SPECT
(ABR 17.k)

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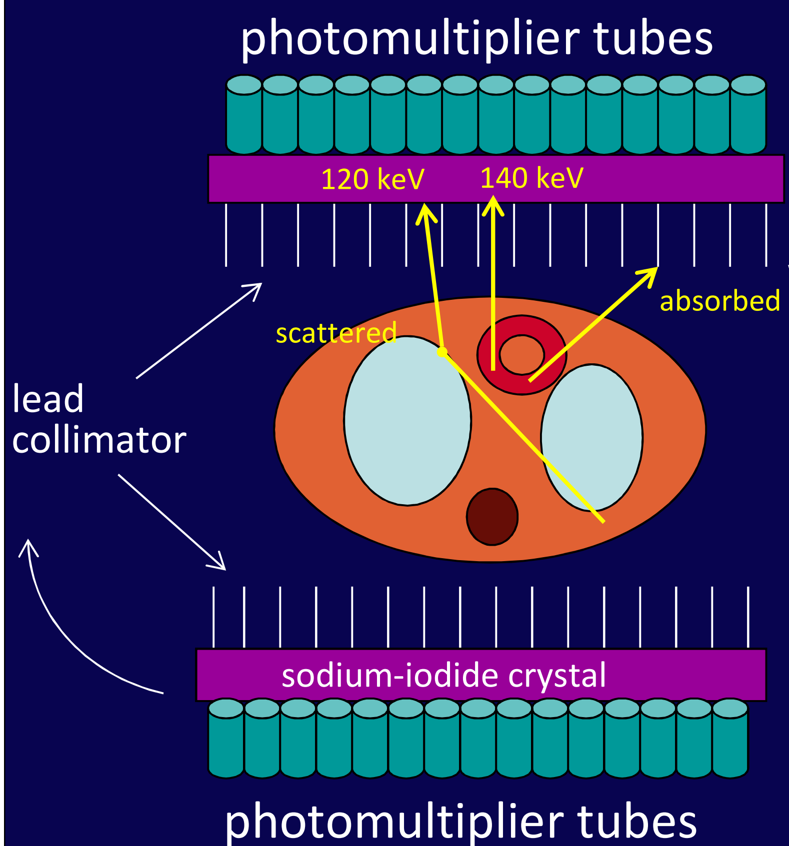
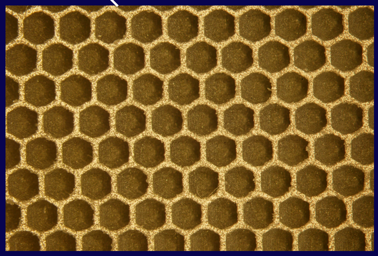
SPECT

- Instrumentation
  - Scintillation camera systems
  - Cardiac systems
  - SPECT/CT
- Quality control
- Corrections
- Accreditation

Conventional scintillation camera systems





1.3mm hex holes
0.3mm septa

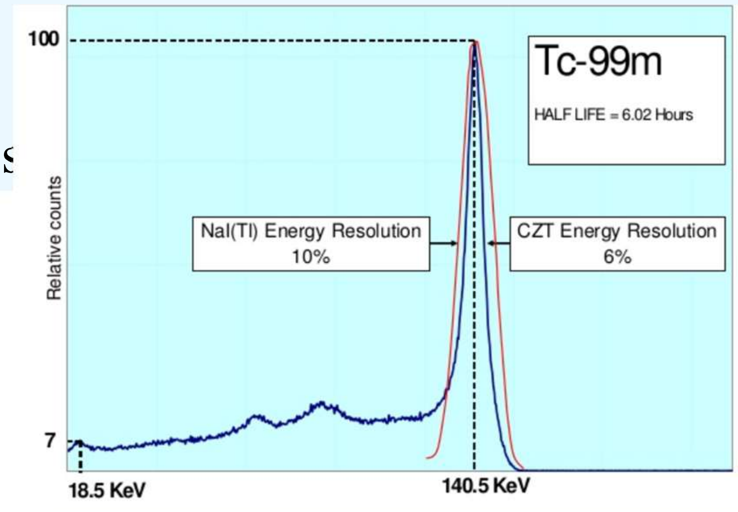
Siemens e.cam SPECT system

1. collimator trade-off: resolution vs. sensitivity
2. each photon's position + energy are measured, one by one,
3. simultaneous imaging of two different physiologic processes is possible, using two different radiotracers

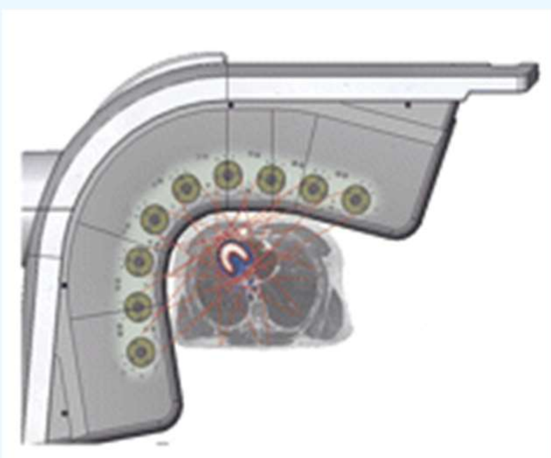
Slide courtesy of Stephen C. Moore, PhD

Dedicated cardiac SPECT systems

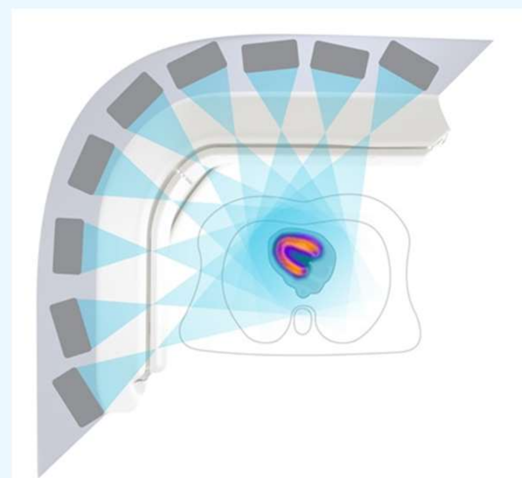
D-SPECT,
Spectrum Dynamics



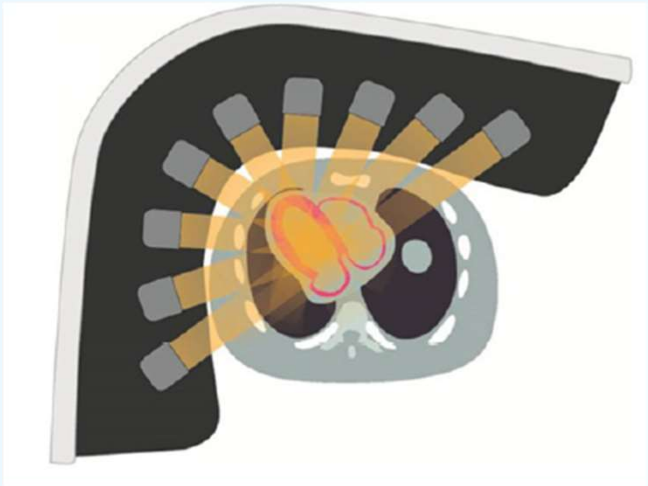
- CZT solid state detector modules (better energy resolution, better intrinsic spatial resolution)
- Small footprint
- High sensitivity
- Resolution recovery

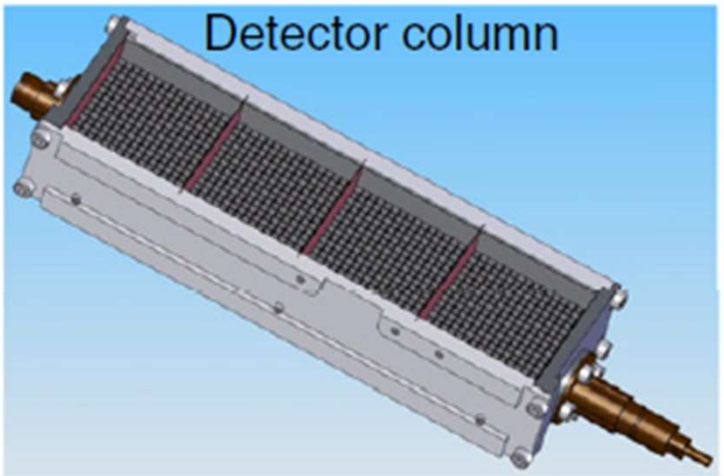


Alcyone system, General Electric



Dedicated cardiac SPECT systems
D-SPECT

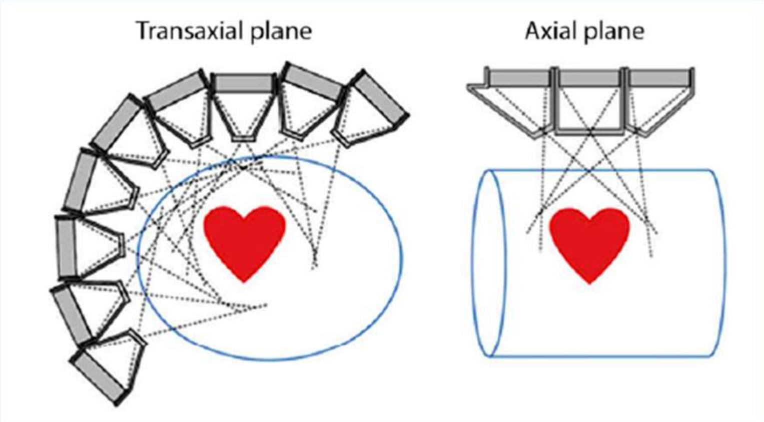


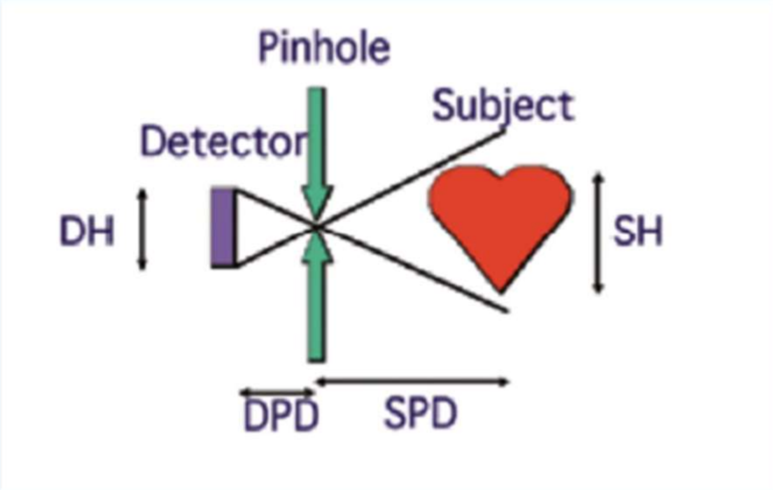


- Parallel hole collimation
- Pixellated CZT detector arrays
- 16 x 64 array of CZT elements
- 2.5 x 2.5 x 5 mm^3
- High sensitivity (scan pattern, large collimator holes)
- Flexible scan pattern

Figures from Slomka P et al., Prog Card Dis 2015; 57:566.

