Nuclear Medicine Imaging Systems: The Scintillation Camera

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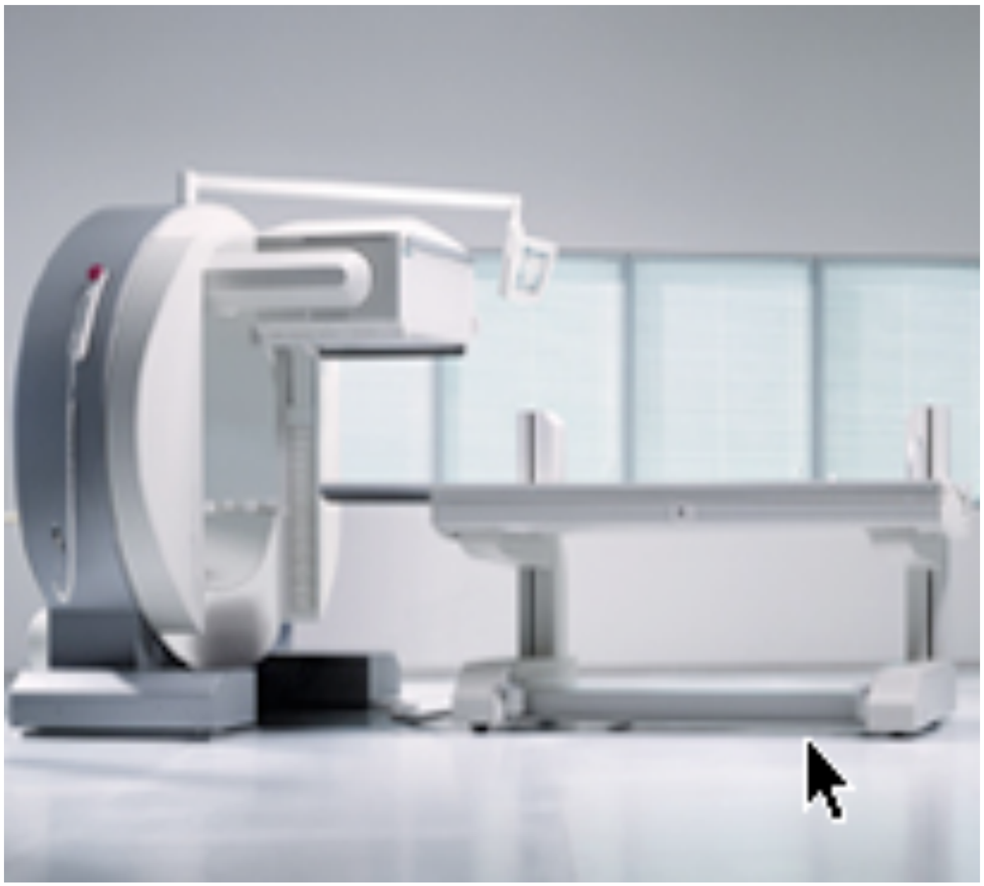
List of Nuclear Medicine Radionuclides

• Tc99m	140.5 keV	6.03 hours
• I-131	364, 637 keV	8.06 days
• I-123	159 keV	13.0 hours
• I-125	35 keV	60.2 days
• In-111	172, 247 keV	2.81 days
• Th-201	~70, 167 keV	3.044 days
• Ga-67	93, 185, 300 keV	3.25 days

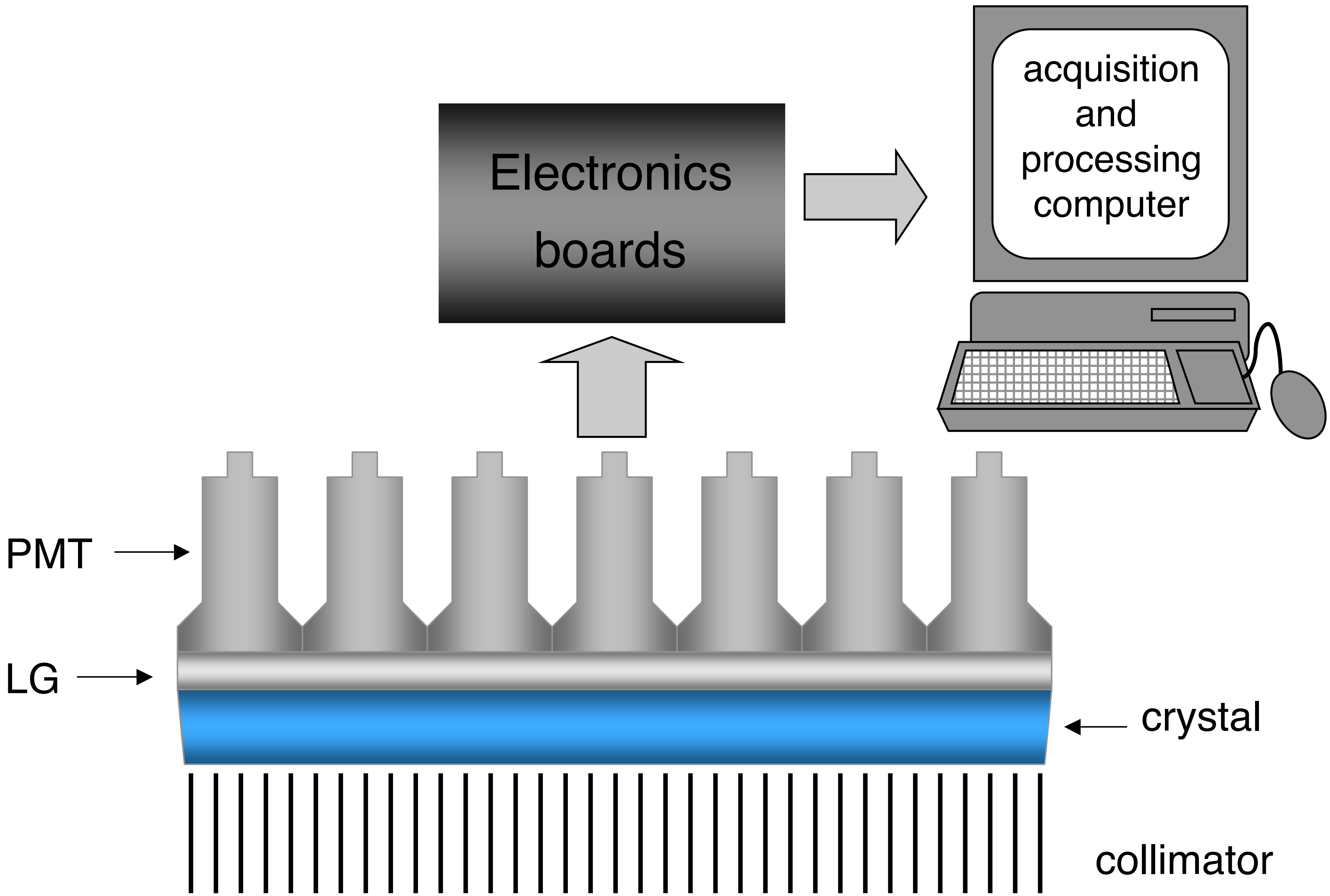
From: Physics in Nuclear Medicine (Sorenson and Phelps)

