SPECT
Single-photon emission computed tomography

i) Instrumentation
ii) Quality Control
iii) Corrections
iv) Accreditation

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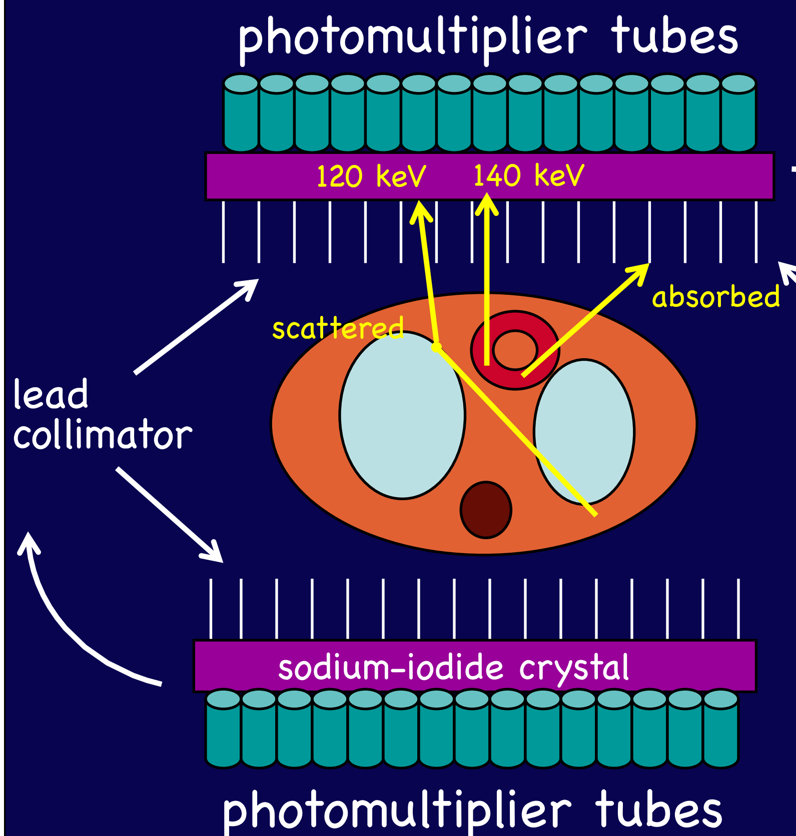
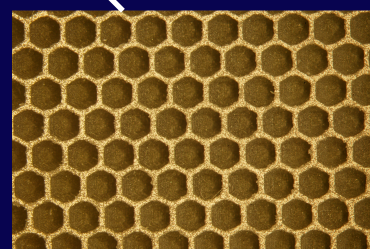
Covering sections 17.k (i) – (iv) of ABR Core Exam Study Guide

Conventional scintillation camera systems





1.3mm hex holes
0.3mm septa

Siemens e.cam SPECT system

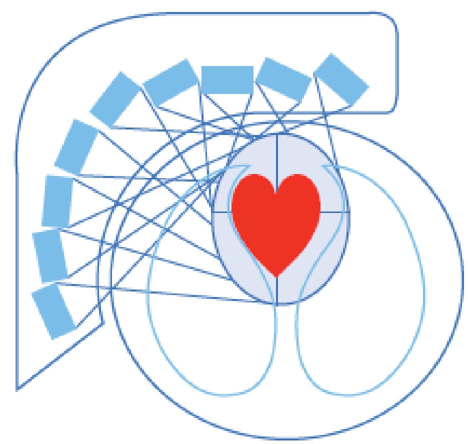
1. collimator trade-off: resolution vs. sensitivity
2. each photon's position + energy are measured, one by one,
3. simultaneous imaging of two different physiologic processes is possible, using two different radiotracers, (e.g., Tl-201 rest / Tc-99m stress myocardial perfusion imaging)

Dedicated Cardiac SPECT Systems

-both systems based on CZT solid-state detector modules
-both systems have 9 detectors

- **D-SPECT System** from Spectrum Dynamics, Inc.
- Parallel-hole collimation
- Each detector rotates to acquire many projections of the heart
- High sensitivity from scan pattern tailored to the heart and from big collimator holes

- **Alcyone System** (Discovery NM 530C) General Electric
- Pinhole collimation
- Stationary detectors allow dynamic scans
- Pinholes always sample the heart region
- CT scanner can be added on for attenuation correction
- Potential for truncation artifacts?

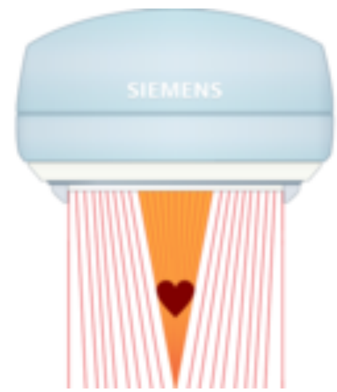


Pinhole collimation strategically positioned to focus on the "quality field of view"

SPECT-CT Systems

- SPECT system with a CT scanner attached to it
- sold by all of the big vendors (e.g., GE, Siemens, Philips)

Example: Siemens Symbia-T SPECT-CT System



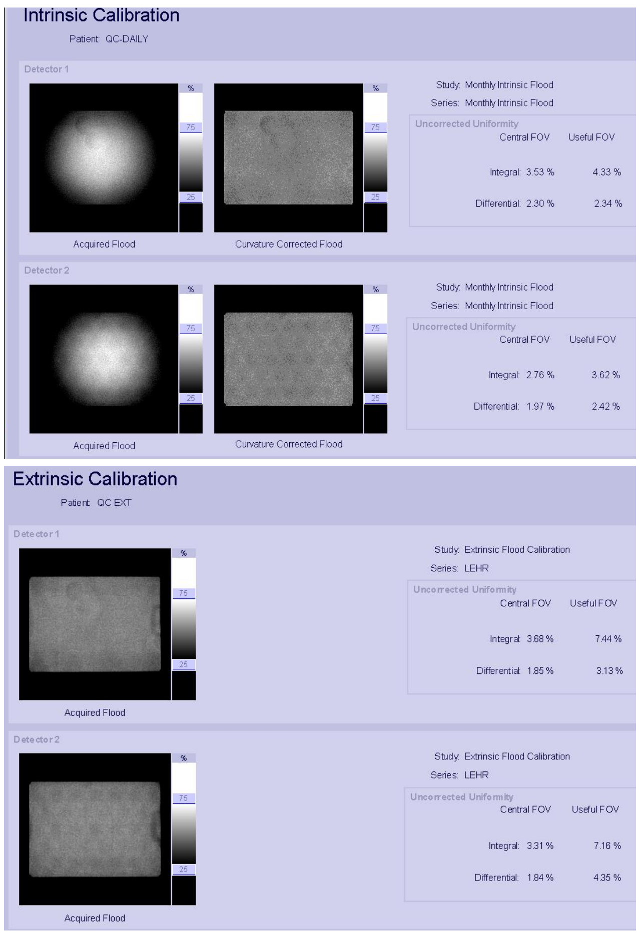
IQ-SPECT Technology:

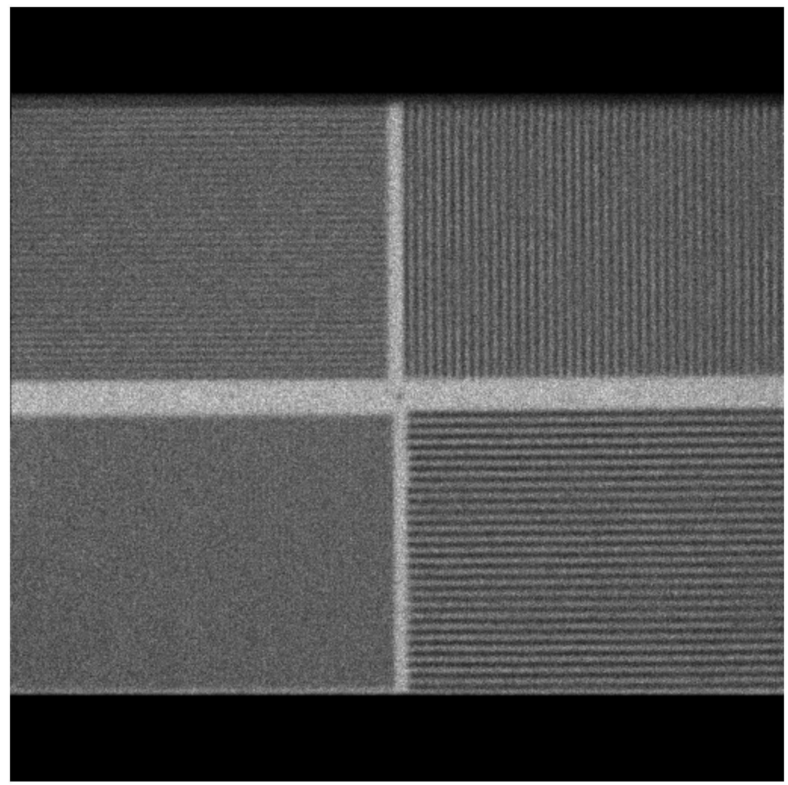
- Siemens' answer to the dedicated cardiac SPECT imaging systems
- Variable-focus collimator provides higher sensitivity and better resolution
- Used with a proprietary iterative reconstruction technique