Dedicated cardiac SPECT systems
Alcyone



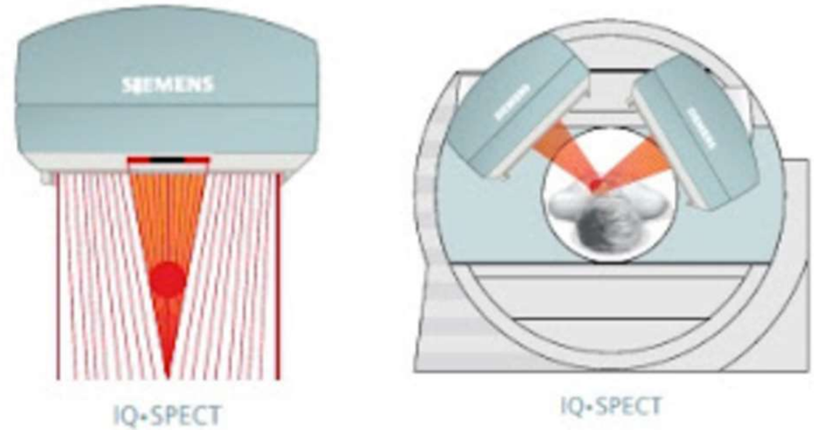


- Pinhole collimation
- 19 CZT detector arrays
- 4 detectors/array
- 16 x 16 CZT elements
- 2.5 x 2.5 x 5 mm^3
- Stationary detectors
- CT option

Figures from Slomka P et al., Prog Card Dis 2015; 57:566.

SPECT-CT Systems

Siemens Symbia-T SPECT-CT System



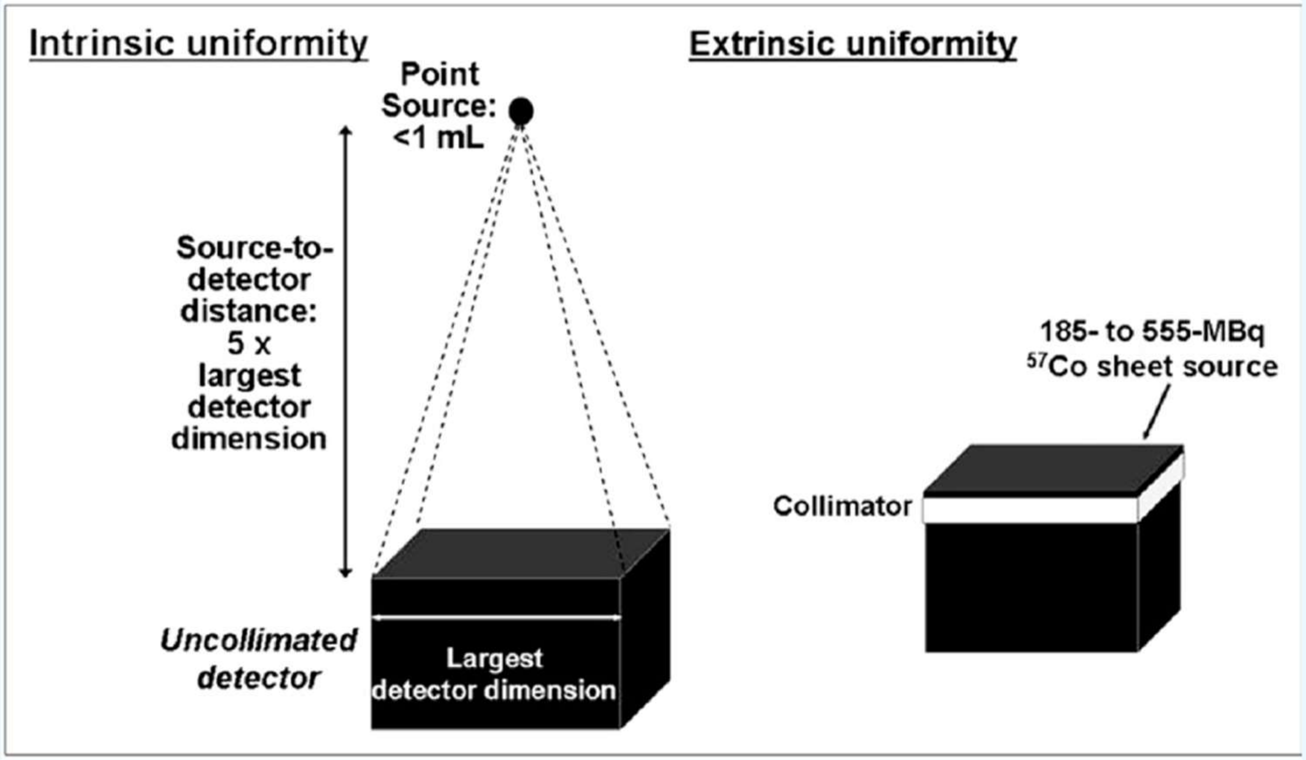
IQ-SPECT

- Siemens' answer to the dedicated cardiac SPECT imaging systems
- Variable-focus collimator provides higher sensitivity and better resolution
- Used with a proprietary iterative reconstruction technique

SPECT

- Instrumentation
- Quality control
  - Planar tests
  - Center of rotation
  - SPECT phantom
- Corrections
- Accreditation

Uniformity



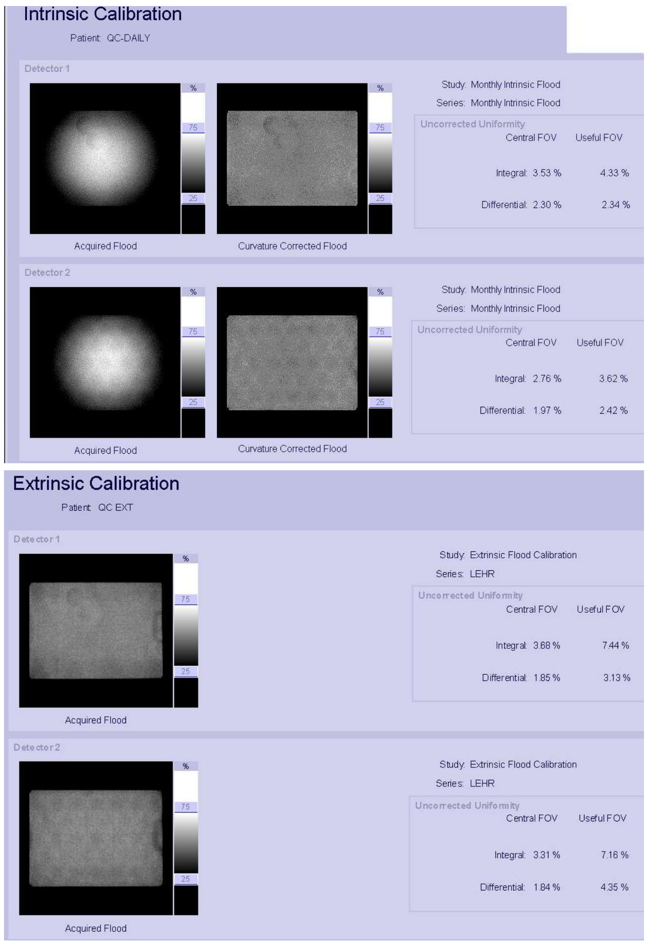
Zanzonico P, J Nucl Med 2008; (49):1114

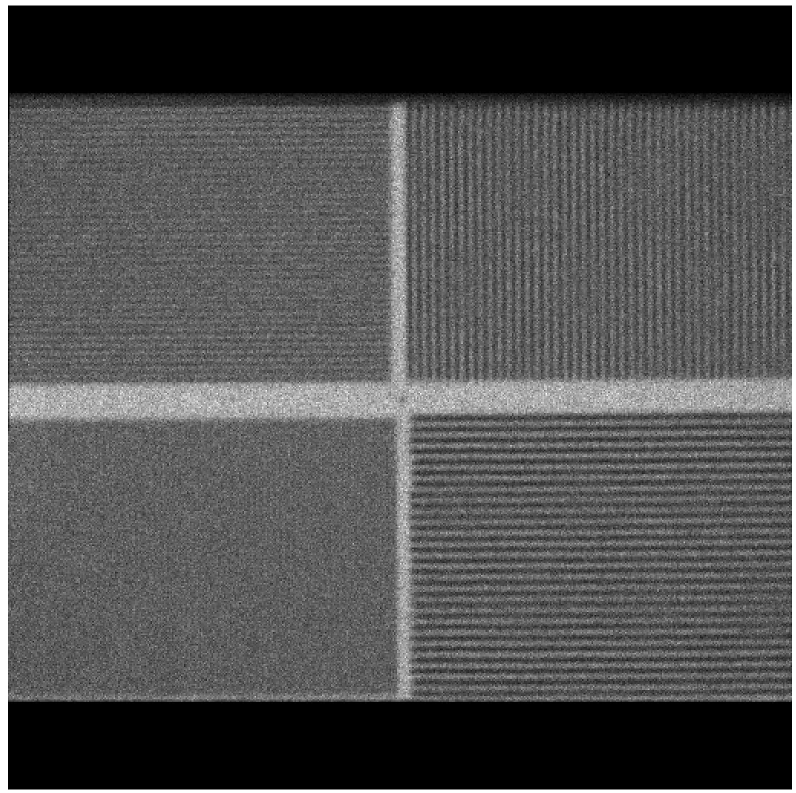
Quality Control of SPECT Cameras

<u>Planar tests</u>

- uniform flood image (intrinsic, using Tc-99m point source, or extrinsic, using a Co-57 sheet source); **daily**
- image a resolution phantom at least **weekly**

$$IU = \frac{\text{Maximum counts per pixel} - \text{Minimum counts per pixel}}{\text{Maximum counts per pixel} + \text{Minimum counts per pixel}} \times 100\%.$$