The Planar Gamma Camera



Siemens e.cam

Gamma Camera Instrumentation



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The Scintillation Camera: Detector System

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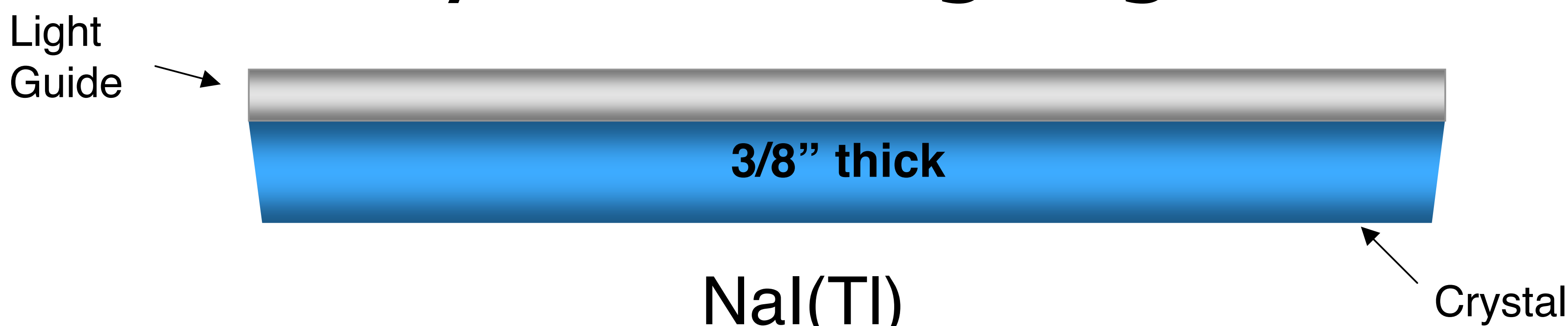
Crystal and light guide



NaI(Tl)

Density	3.67 g/cm^3
Attenuation Coefficient (@140 keV)	2.64 cm^{-1}
PE fraction	~80%
Light output	40K/MeV
Decay time	230 nsec
Wavelength	410 nm

