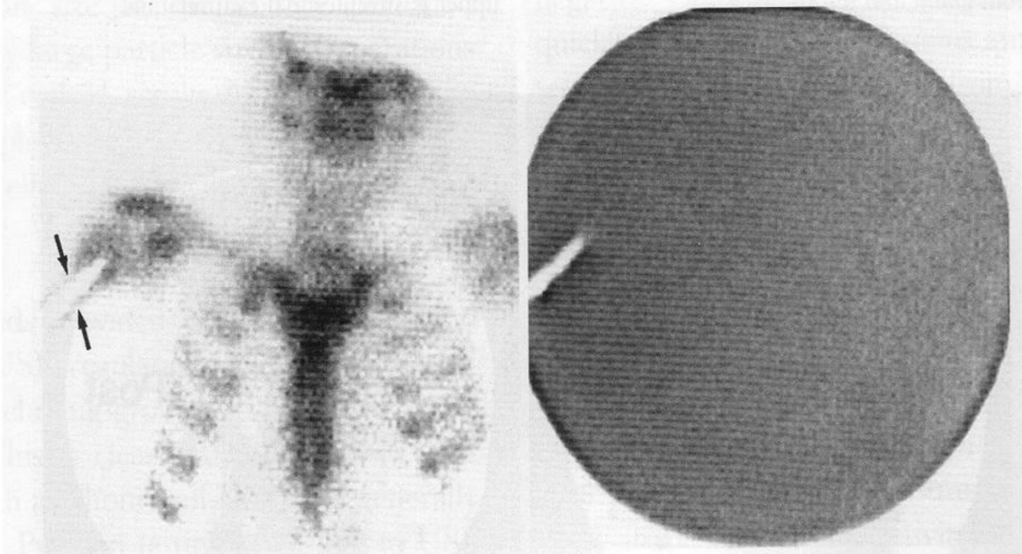


FIGURE 3–18. Cracked crystal artifact. *Left,* A linear area of decreased activity is seen over the upper right humerus (*arrows*). This was due to a cracked crystal in the gamma camera, as evidenced by the linear defect seen on the flood-field image (*right*).

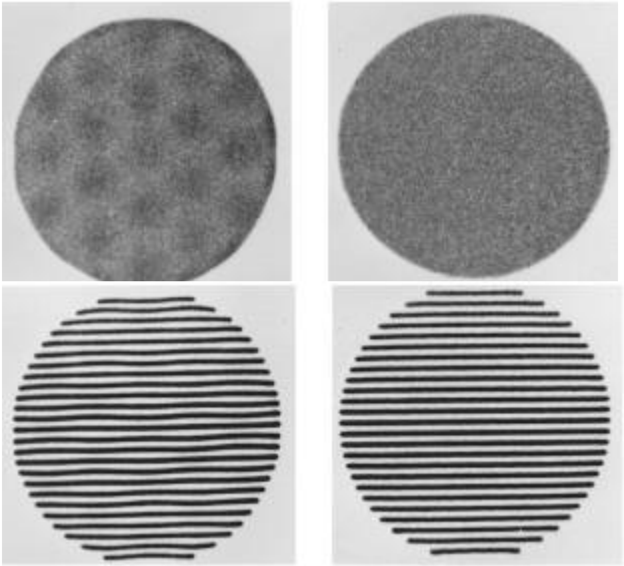
Do your QC!

Figs 3-18, "Essentials of Nuclear Medicine Imaging", Mettler and Guiberteau

17.5.7 - Non-uniformity

Caused by

- Spatial nonlinearity : systematic mispositioning of events
- Non-uniform detection efficiency : position dependent efficiency, different PMT response.



uncorrected corrected

Cherry & Bushberg

What happens if you lose a PMT?

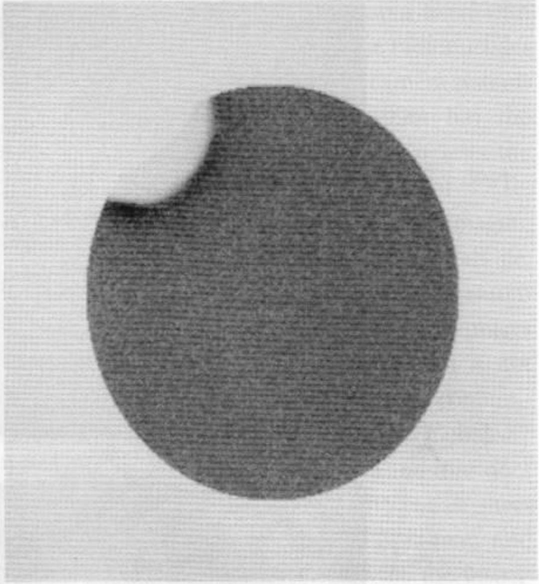


FIGURE 3–4. Photomultiplier defect. The flood field image shows a peripheral cresentic defect due to a non-functioning photomultiplier tube (PMT).