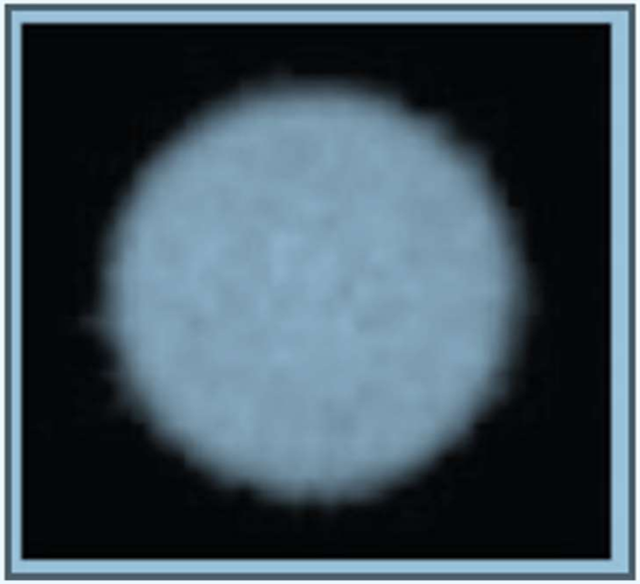




Slide courtesy of Stephen C. Moore, PhD

Uniformity

IU ~ 10%

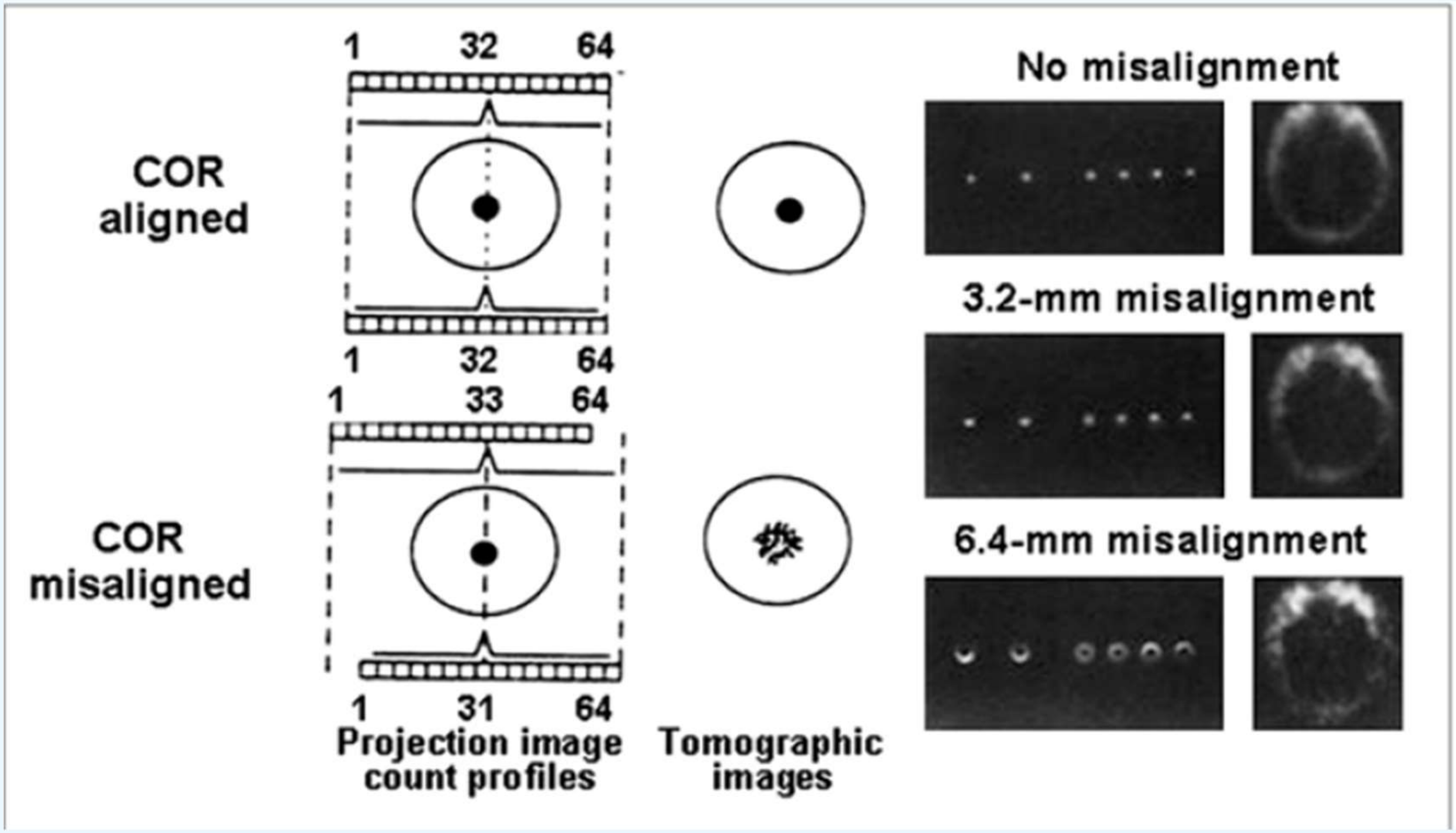


IU ~ 2%

20-cm diameter cylindrical phantom filled with Tc-99^m

Zanzonico P, J Nucl Med 2008; (49):1114

Center of Rotation

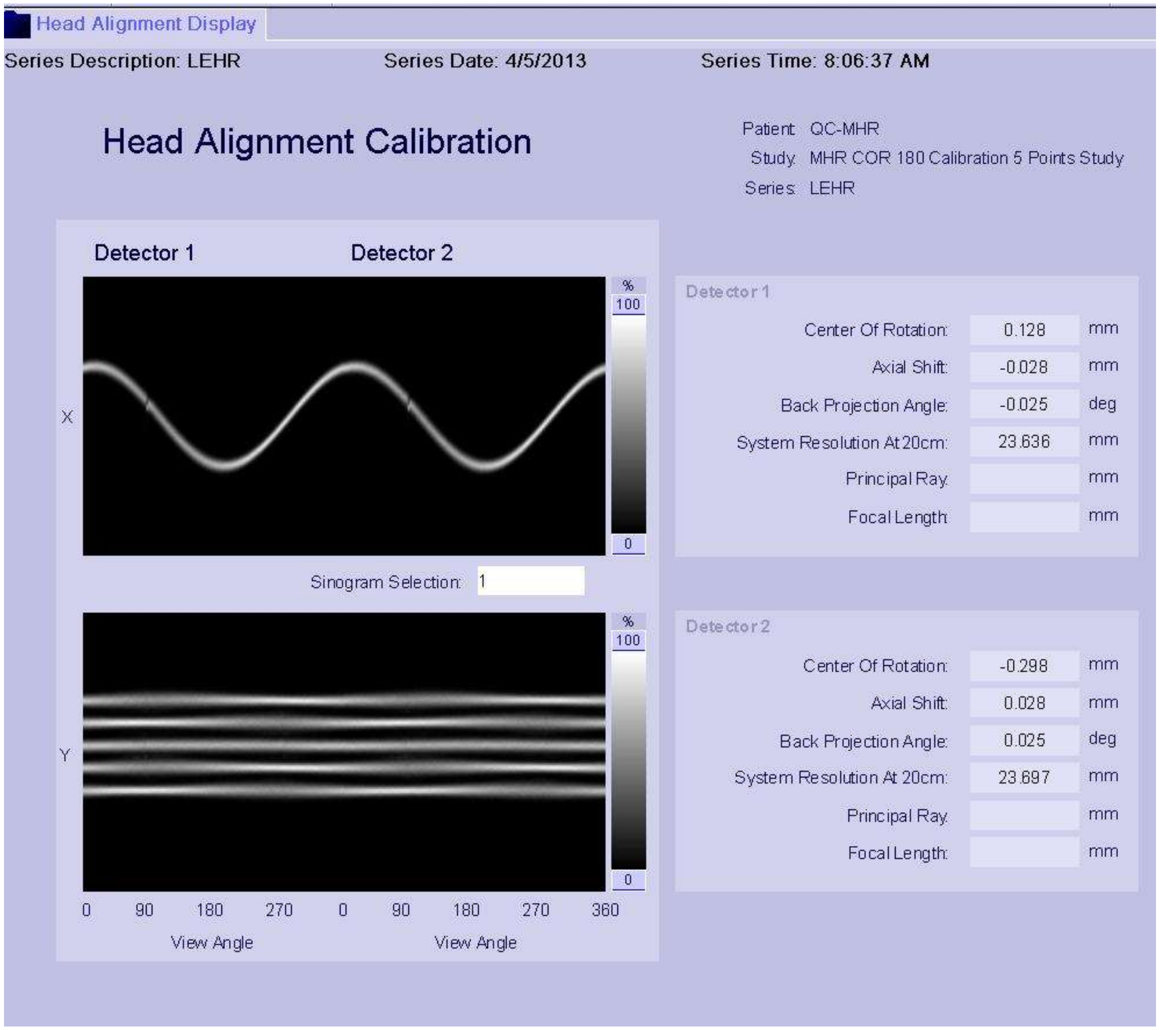


Zanzonico P, J Nucl Med 2008; (49):1114

Quality Control of SPECT Cameras

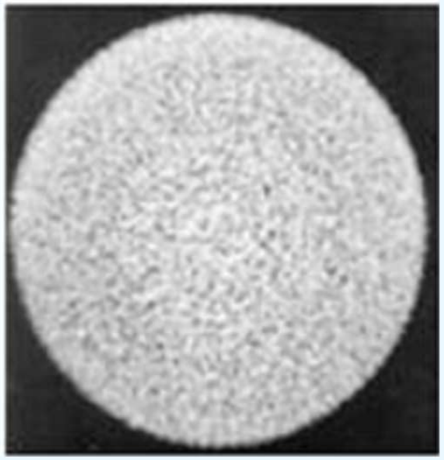
Center-of-rotation (COR) and multi-head registration (MHR)