Detection Efficiency

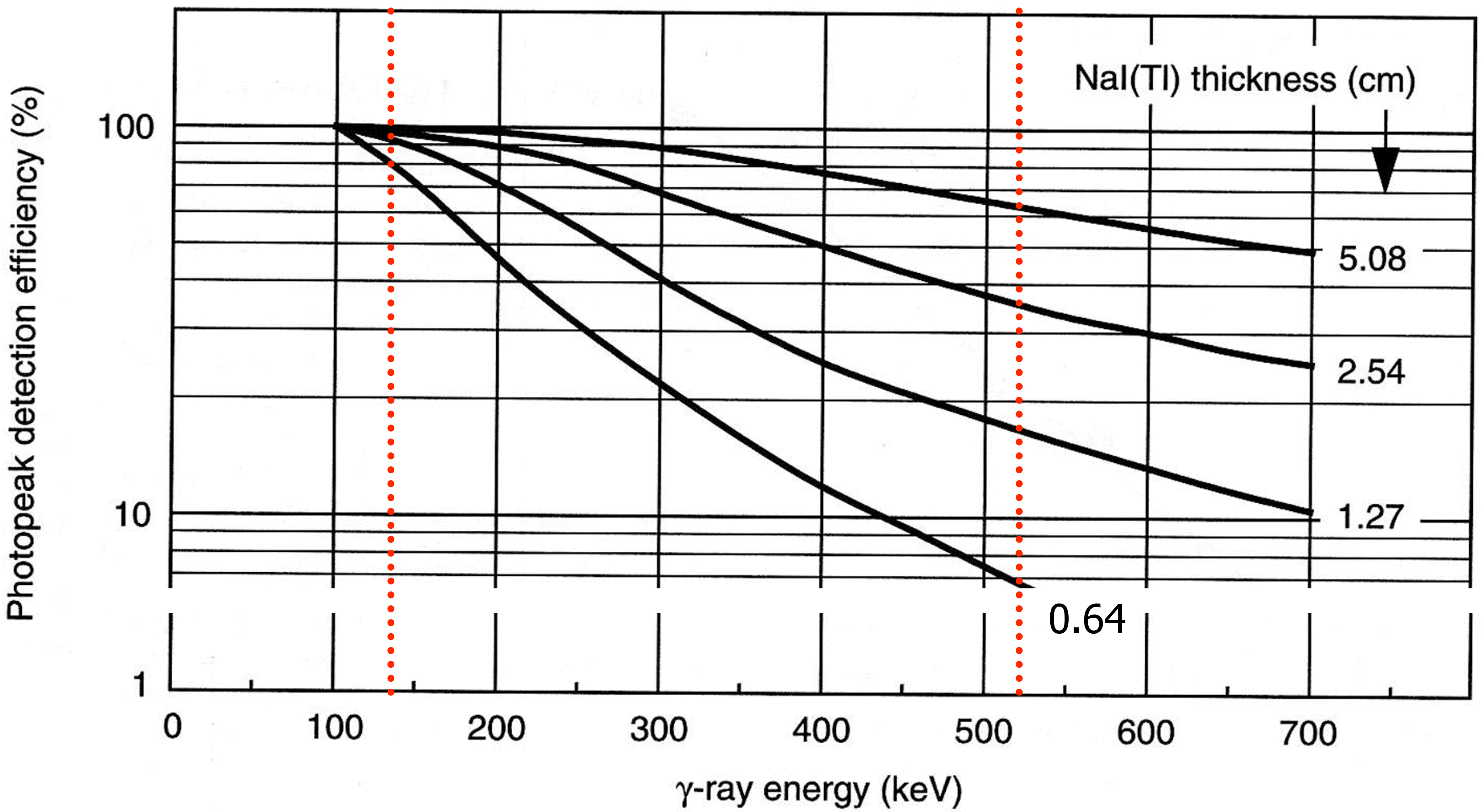
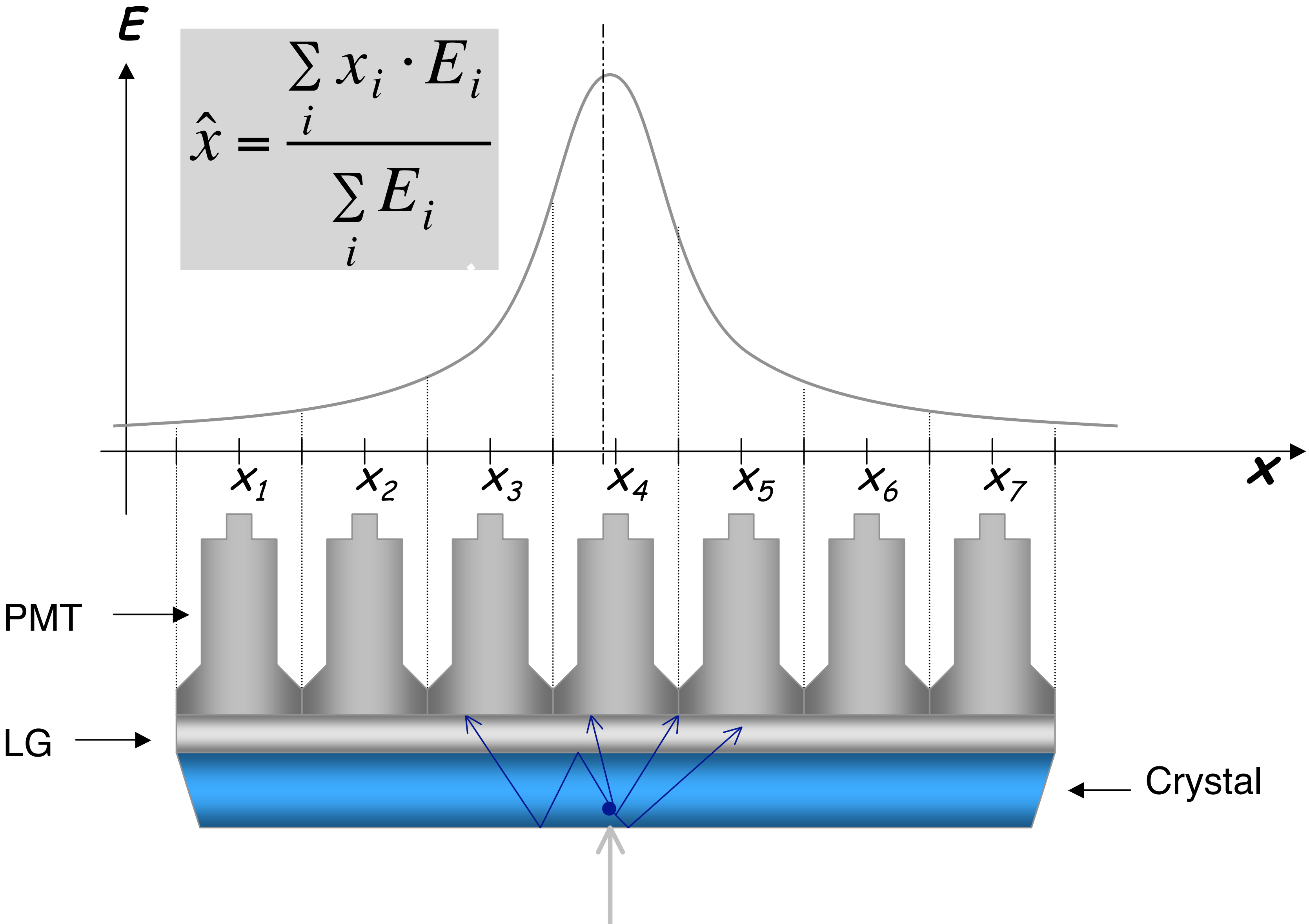


Figure 14–3. Photopeak detection efficiency versus γ-ray energy for NaI(Tl) detectors of different thicknesses. (Adapted from Anger HO: Radioisotope cameras. In Hine GJ [ed]: Instrumentation in Nuclear Medicine, Vol 1. New York, Academic Press, 1967, p 506.)

Light response function versus position
(spatial resolution)