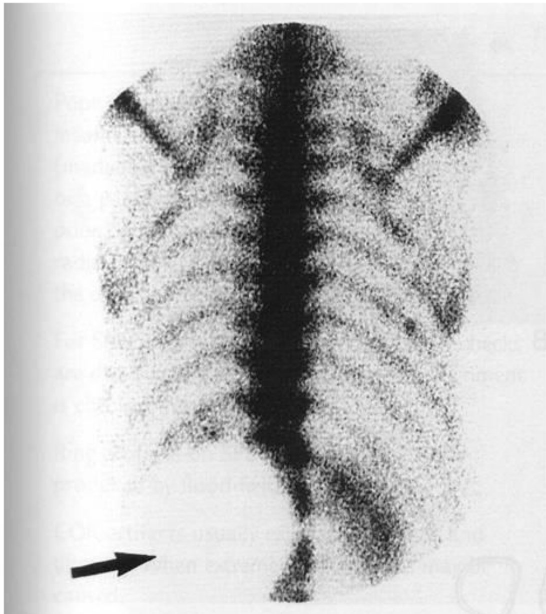
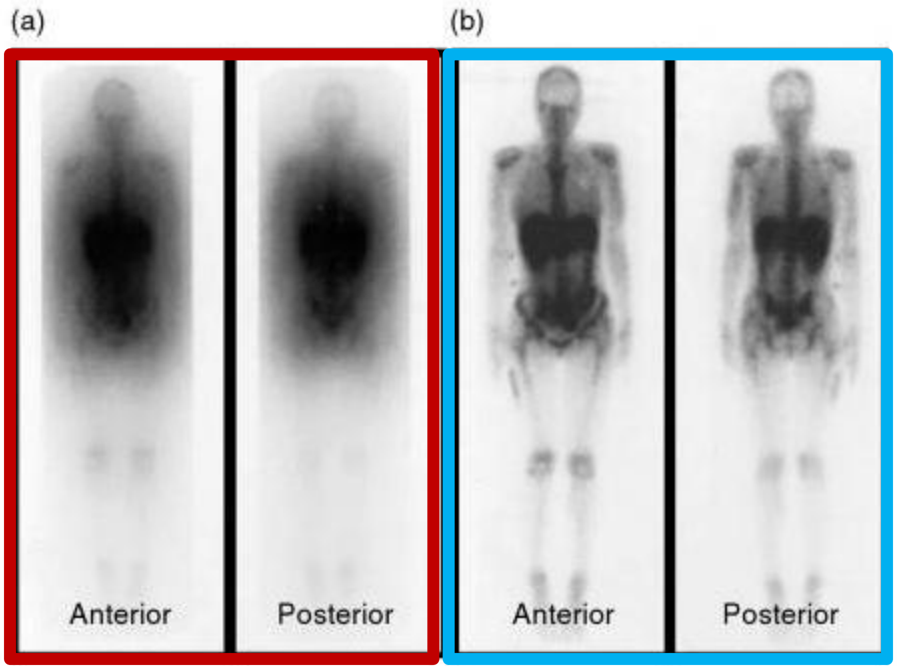


FIGURE 3–19. Photomultiplier tube (PMT) artifact. A nonfunctional PMT caused a round, focal defect (*arrow*) on this posterior image from a bone scan.

Optically decoupled PMT

Figs 3-4, 3-19, “Essentials of Nuclear Medicine Imaging”, Mettler and Guiberteau

Wrong collimator



LEAP MEAP

Used Low-energy collimator for a medium-energy radionuclide, Ga-67 tracer.

Emission Tomography: The Fundamentals of PET and SPECT
By Miles N. Wernick, John N. Aarsvold

Collimator defects

Destroyed septa

1	c	9	F
2	c	10	F
3	a	11	T
4	a	12	T
5	b	13	F
6	b	14	T
7	b	15	F
8	T		