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**

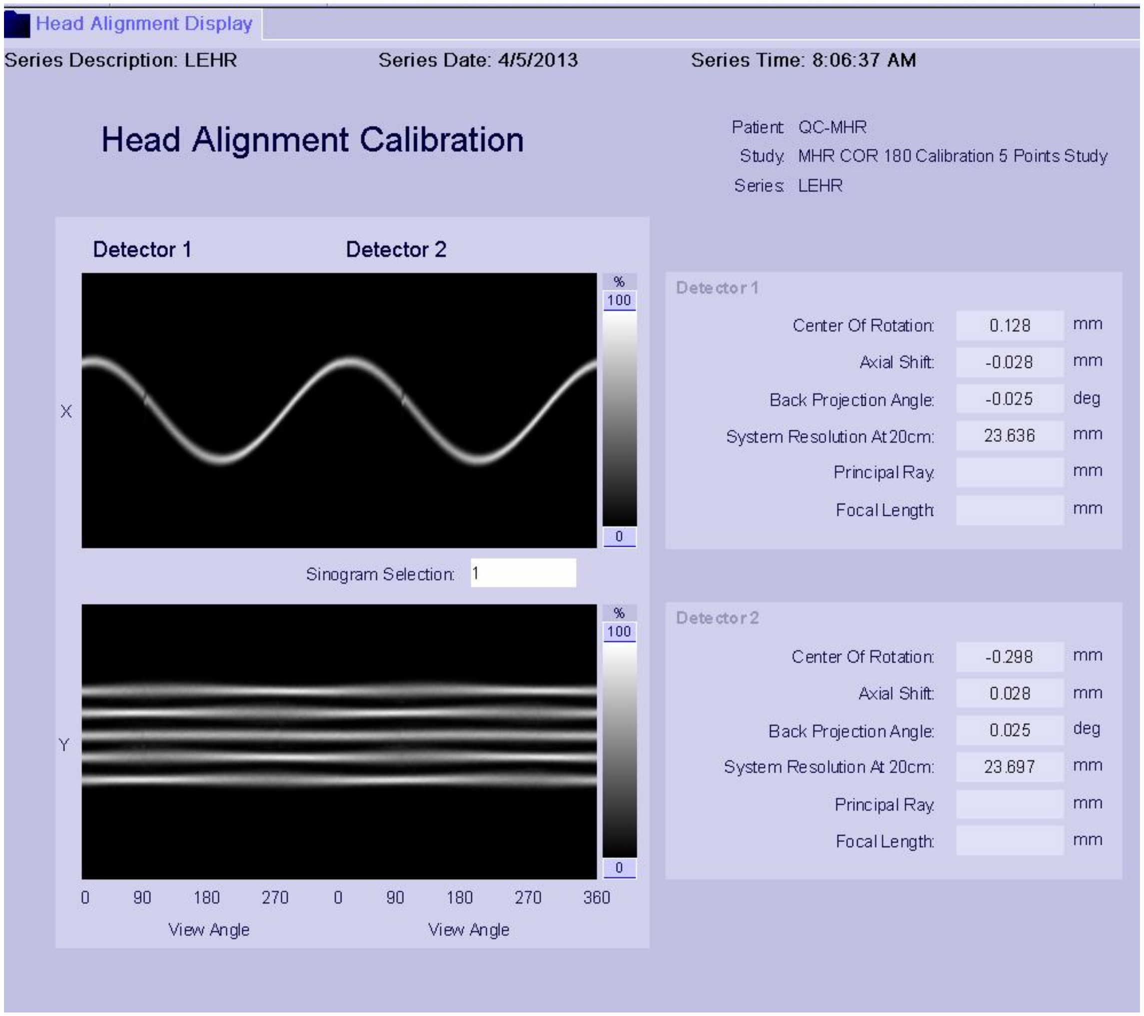




Quality Control of SPECT Cameras

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

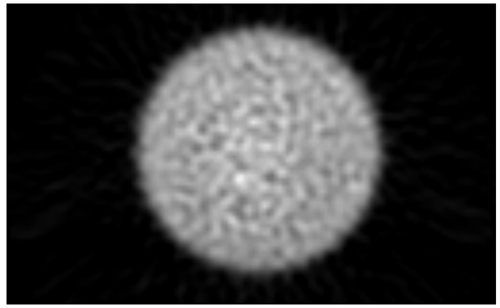
- perform SPECT scan of several point sources. Fit data to a sinusoidal function to determine COR and MHR offsets. **Monthly test.**