$$\hat{x} = \frac{\sum_i x_i \cdot E_i}{\sum_i E_i}$$



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Spatial Positioning

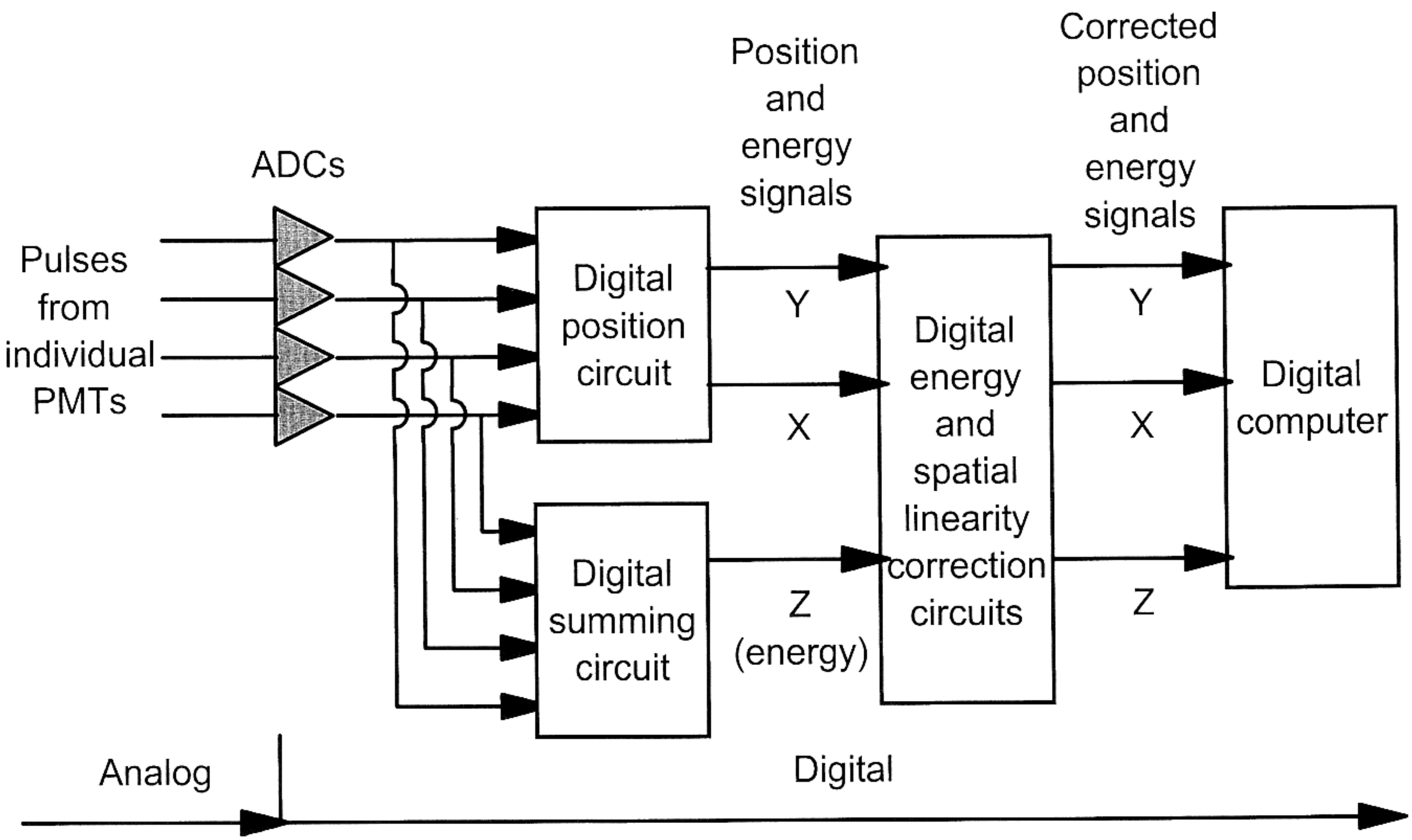
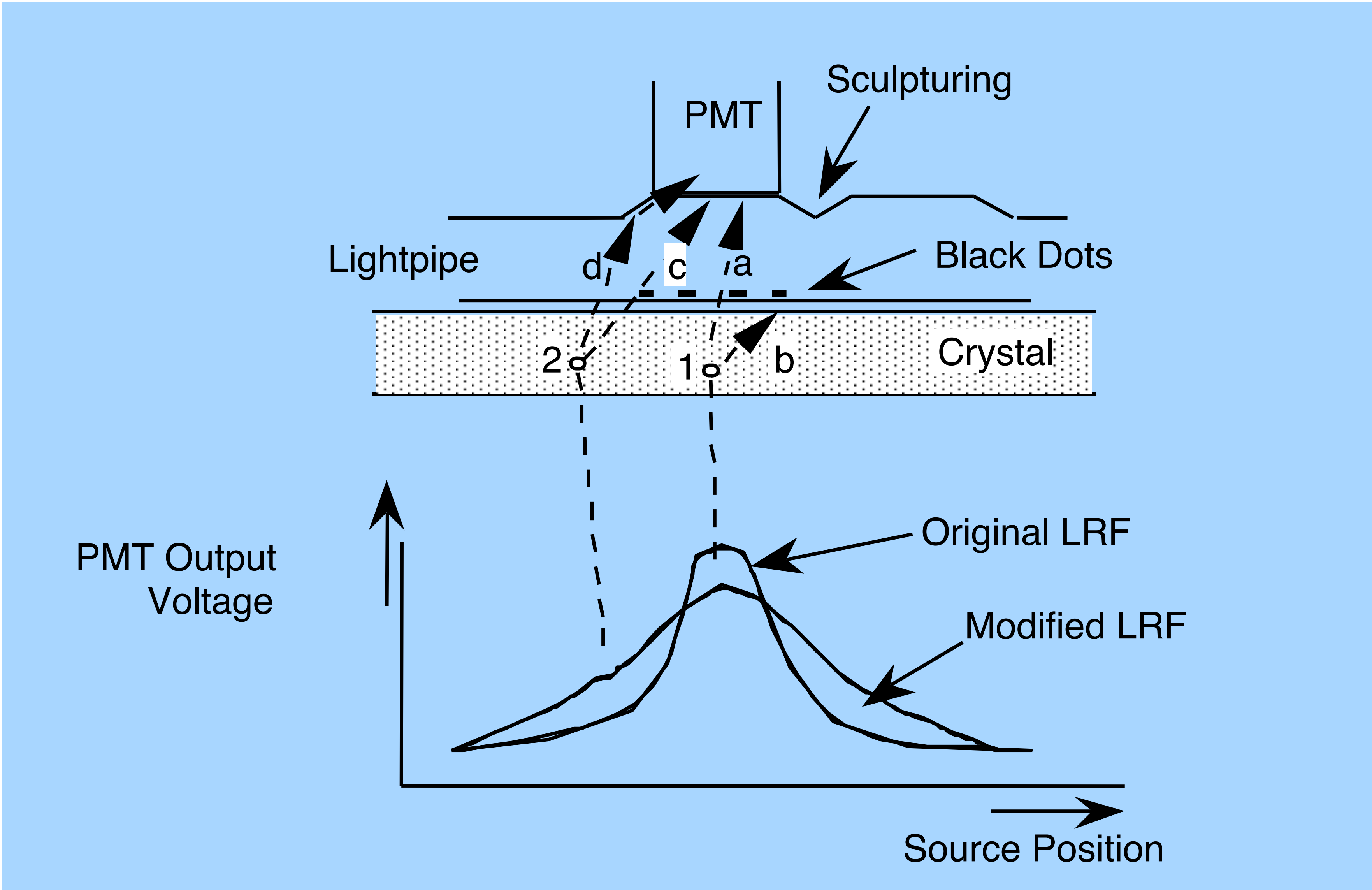


FIGURE 21-5. Electronic circuits of a modern digital scintillation camera.