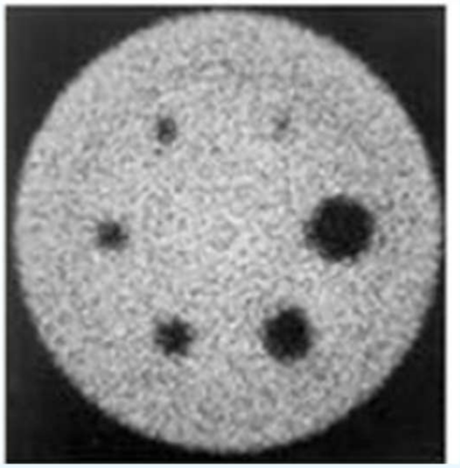
- perform SPECT scan of several point sources. Fit data to a sinusoidal function to determine COR and MHR offsets. **Monthly test.**

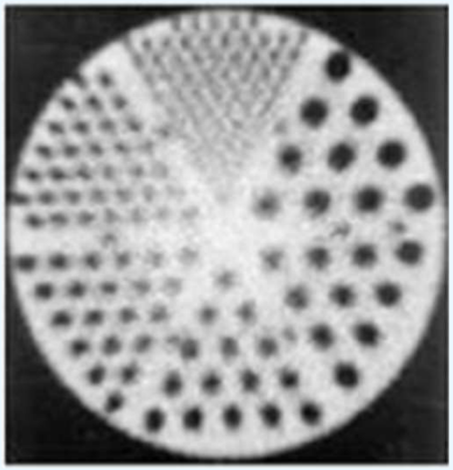


SPECT QC Phantom

(evaluated quarterly)







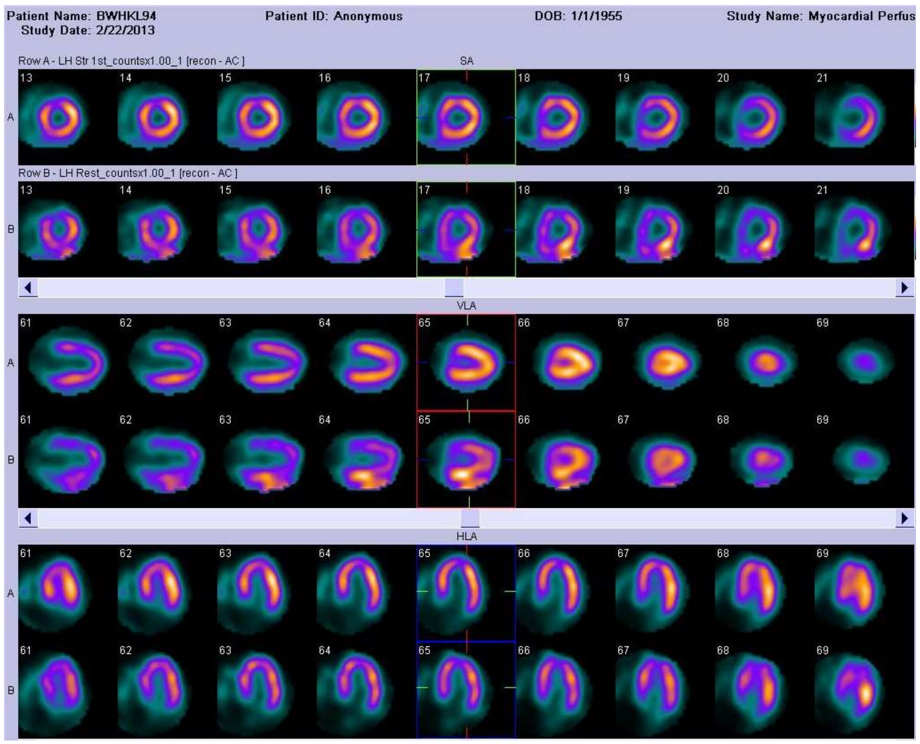
Zanzonico P, J Nucl Med 2008; (49):1114

SPECT

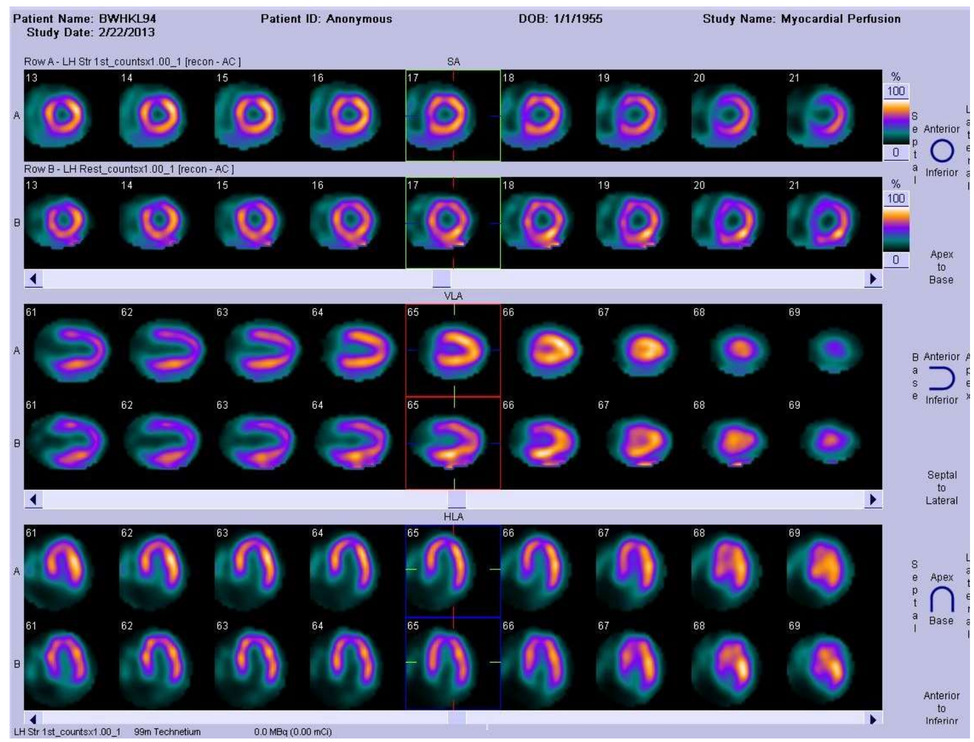
- Instrumentation
- Quality control
- Corrections
  - Motion
  - Attenuation
  - Scatter
  - Spatial resolution
- Accreditation

SPECT Corrections: Motion

Motion correction is accomplished (generally using manufacturer's software) by shifting projections to achieve better alignment with neighboring projections. Works best for motion in axial direction.



without motion correction



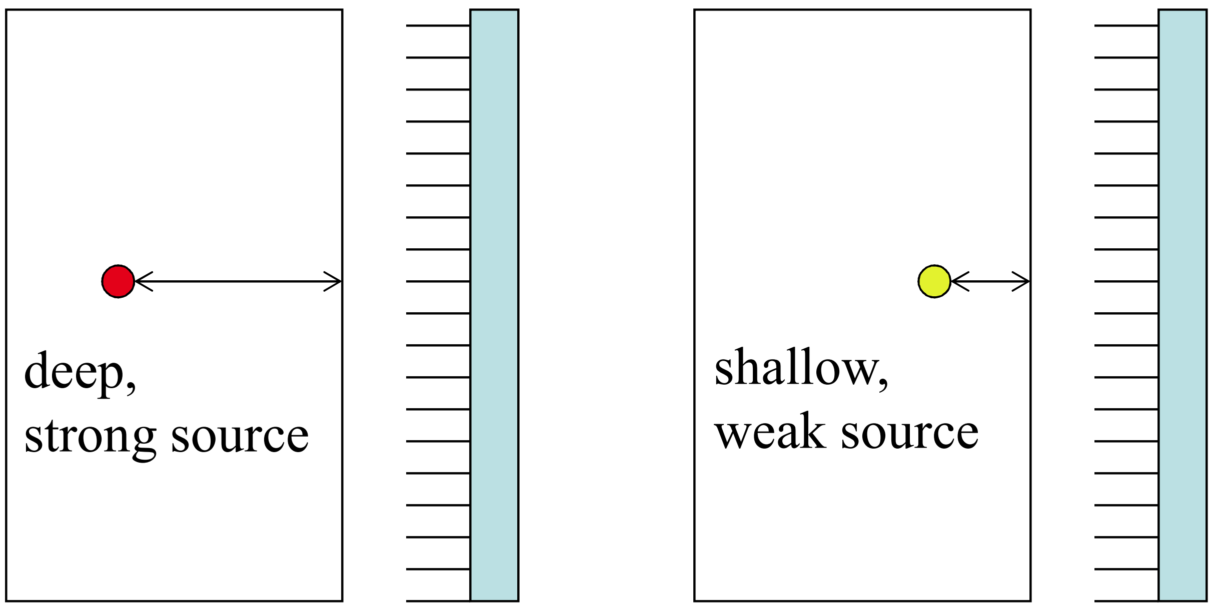
with motion correction

Slide courtesy of Stephen C. Moore, PhD

SPECT Corrections: Attenuation

Why is attenuation correction required for accurate image reconstruction in SPECT?