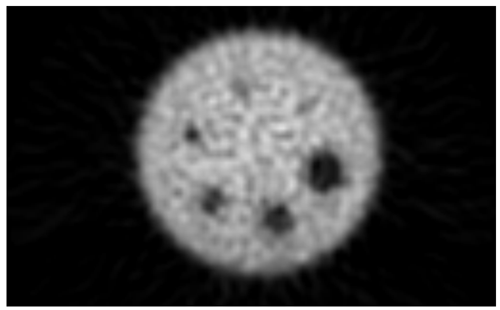
Quality Control of SPECT Cameras

<u>SPECT phantom test of overall imaging performance, **quarterly**</u>

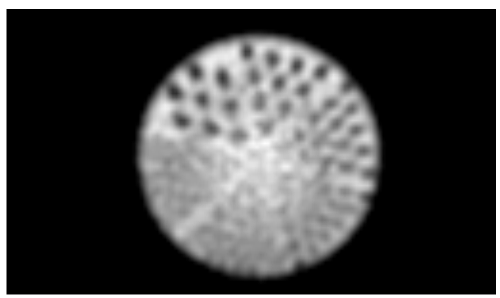
uniformity,
noise, artifacts

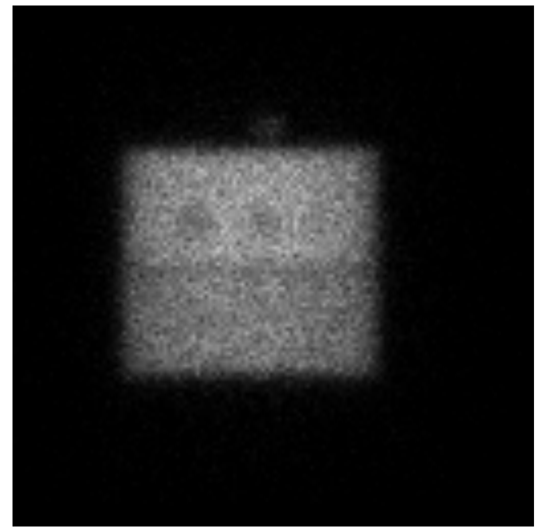


contrast and
resolution



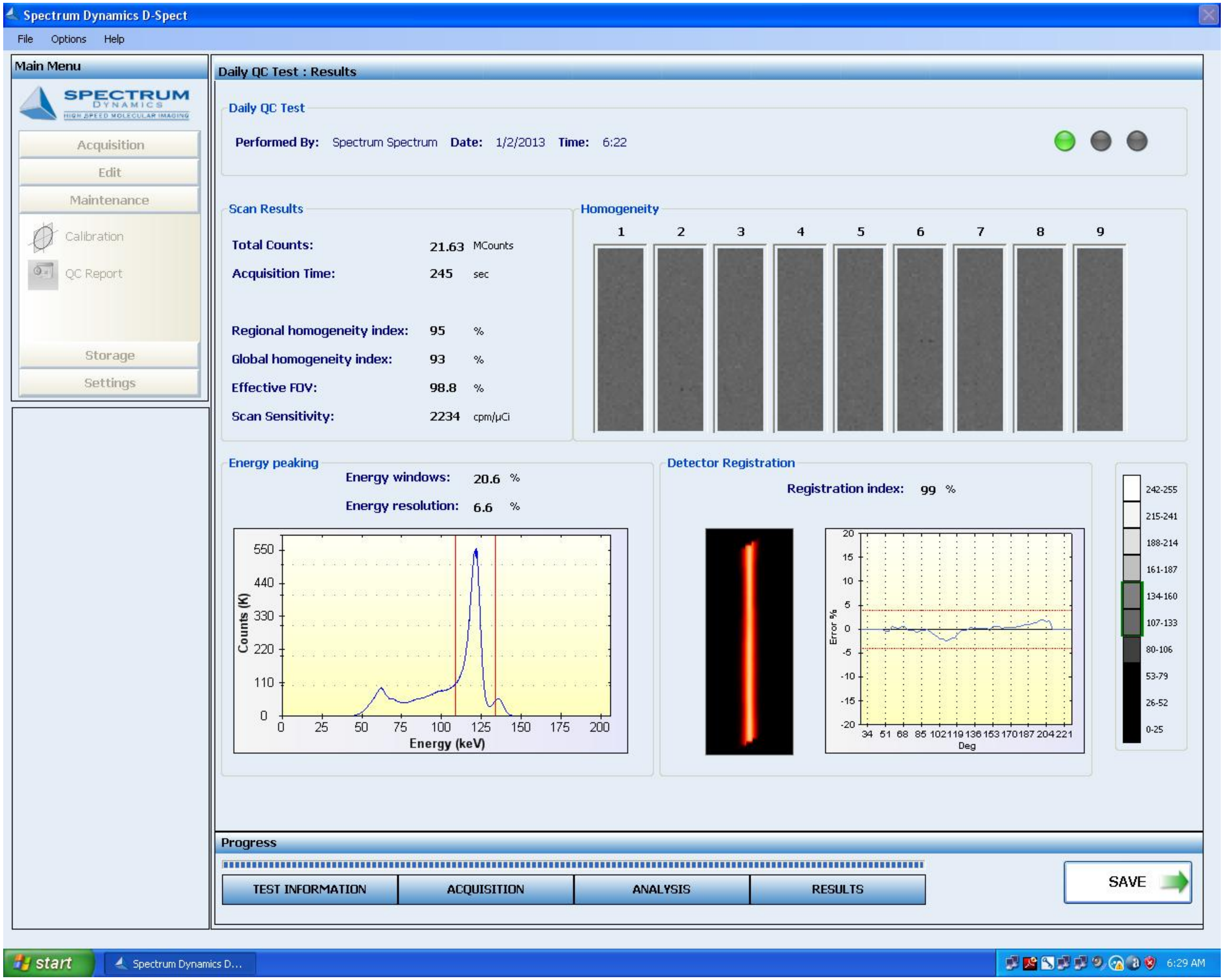
distance-dependent
resolution





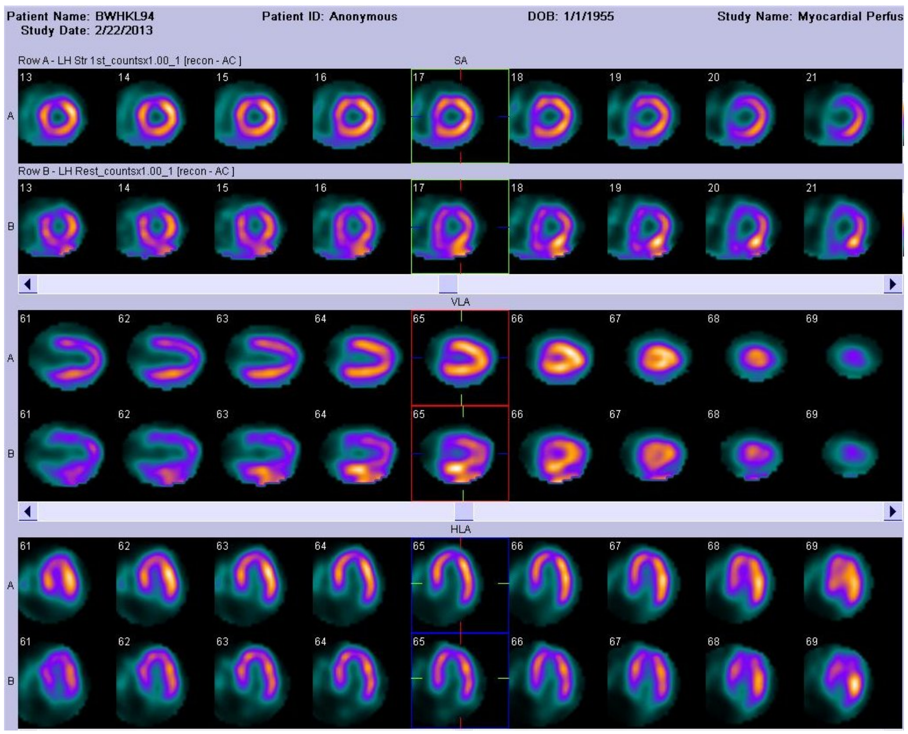
Quality Control of SPECT Cameras

<u>Daily tests on a dedicated organ-specific imaging system</u>