From: The Essential Physics of Medical Imaging (Bushberg, et al)

Techniques to optimize shape of light response function



Siemens Medical Solutions product literature

Energy Resolution

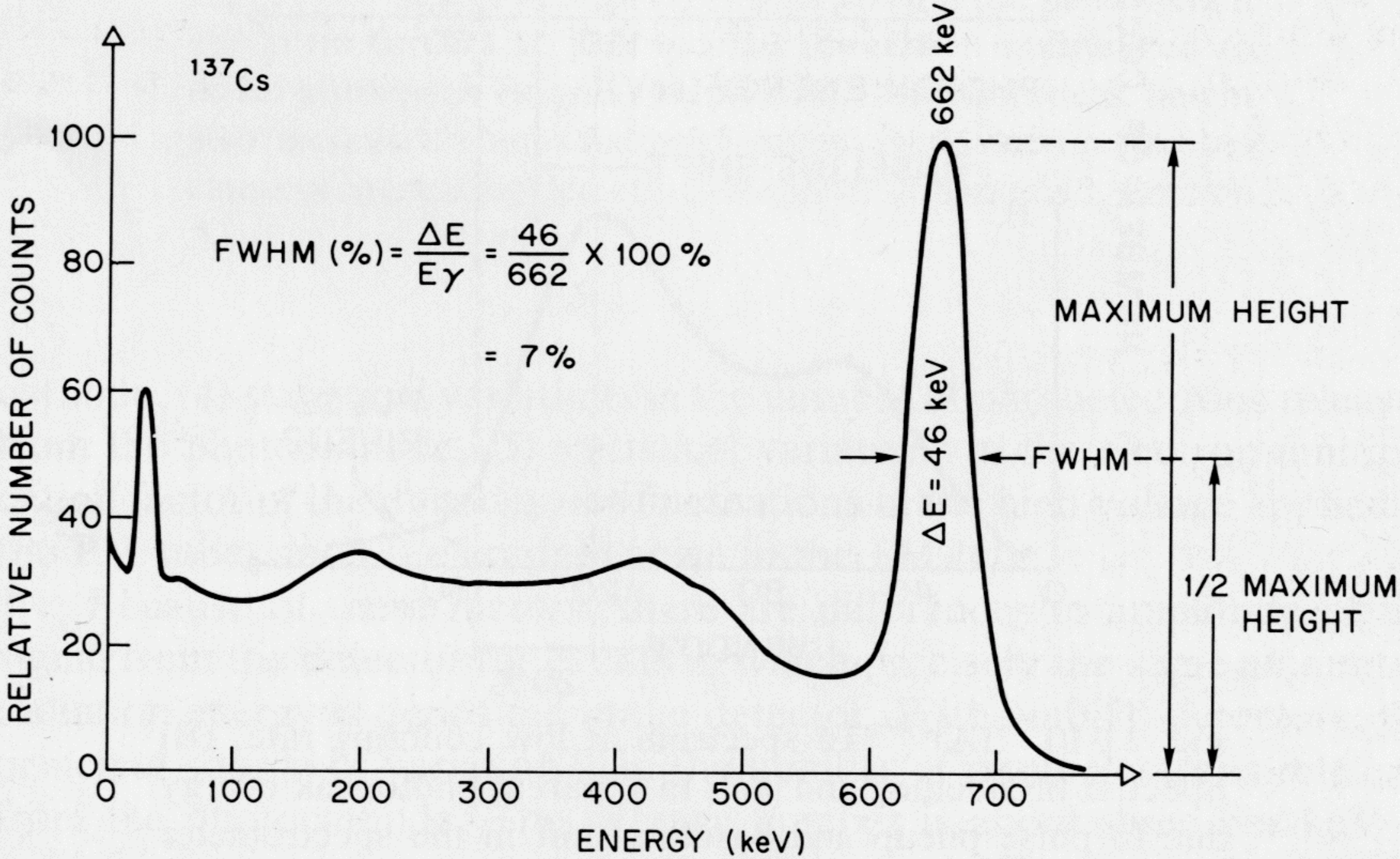
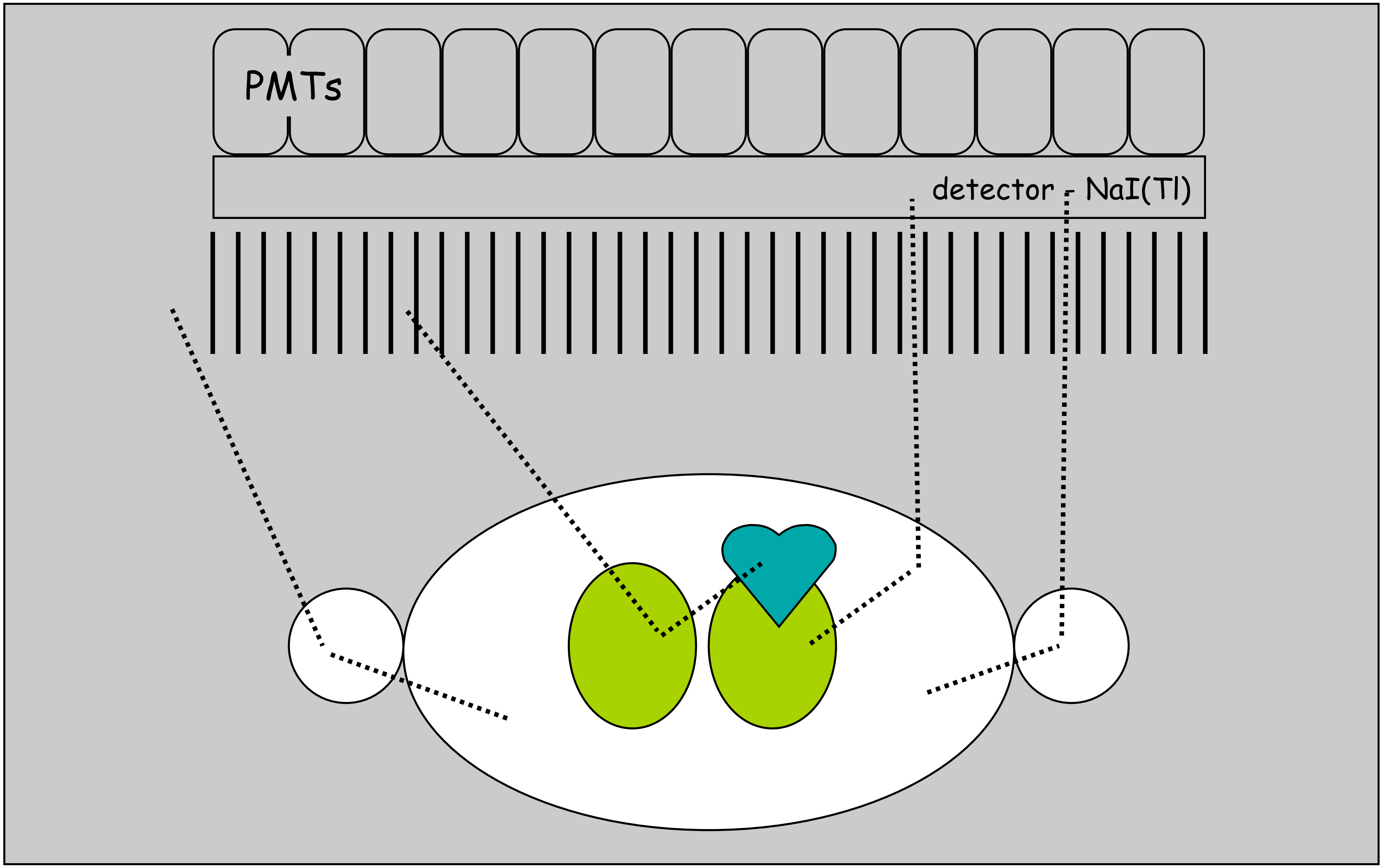