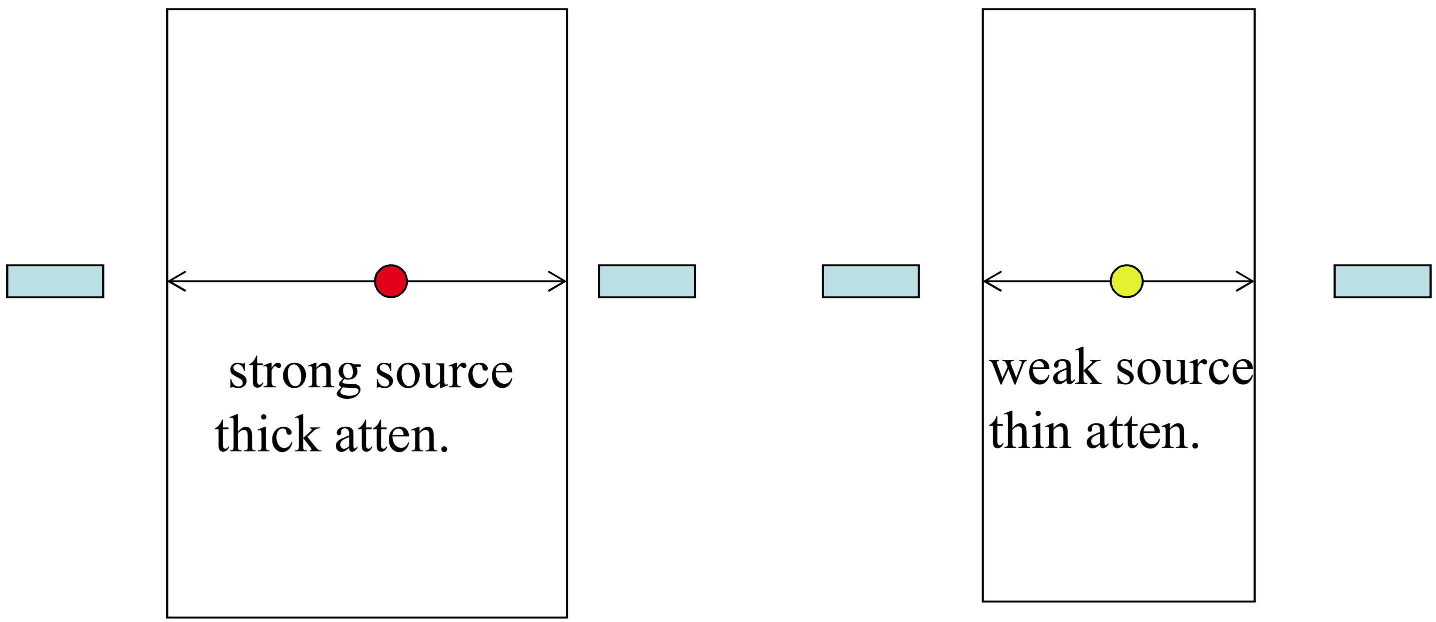
To resolve a fundamental ambiguity in the measurement, i.e., same number of counts can be detected in both of the following situations:



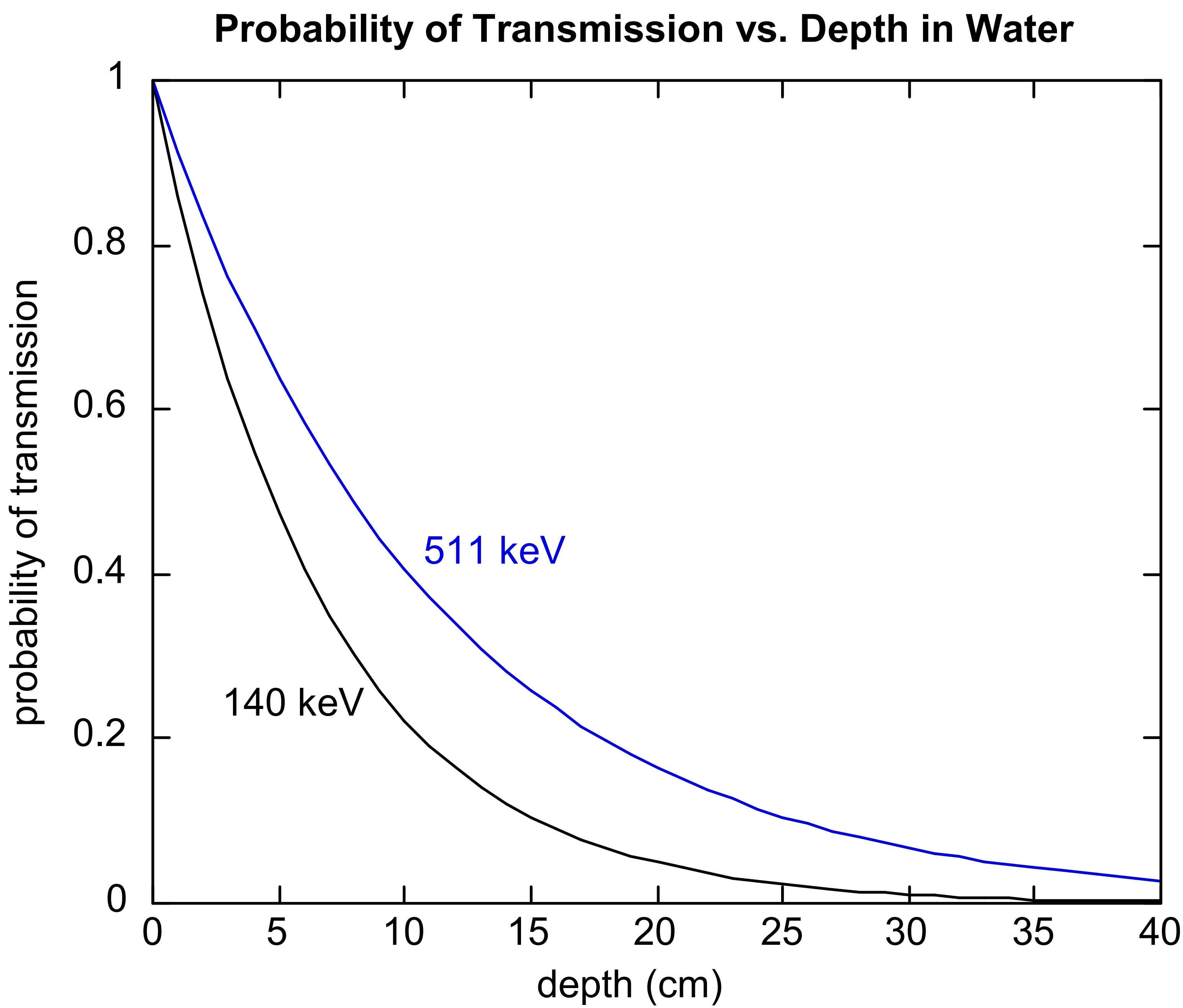
Slide courtesy of Stephen C. Moore, PhD

What about PET?

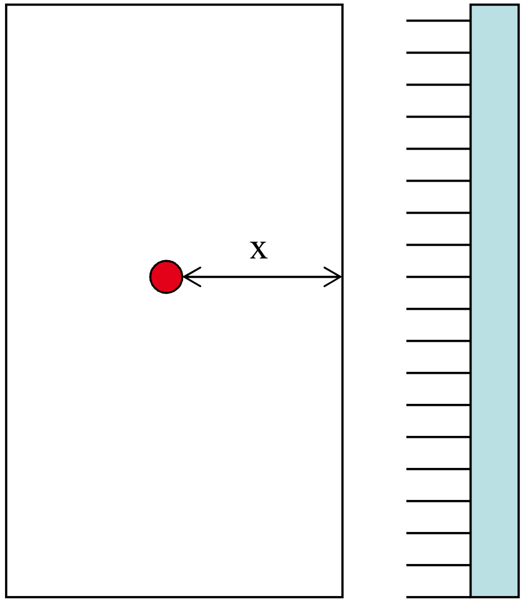
Slightly different ambiguity:



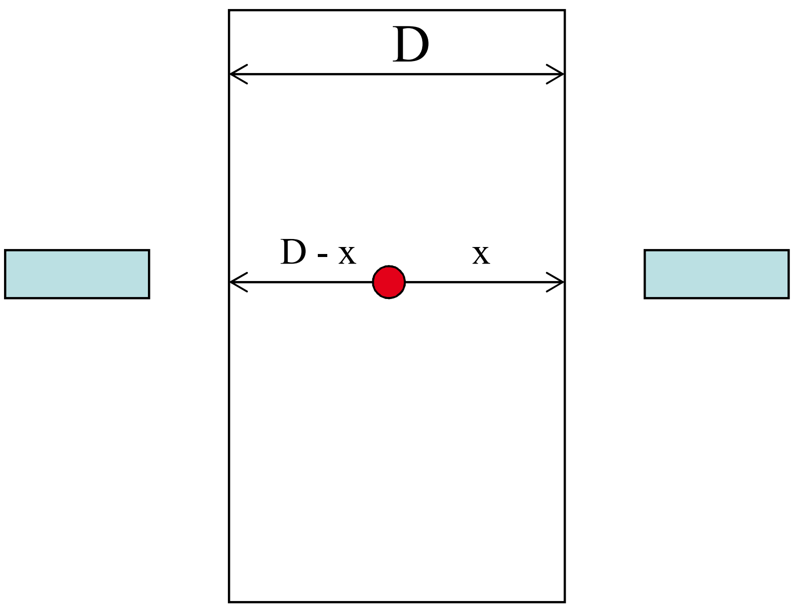
Slide courtesy of Stephen C. Moore, PhD



Slide courtesy of Stephen C. Moore, PhD



Prob. trans. = $e^{-0.12*x}$
(SPECT)