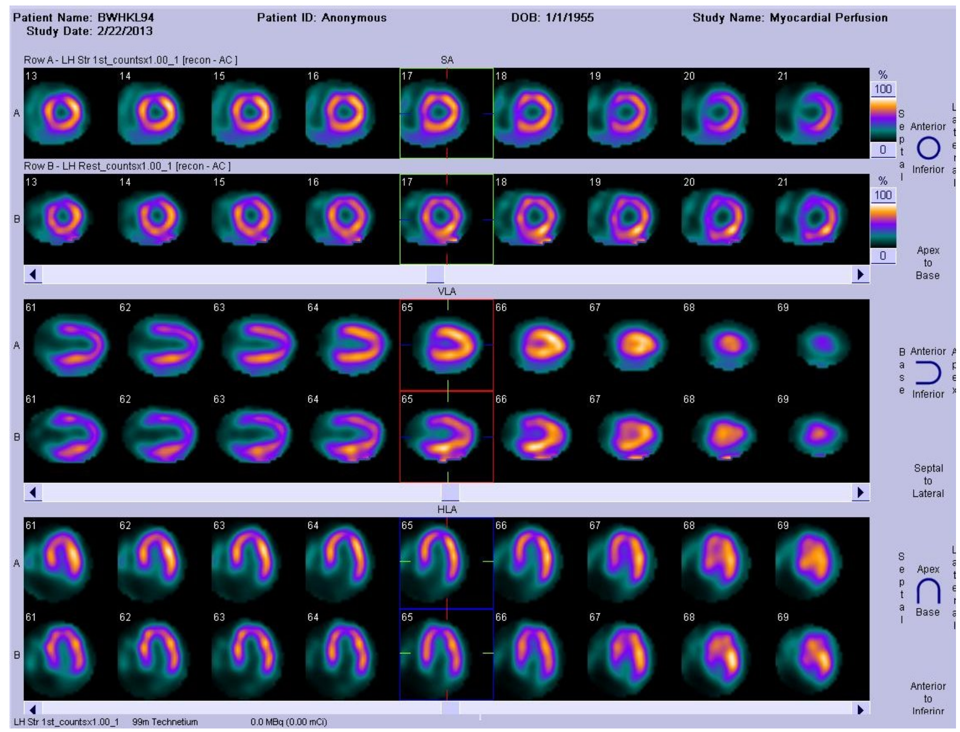


SPECT Corrections: Motion

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

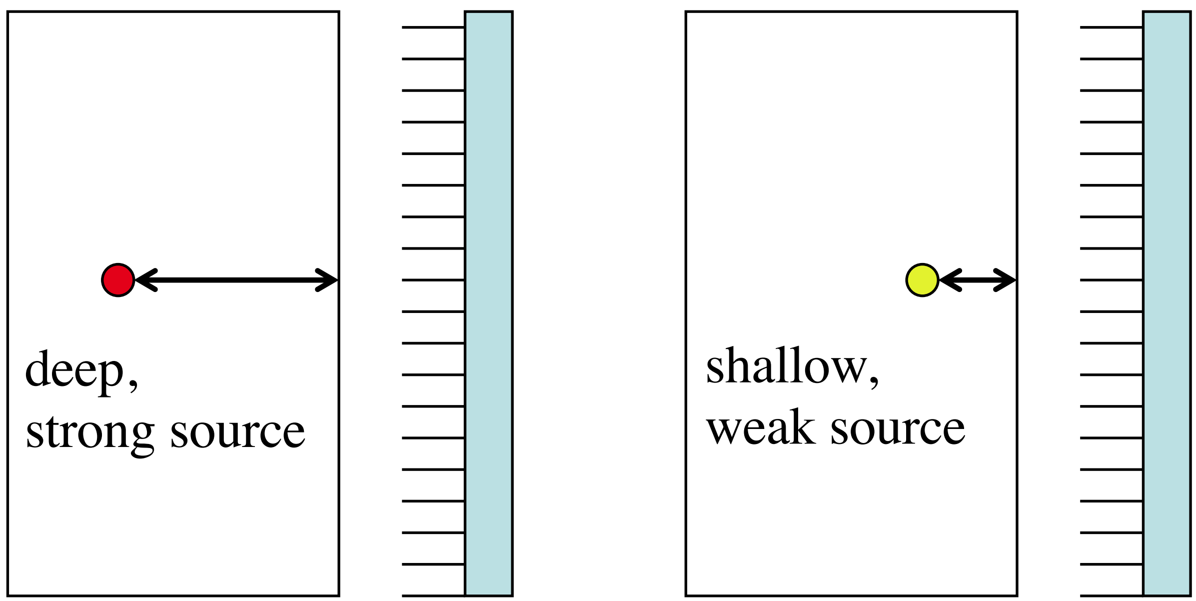


with motion correction

SPECT Corrections: Attenuation

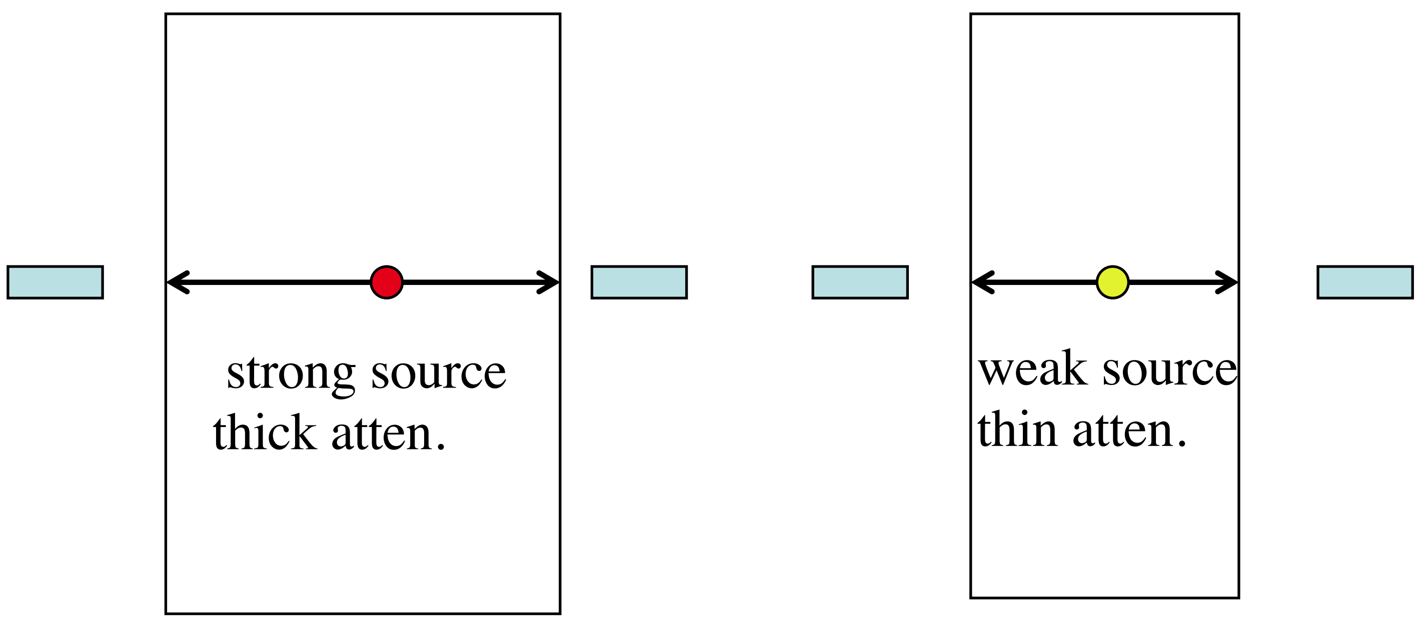
Why is attenuation correction required for accurate image reconstruction in SPECT?

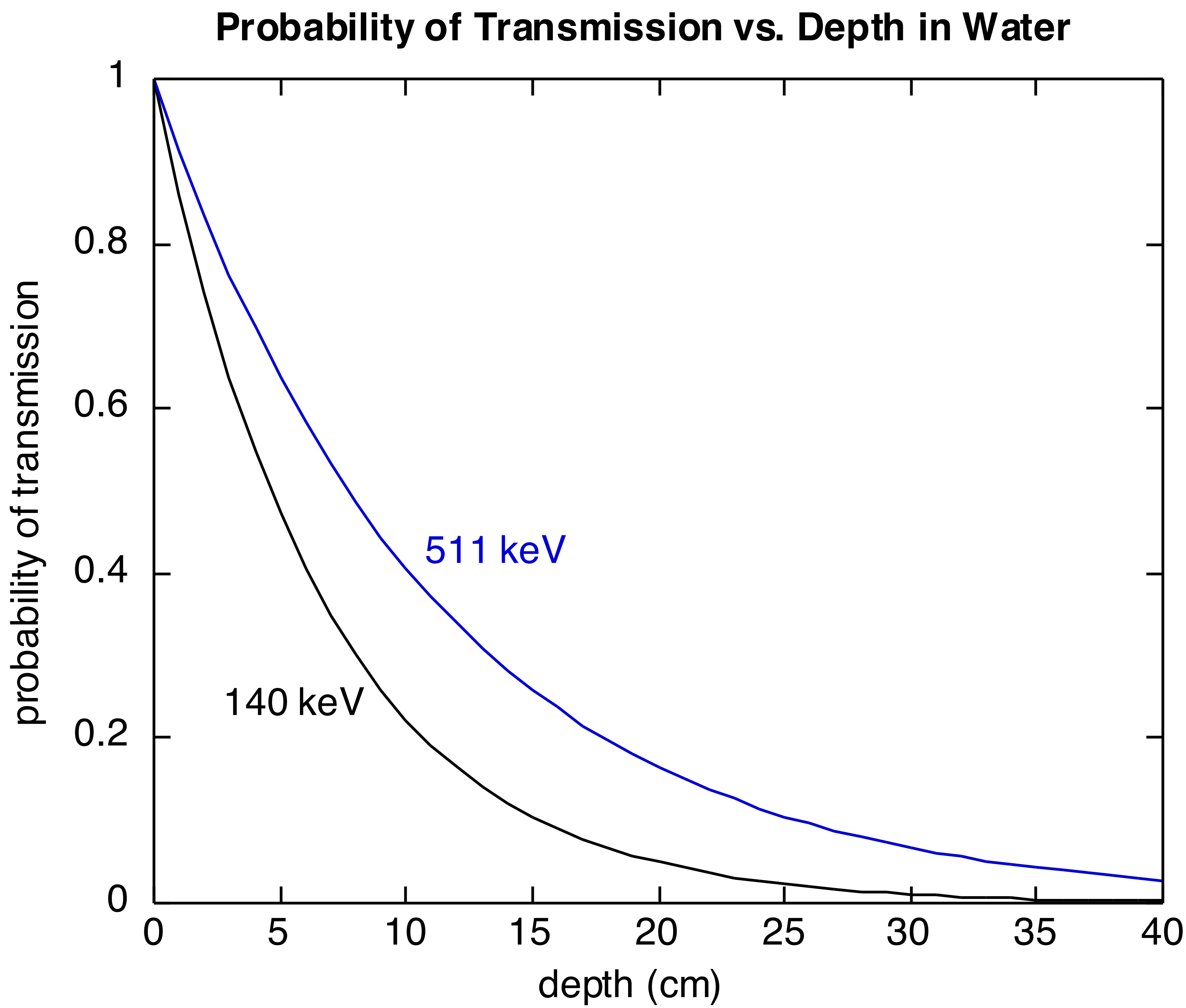
To resolve a fundamental ambiguity in the measurement, i.e., same number of counts can be detected in both of the following situations:

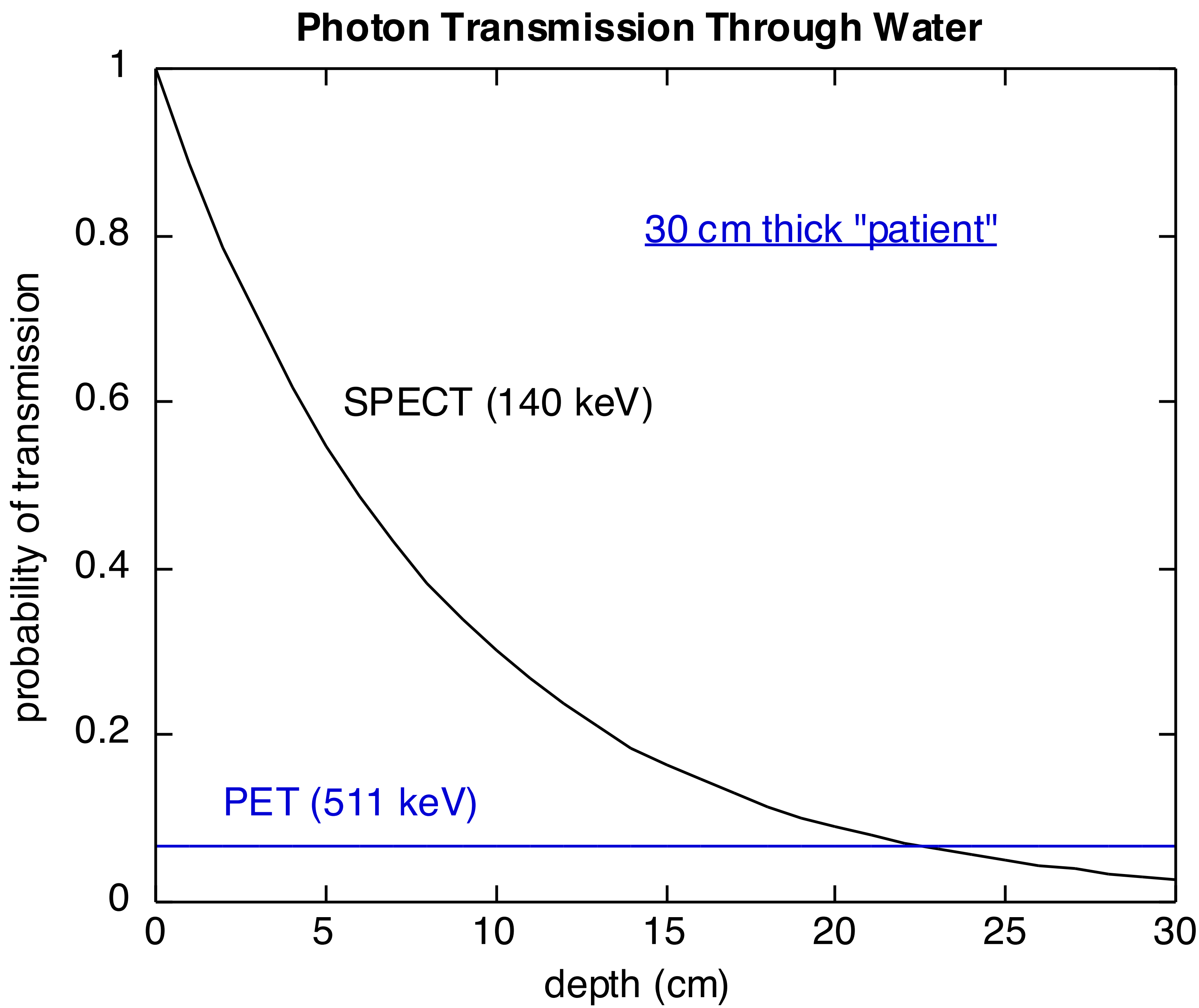


What about PET?

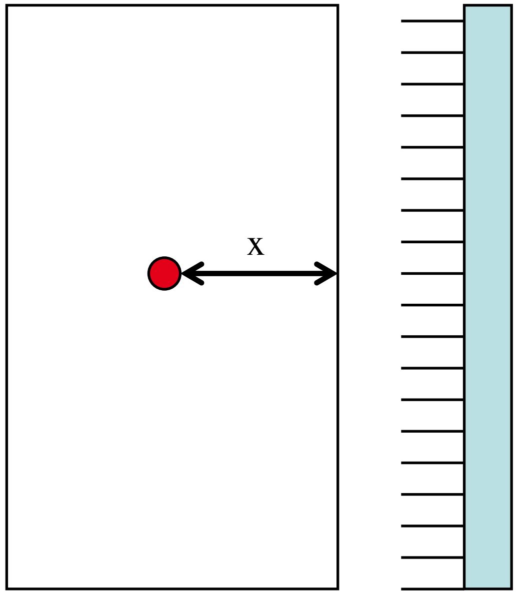
Slightly different ambiguity:



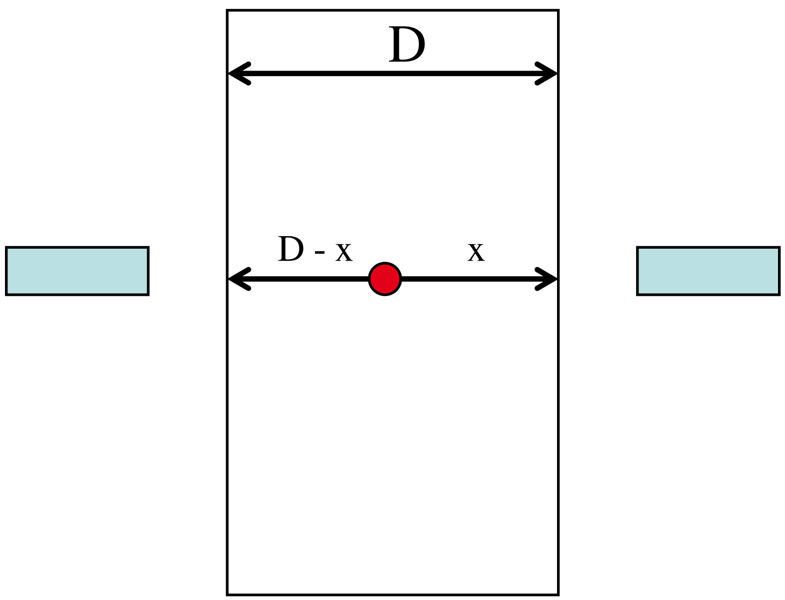

Probability of Transmission vs. Depth in Water
probability of transmission
depth (cm)
511 keV
140 keV
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40



Photon Transmission Through Water
30 cm thick "patient"
SPECT (140 keV)
PET (511 keV)
probability of transmission
depth (cm)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30



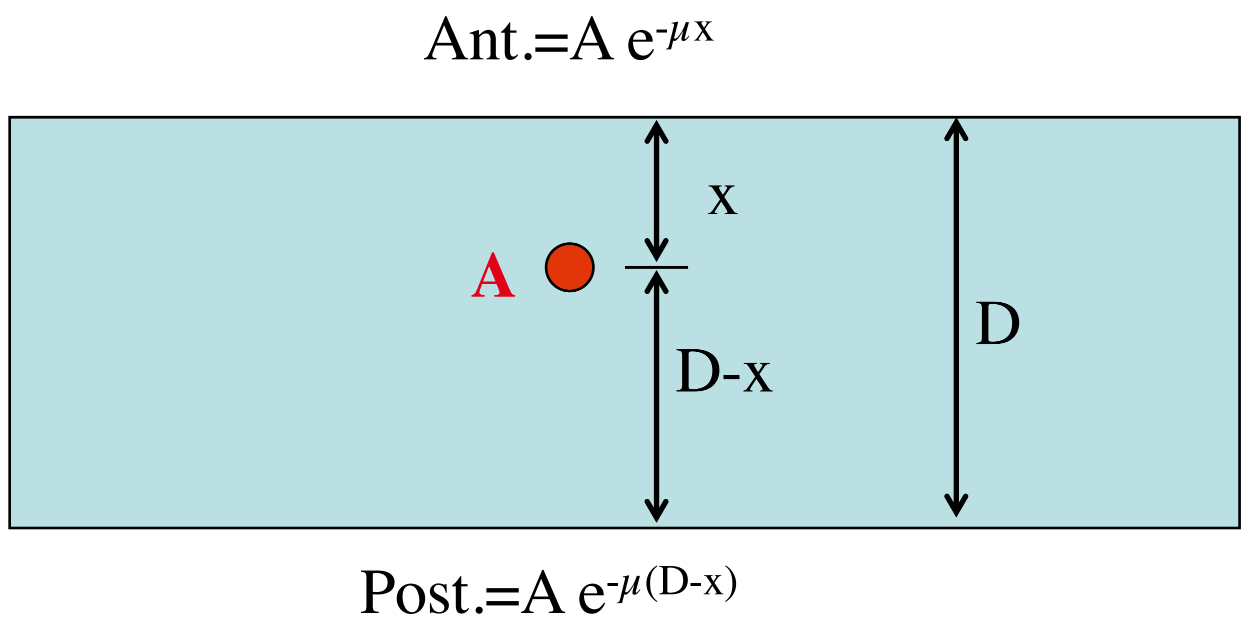
Prob. trans. = $e^{-0.12*x}$
(SPECT)