Fig. 11-11. Calculation of FWHM energy resolution of a NaI(Tl) detector for ^{137}Cs 662 keV γ rays.

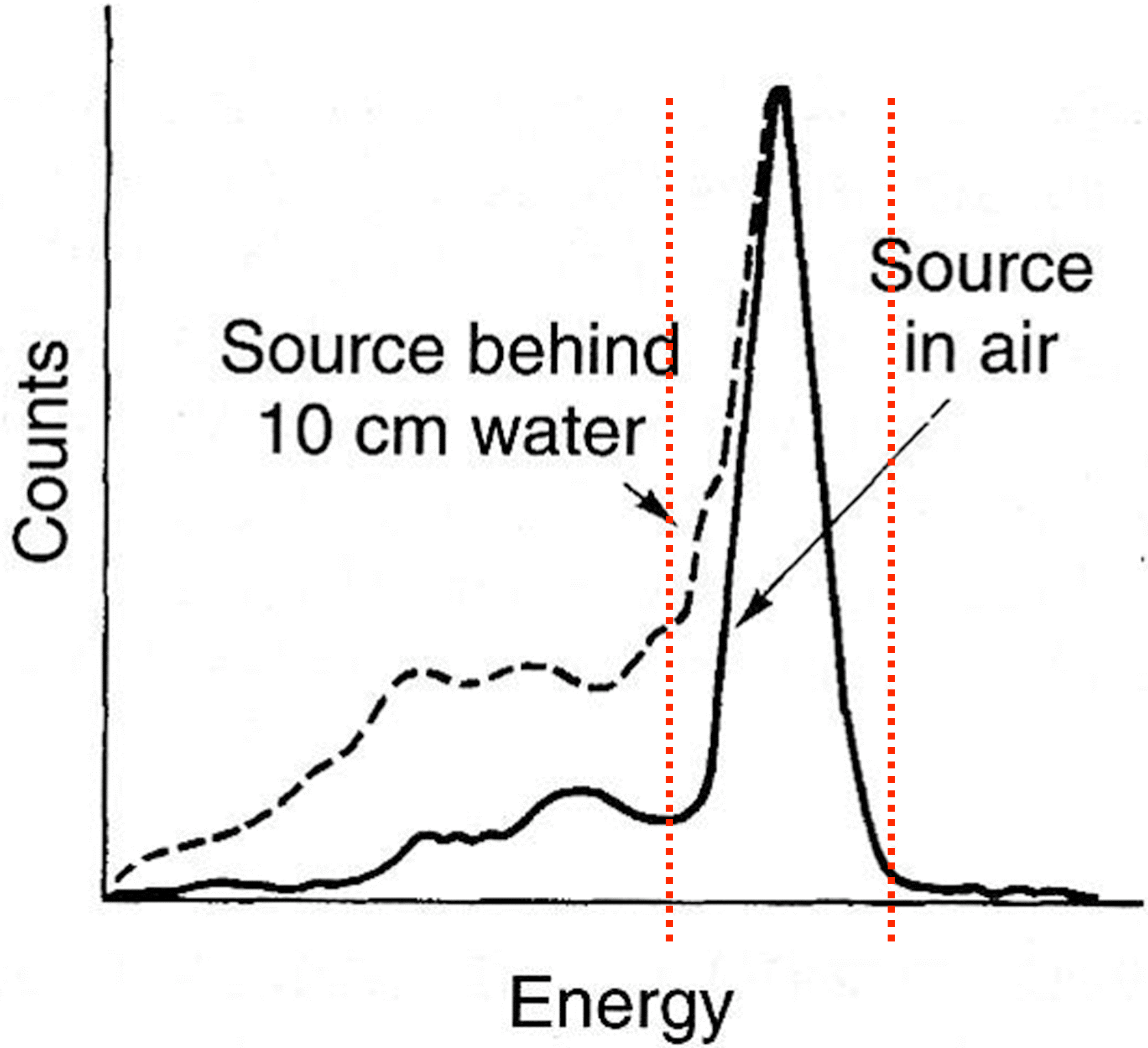
From: Physics in Nuclear Medicine (Sorenson and Phelps)