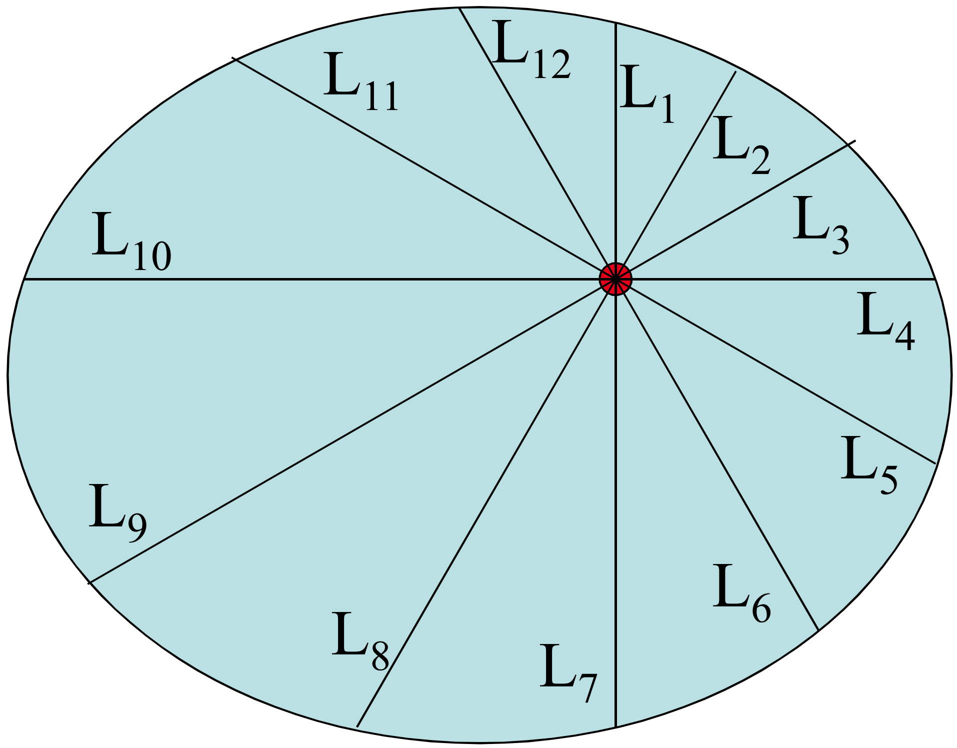


Prob. trans. = $e^{-0.09*D}$
(PET)

(since $e^{-0.09(D-x)}e^{-0.09x} = e^{-0.09D}$)

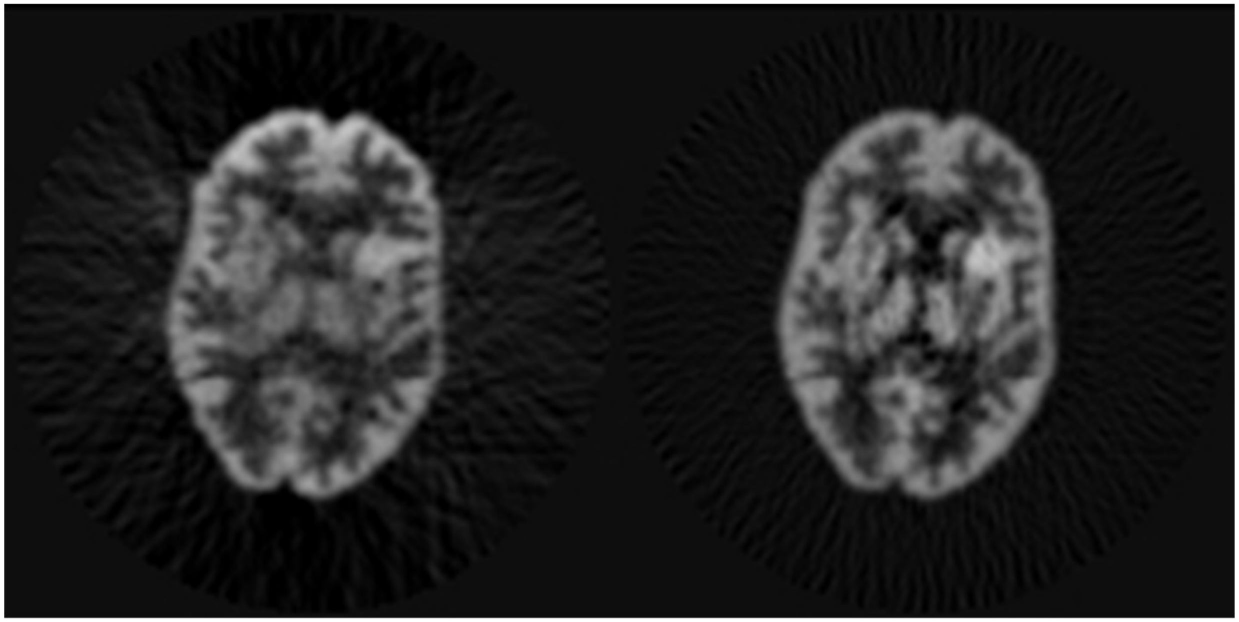
Slide courtesy of Stephen C. Moore, PhD

Chang Post-Reconstruction Correction



Attenuation Correction Factor: $$ACF(x,y) = \frac{1}{\frac{1}{N}\sum_{i=1}^{N} e^{-\mu L_i}}$$

Slide courtesy of Stephen C. Moore, PhD

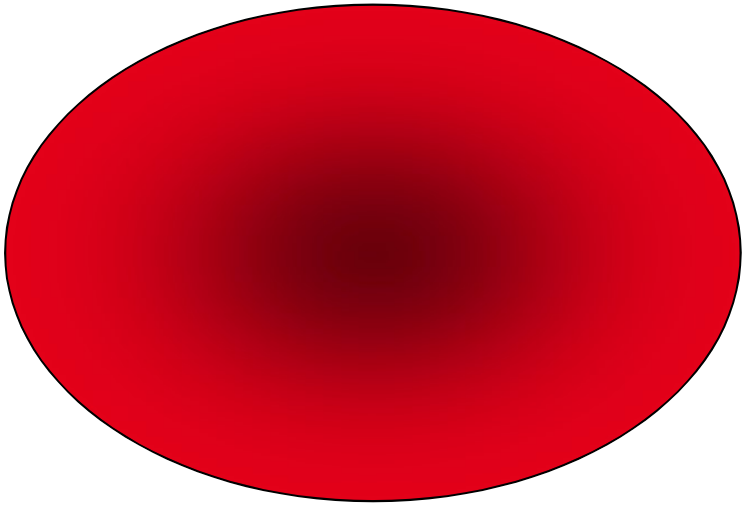


No AC

with AC

(from J. Liang et al.)