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

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

Geometric Mean Correction



$$G.M. = [Ant.\bullet Post.]^{1/2} = [A^2 e^{-\mu D}]^{1/2} = A\, e^{-\mu D/2}$$

Correction: Multiply G.M. by $e^{+\mu D/2}$

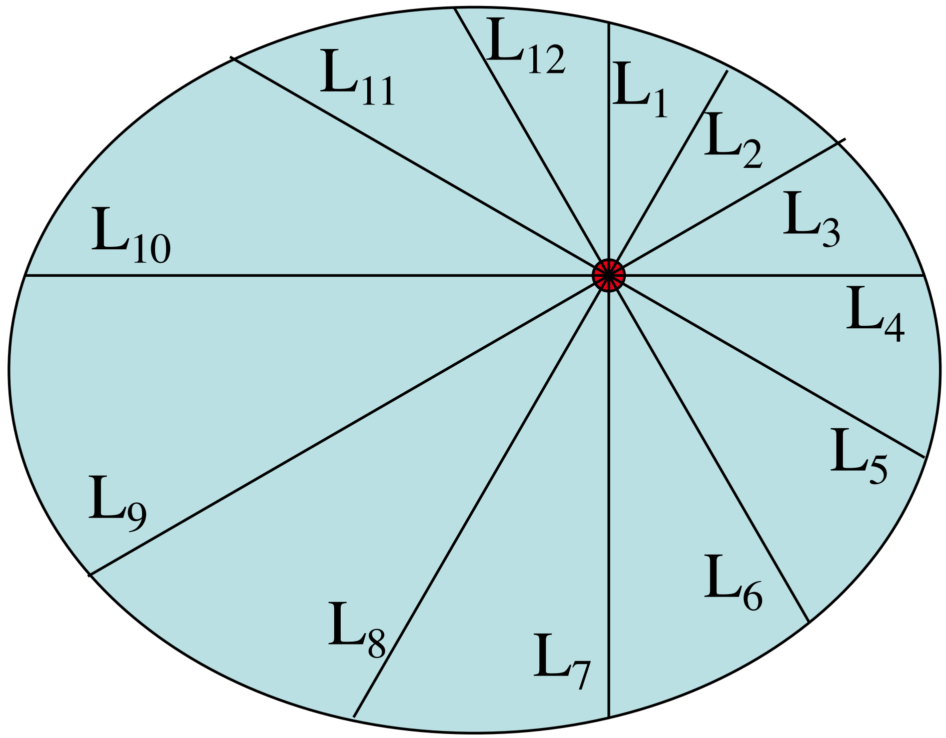
Geometric Mean Correction is useful for:

- planar scans with dual-detector systems
- quantitation of tumors in weak background

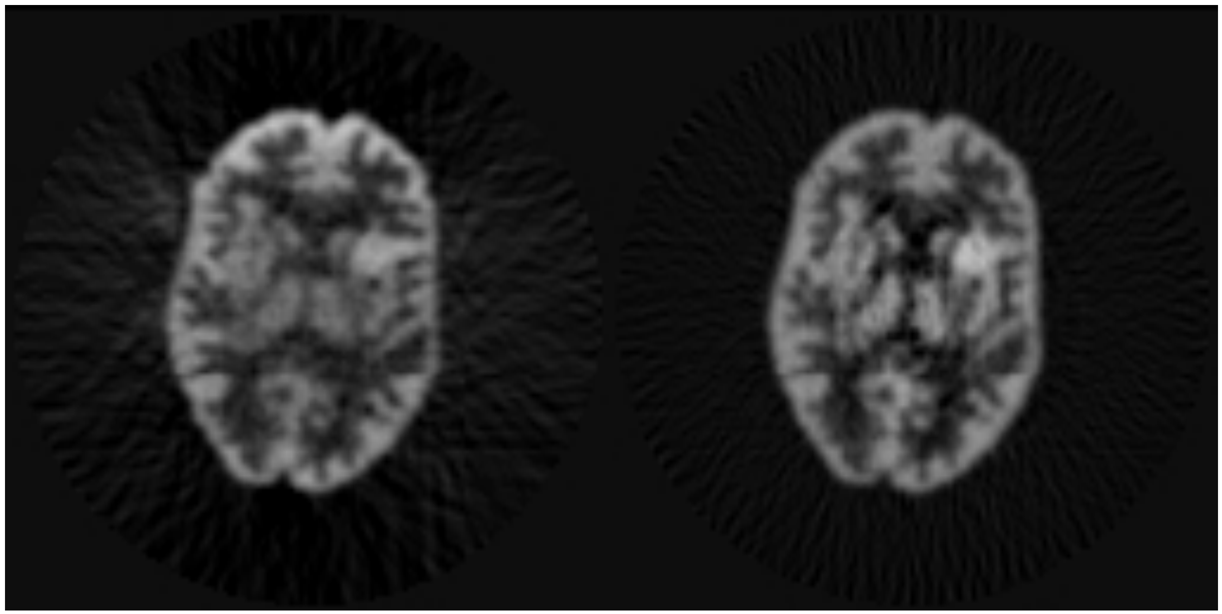
Limitations:

- assumption of uniform attenuation
- must know thickness of body at lesion location
- only for small sources at a single depth

Chang Post-Reconstruction Correction

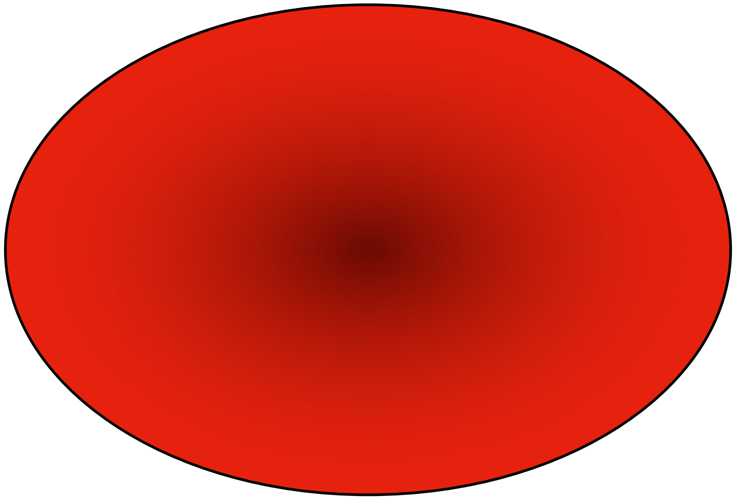


Attenuation Correction Factor: $ACF(x,y) = \dfrac{1}{\dfrac{1}{N}\sum_{i=1}^{N} e^{-\mu L_i}}$



No AC with AC

(from J. Liang et al.)