Scatter



All scatter counts are within the object (unlike in PET)

Gamma Camera Energy Spectra



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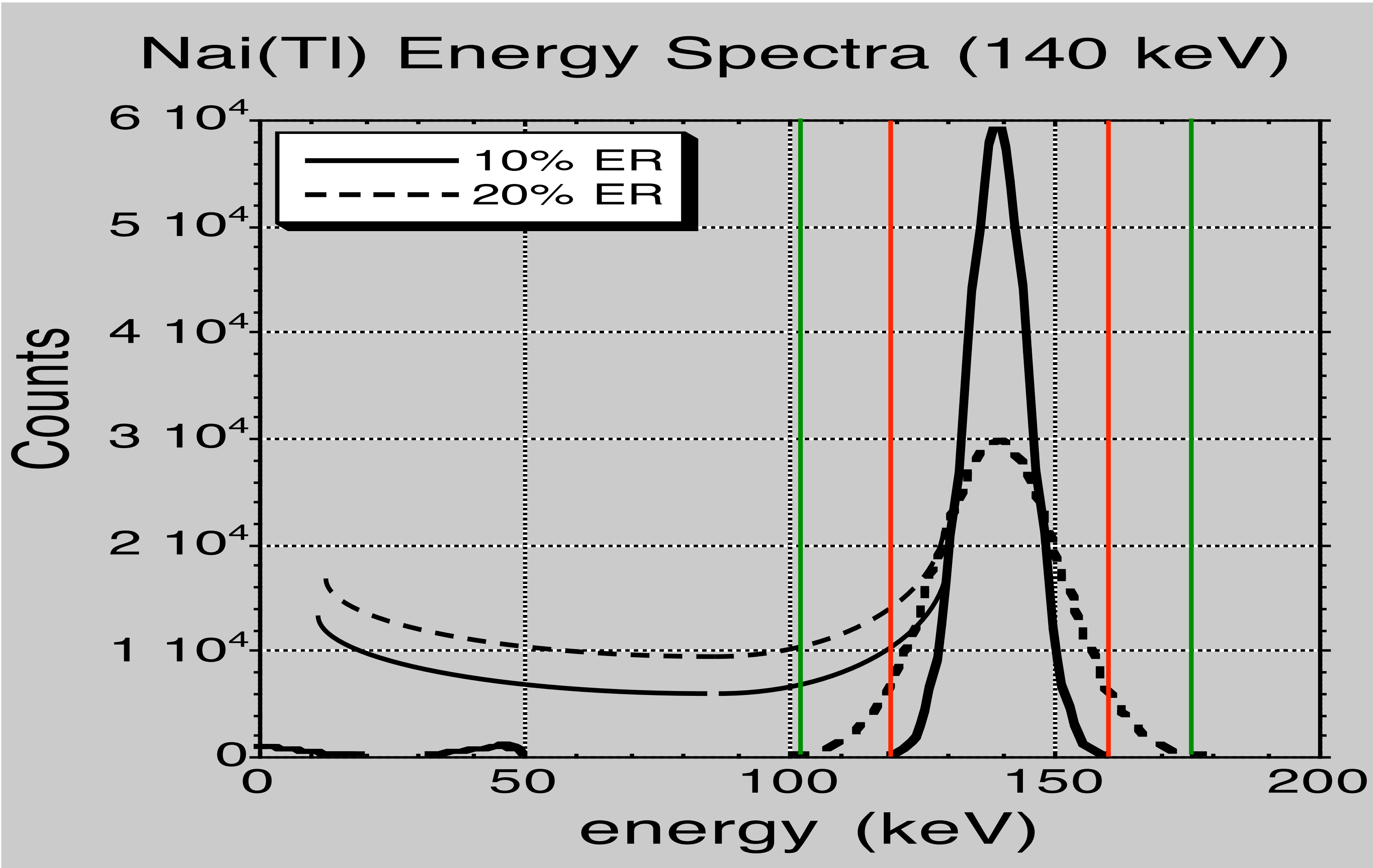
Gamma Camera Energy Spectra



140 keV photons, 9.5 mm crystal

Standard Performance Specifications

Detection efficiency approaching ~85% for 140 keV photons (10 mm thick NaI(Tl))