Slide courtesy of Stephen C. Moore, PhD

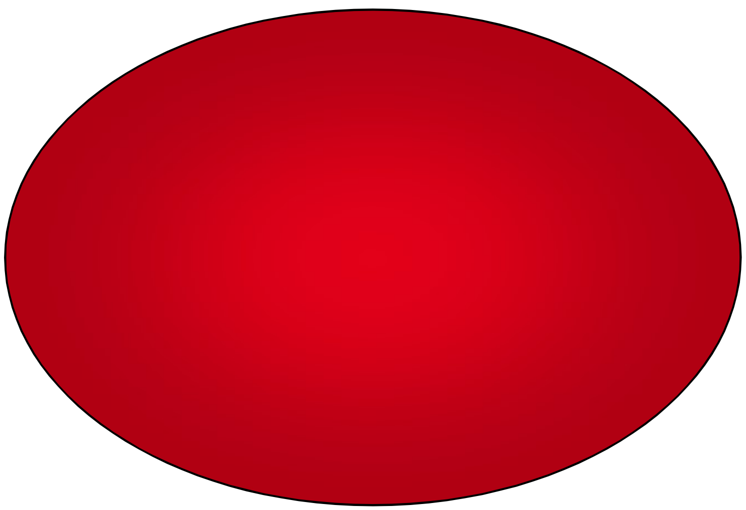


Tc-99m uniform source

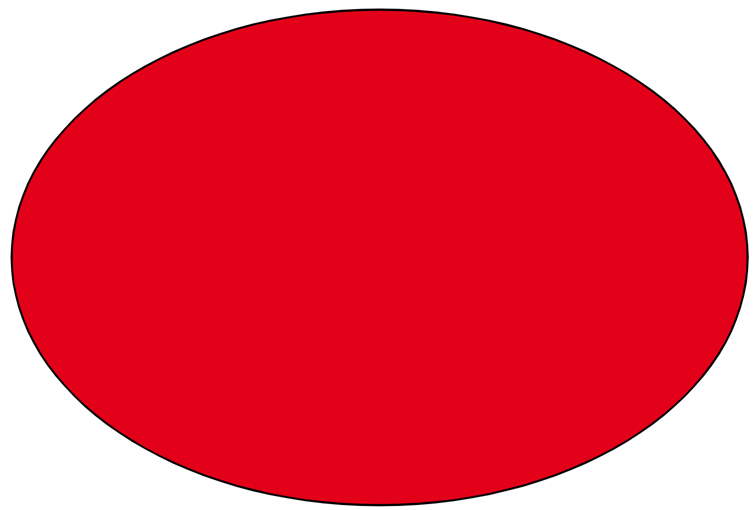
Filtered Back-Projection

No Correction

Chang, with $\mu = 0.15\ cm^{-1}$

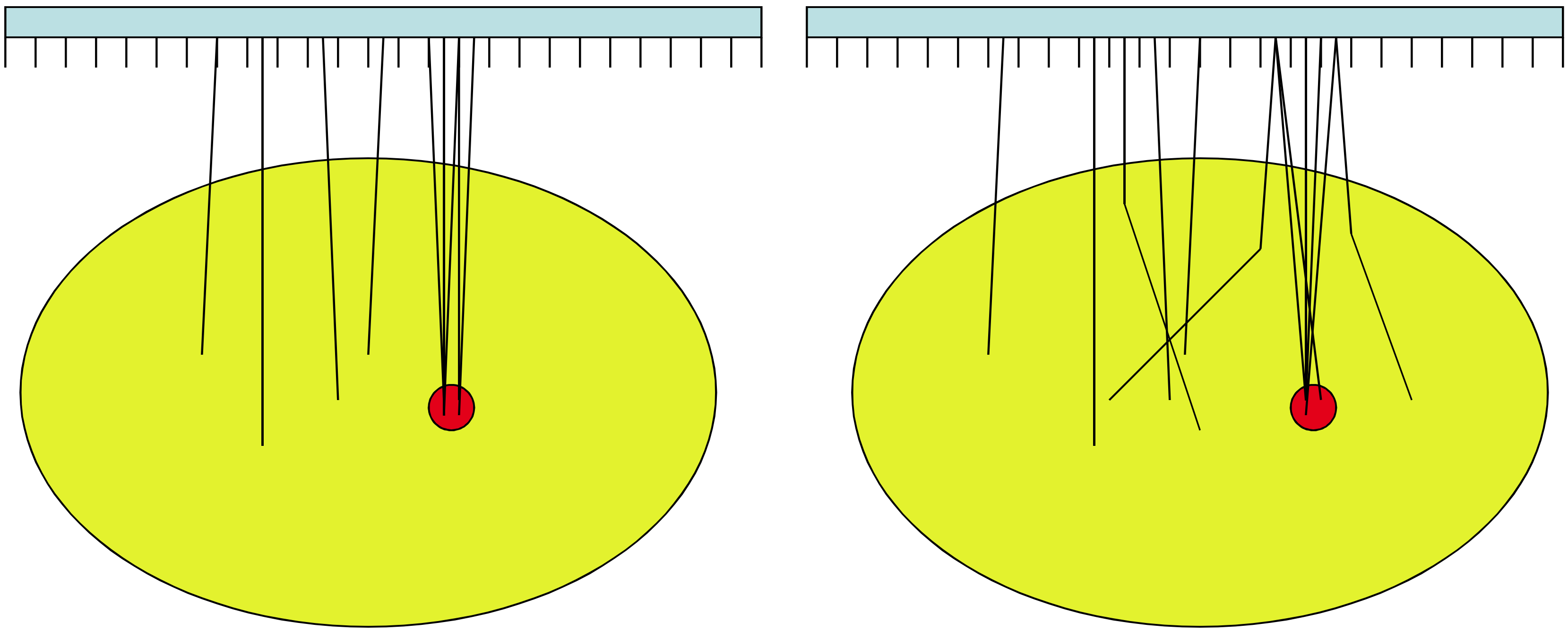


Chang, with $\mu = 0.12\ cm^{-1}$



Slide courtesy of Stephen C. Moore, PhD

Use of effective μ compensates for scattered photons



$\mu = 0.15\ cm^{-1}$
narrow-beam geometry

$\mu = 0.12\ cm^{-1}$
broad-beam geometry
more counts in center
(attenuation less apparent)

Slide courtesy of Stephen C. Moore, PhD

Chang correction is:

- exact for a point source in a uniform attenuator
- reasonable approximation for uniform source

Limitations:

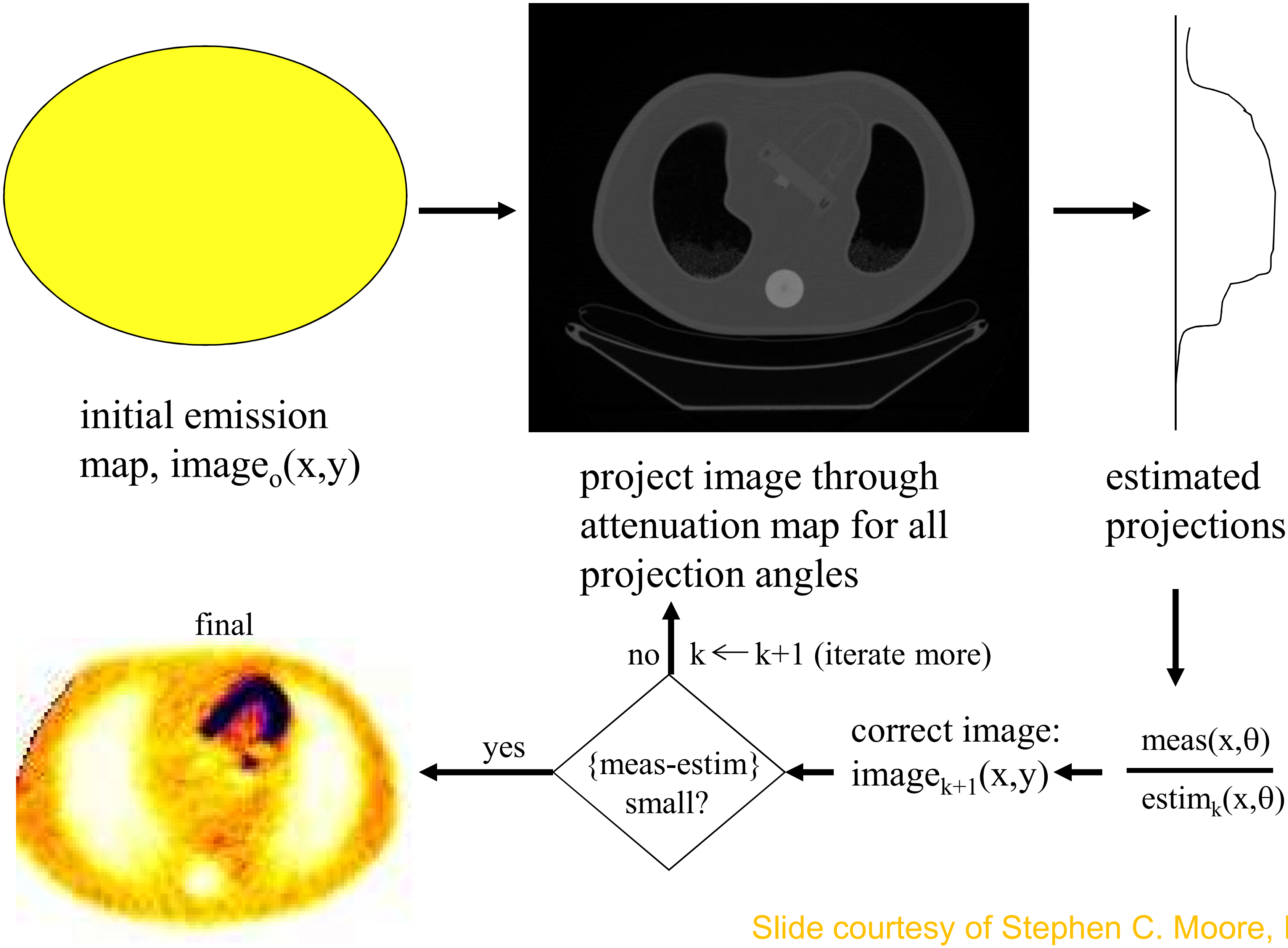
- assumption of uniform attenuation
- serious drawback for cardiac SPECT

Solution?

- iterative reconstruction, e.g., OSEM

Slide courtesy of Stephen C. Moore, PhD

Basic Iterative Reconstruction Flowchart



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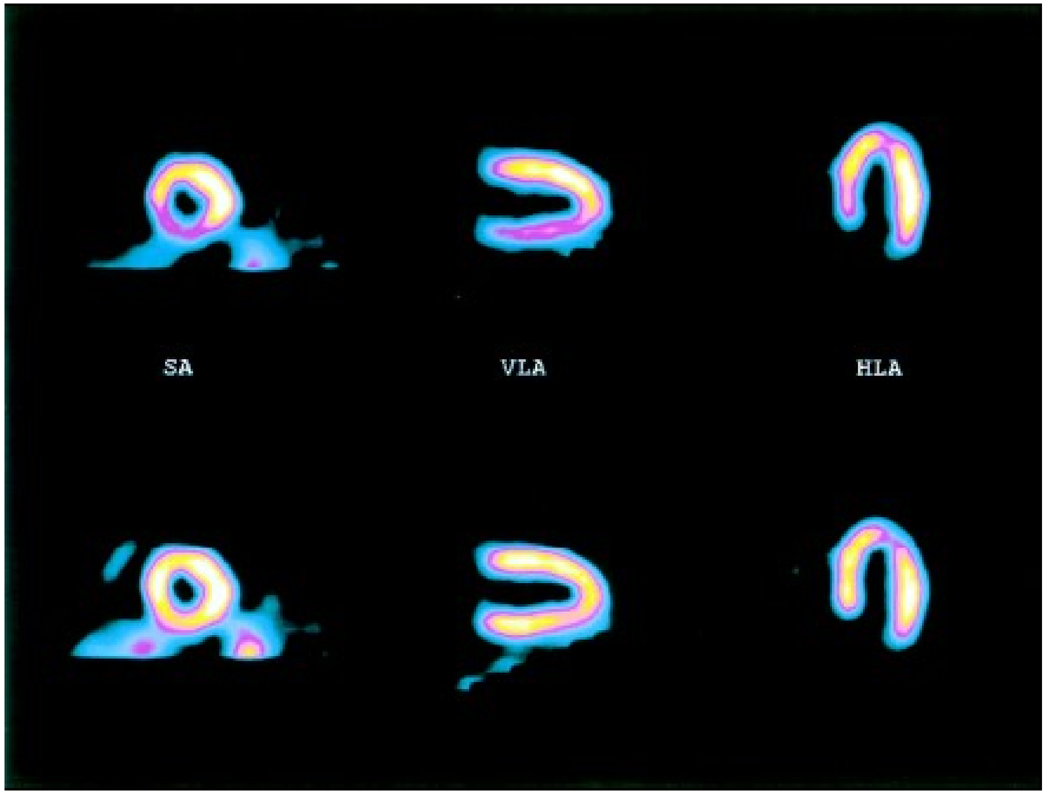


Figure 2. Diaphragmatic attenuation artifact SPECT perfusion images from a 61-year-old man who initially presented to his physician with chest pain, but coronary angiography revealed normal coronary arteries. 99mTc sestamibi (17.5 mCi) was injected during adenosine infusion. Images displayed in the short axis (SA), vertical long axis (VLA), and horizontal long axis (HLA) reveal apparent perfusion abnormality in the inferior wall in the uncorrected images (top row). However, after attenuation/scatter correction with resolution recovery, more uniform tracer distribution is apparent (bottom row), consistent with the absence of coronary artery disease.