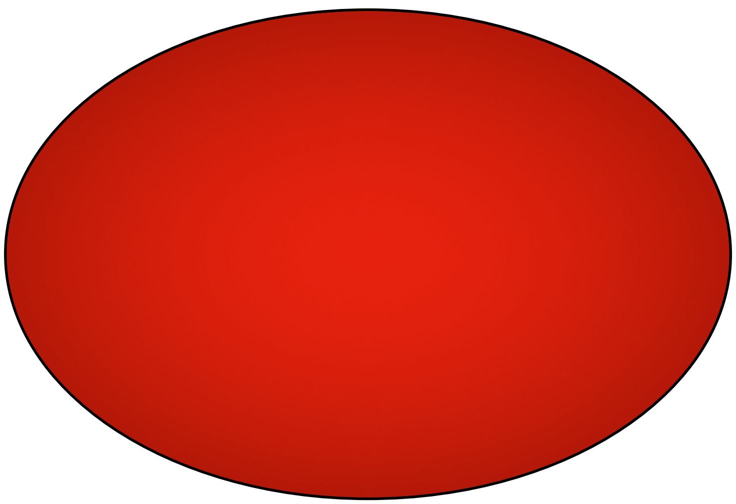


Tc-99m uniform source

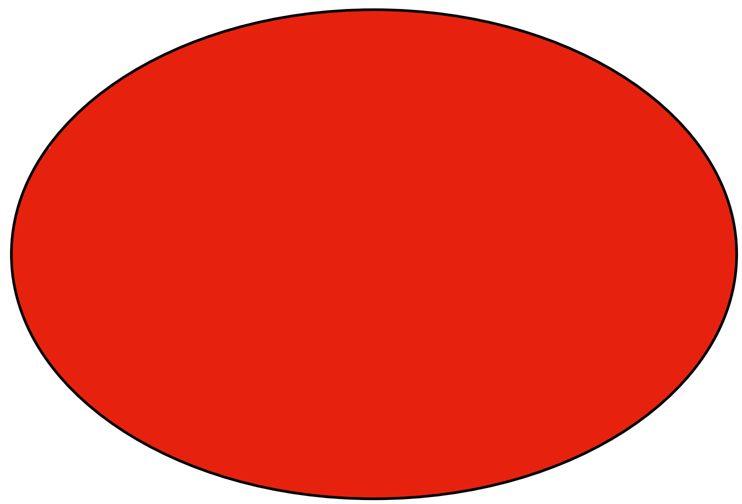
Filtered Back-Projection

No Correction

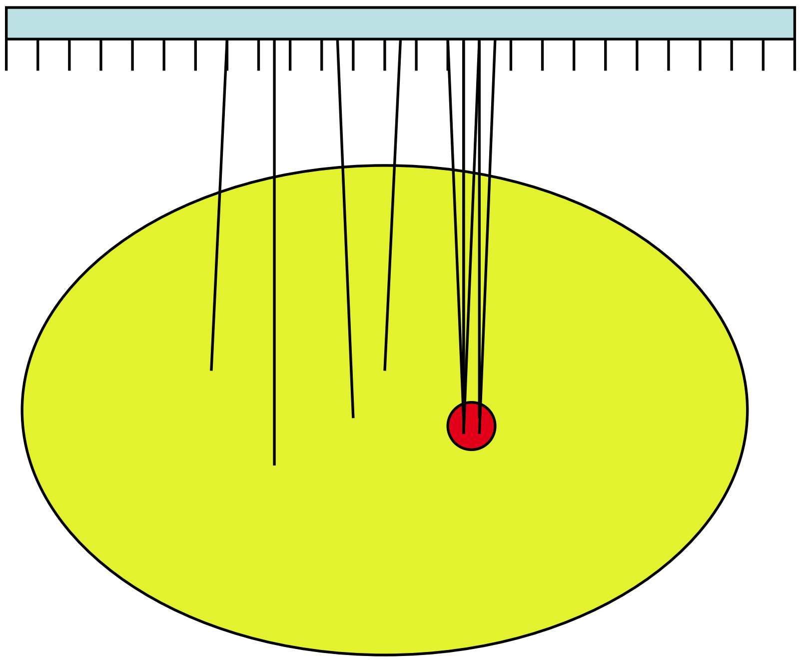
Chang, with $\mu = 0.15\ cm^{-1}$



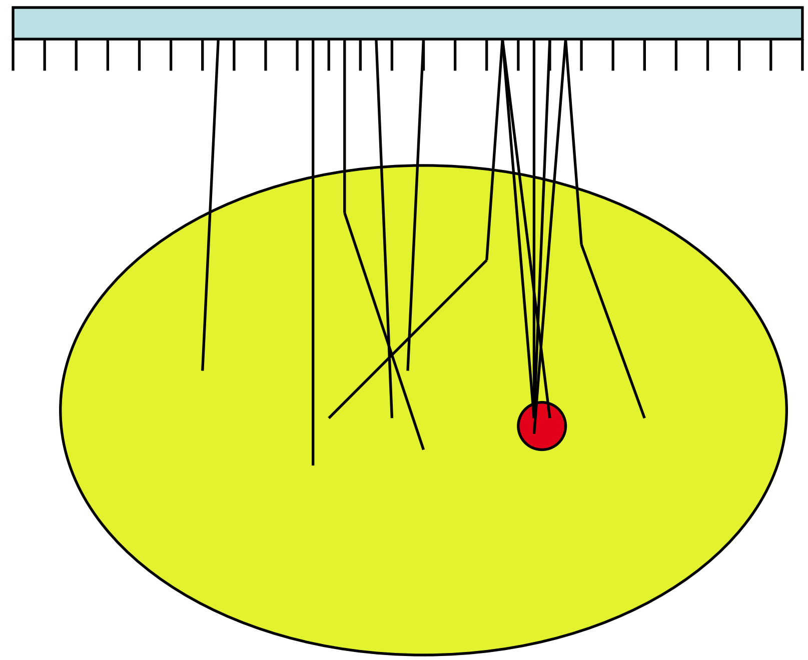
Chang, with $\mu = 0.12\ cm^{-1}$



Use of effective μ compensates for scattered photons



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



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

Chang correction is:

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

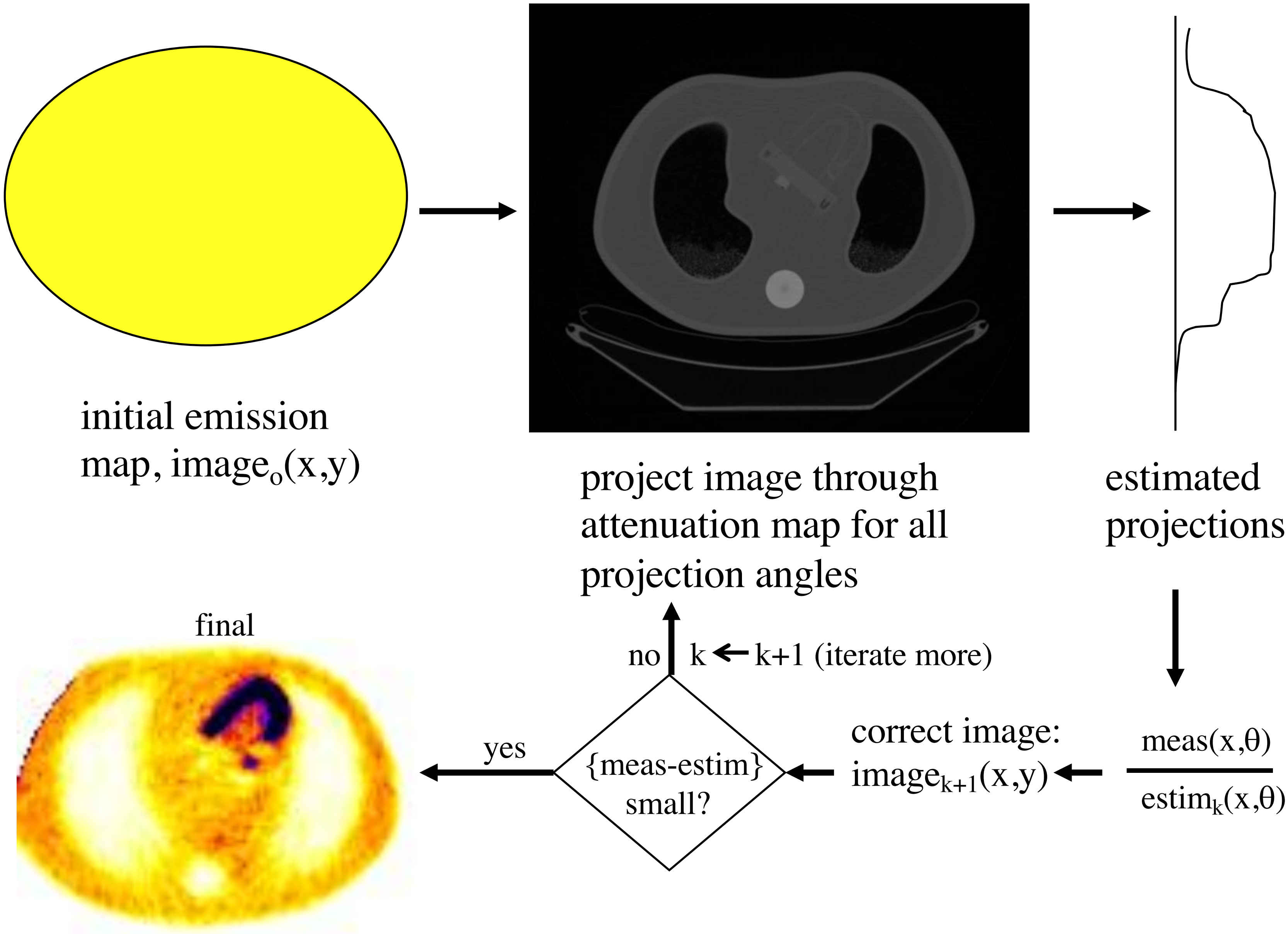
Limitations:

- assumption of uniform attenuation
- serious drawback for cardiac SPECT

Solution?

- iterative reconstruction, e.g., OSEM

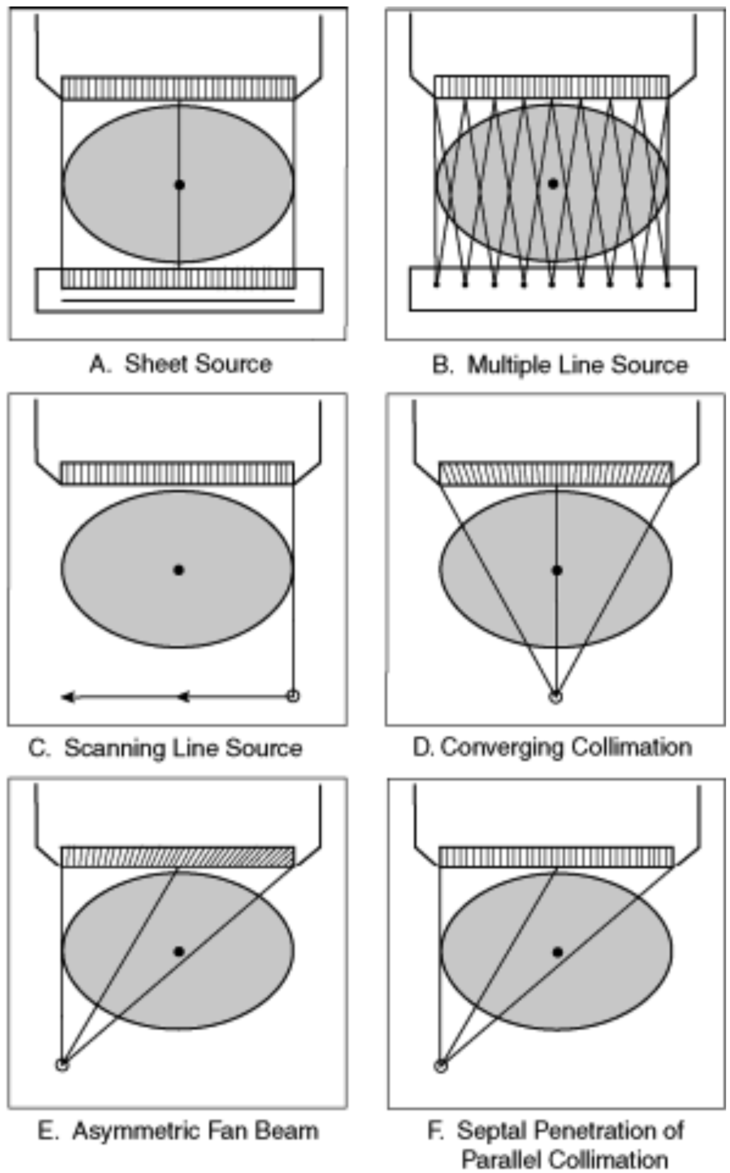
Basic Iterative Reconstruction Flowchart



SPECT Corrections: Attenuation Measurement Devices

Siemens Profile system

ADAC (Philips) Vantage



Picker (Philips) “Beacon”

(diagram from M.A. King et al.)

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

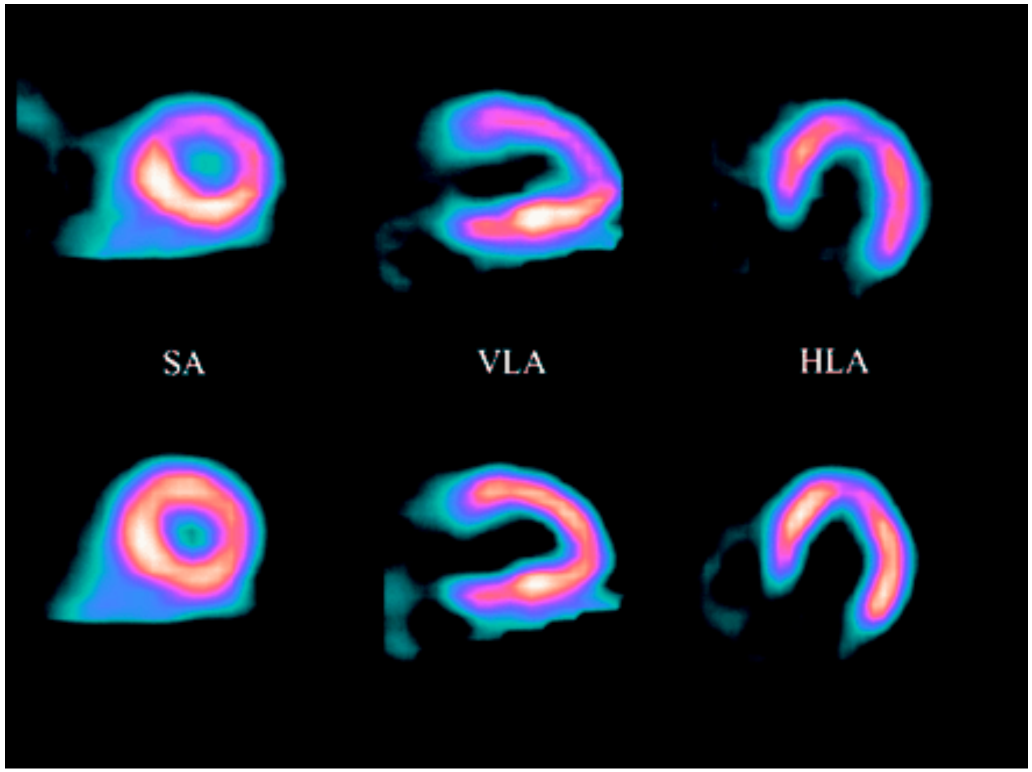


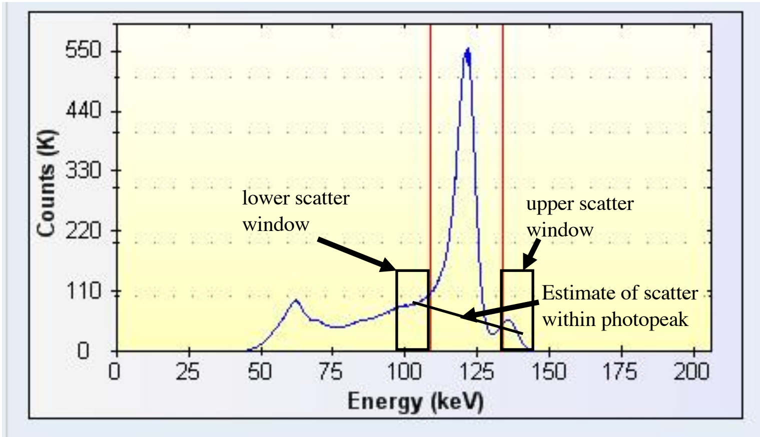
Figure 3. Breast attenuation artifact mid-cavity short axis (SA), vertical long axis (VLA), and horizontal long axis (HLA) perfusion images from a 49-year-old woman who achieved a heart rate of 155 bpm (91% MPHR) without chest pain or ECG changes. She received 33 mCi of 99mTc sestamibi at peak treadmill 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

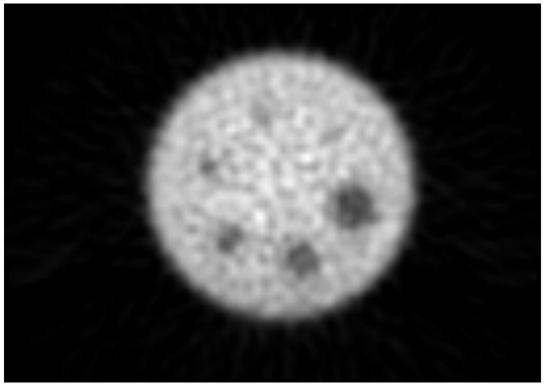
SPECT Corrections: Scatter

Scatter correction methods:

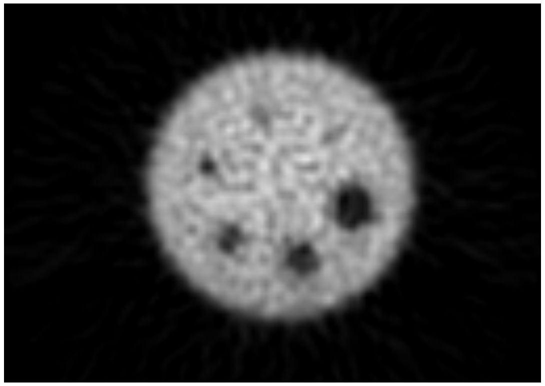
1. Model scatter in the forward projector of an iterative reconstruction program (described earlier).
2. Triple-energy window (TEW) method; estimate and subtract scatter pixel-by-pixel:



with scatter



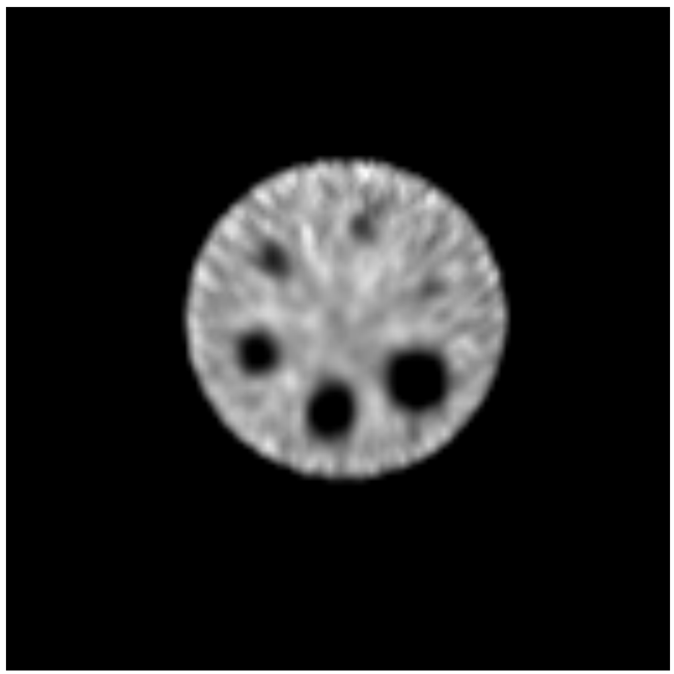
without scatter



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.



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