From RC Hendel et al., *Circulation.* 1999;99:2742-2749

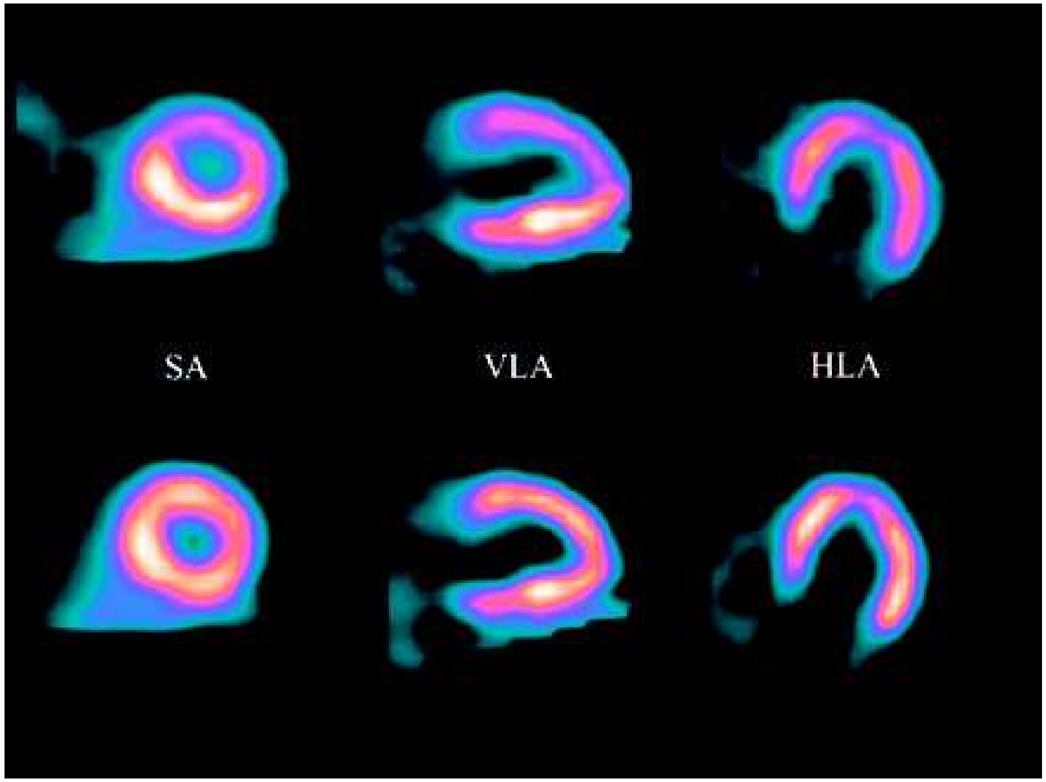


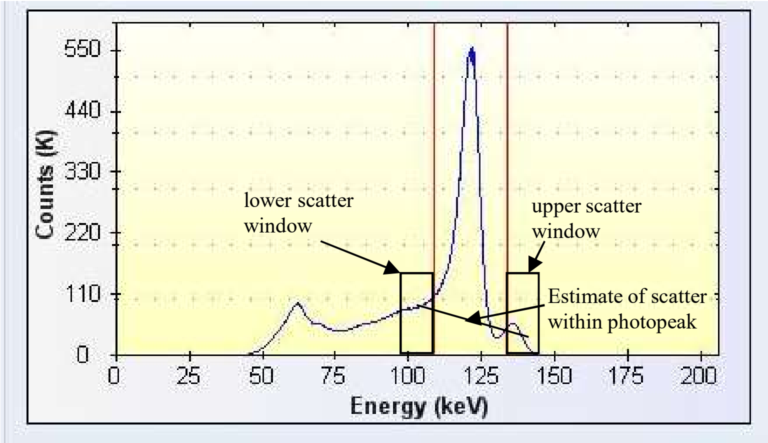
Figure 3. Breast attenuation artifact mid-cavity short axis (SA), vertical long axis (VLA), and horizontal long axis (HLA) perfusion images from a 49-year-old woman who achieved a heart rate of 155 bpm (91% MPHR) without chest pain or ECG changes. She received 33 mCi of 99mTc sestamibi at peak treadmill exercise. She is 5 ft 2 inches tall and weighs 223 lbs, with large breasts. Top row of images reveal a moderate sized perfusion defect of mild severity in the anterior and anterolateral walls. Bottom row of images are after application of attenuation and scatter correction, with resolution compensation. These SPECT images demonstrate substantial correction of the attenuation artifact.

From RC Hendel et al., *Circulation.* 1999;99:2742-2749

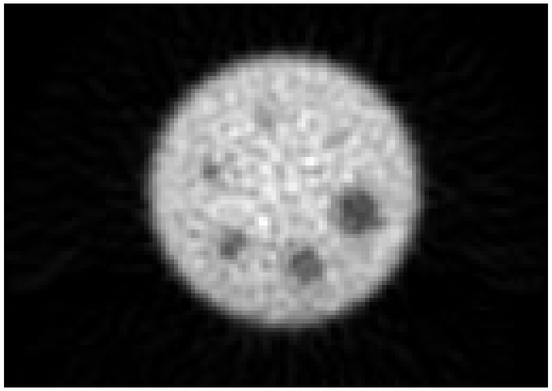
SPECT Corrections: Scatter

Scatter correction methods:

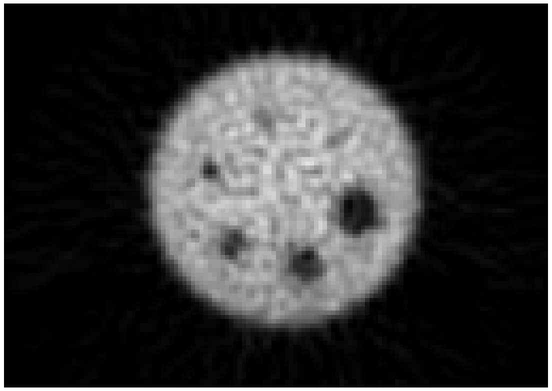
1. Model scatter in the forward projector of an iterative reconstruction program (described earlier).
2. Triple-energy window (TEW) method; estimate and subtract scatter pixel-by-pixel:



with scatter



without scatter

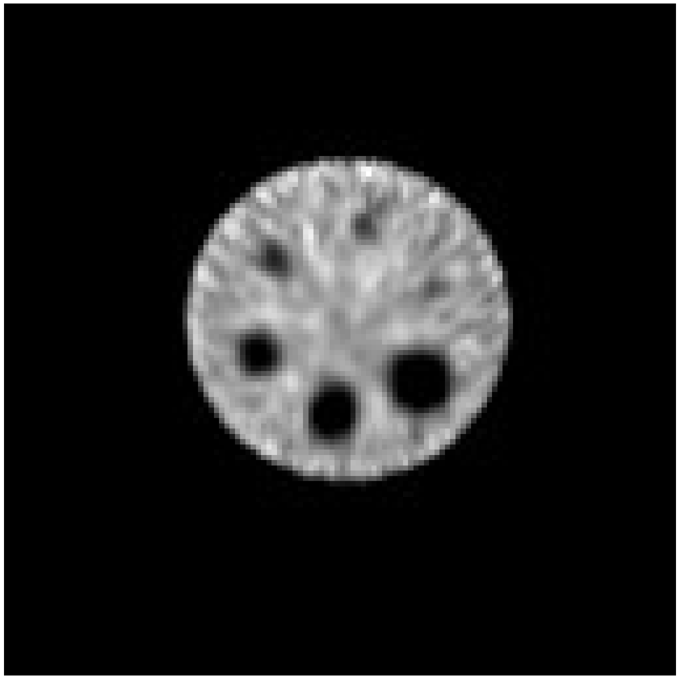


Slide courtesy of Stephen C. Moore, PhD

SPECT Corrections: Spatial resolution

Compensation for distance-dependent collimator resolution and intrinsic detector resolution can also be accomplished by modeling these resolution degrading factors in the forward projector of an iterative reconstruction program, e.g., ML-EM or OS-EM.

Lesion boundaries and contrast can be improved; however, if the resolution model is not accurate, shape distortions or artifacts may result.



Slide courtesy of Stephen C. Moore, PhD

SPECT

- Instrumentation
- Quality control
- Corrections
- Accreditation
  - ACR
  - ICANL
  - JCAHO

Equipment QC Requirements for SPECT Accreditation

JCAHO (accreditation by ABR or ICANL should help with JCAHO)

1. Maintain service records signed by a qualified individual (service engineer) to indicate the equipment has been cleared for return to clinical use.
2. Must have written equipment QC plan in the Procedure Manual. Must include monitoring of instrument performance at least quarterly by a Medical Physicist or other qualified person.

ICANL (Intersocietal Commission for the Accreditation of Nuclear Laboratories)

1. Includes requirements above for JCAHO
2. Daily camera peaking and uniformity tests with calculation of uniformity values
3. Weekly check of camera spatial resolution and linearity
4. Monthly COR tests on all SPECT systems
5. High-count flood uniformity acquisitions (per manufacturer's recommendation)
6. Preventive maintenance of all gamma cameras every 6 months
7. SPECT-CT accuracy of image registration and CT-based attenuation correction (monthly or per manufacturer's recommendation).
8. Usual CT required tests, including annual tests by a medical physicist.
9. Recommendation: SPECT phantom overall test of image quality, annually.
10. Collimator integrity check and comparing extrinsic vs. intrinsic uniformity, annually.

Equipment QC Requirements for SPECT Accreditation

ACR Requirements

1. Basically, same procedures for service and QC as required by JCAHO and ICANL.

In addition:

2. Acceptance testing must be performed on systems when they are installed.

3. The following tests must be performed at least annually thereafter:

- intrinsic uniformity
- system uniformity (extrinsic, with collimators present)
- intrinsic or system spatial resolution
- relative sensitivity (count rate on the detectors is the same, within 5%)
- energy resolution
- count-rate parameters
- video display quality
- overall system performance with SPECT phantom
- system safety interlock checks