Energy resolution better than 10% for 140 keV photons

Intrinsic spatial resolution of better than 4 mm FWHM for 140 keV photon source

The Scintillation Camera: Collimators

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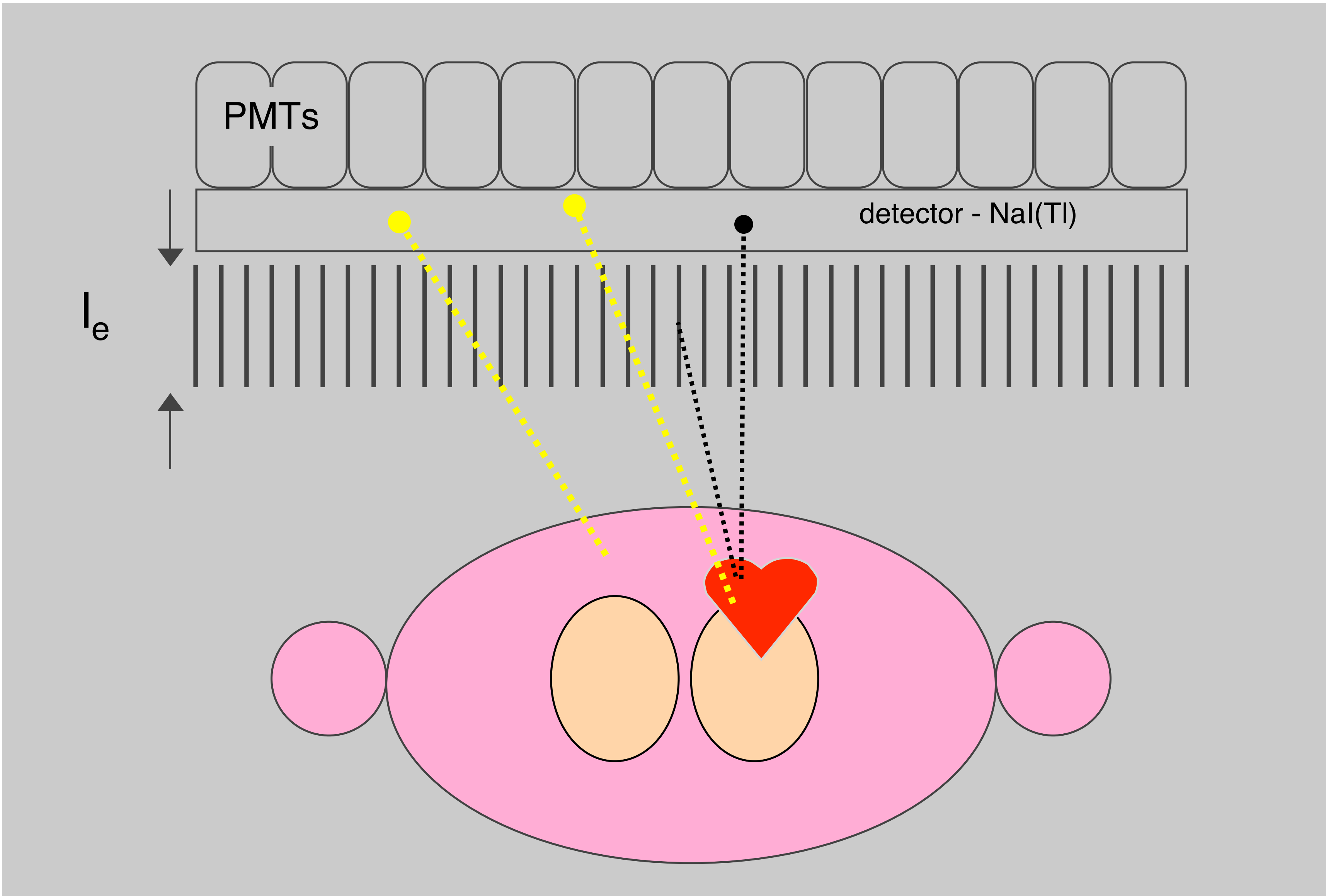
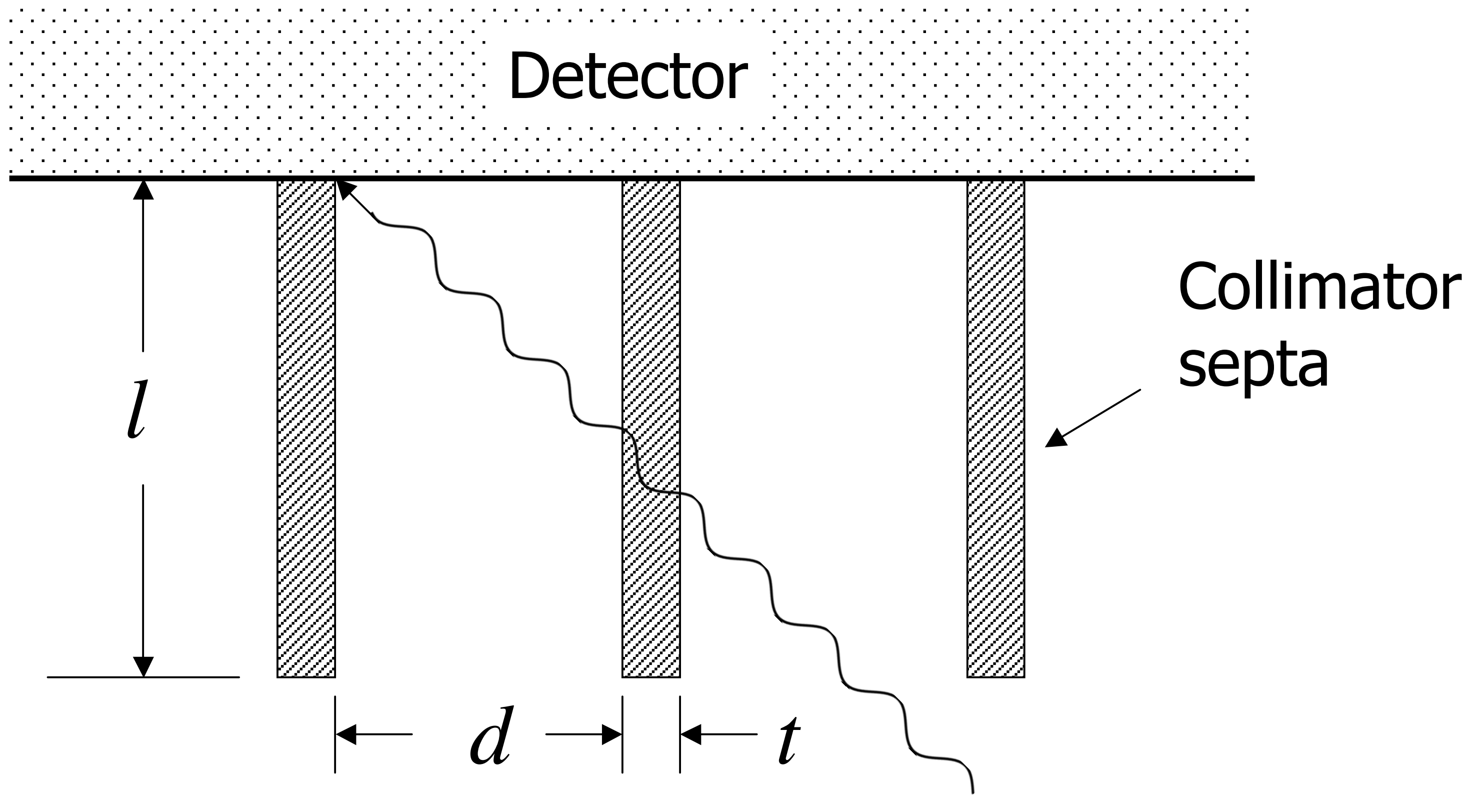
Parallel Hole Collimator



Collimators - Septal Penetration



Minimum septa thickness, t, for <5% septal penetration:

$$t \geq \frac{6d/\mu}{l - (3/\mu)}$$

From: Physics in Nuclear Medicine (Cherry, Sorenson and Phelps)

Collimator Efficiency

Collimators typically absorb well over 99.95% of all photons emitted from the patient.

Trade-off between spatial resolution and detection efficiency.

Collimator Resolution

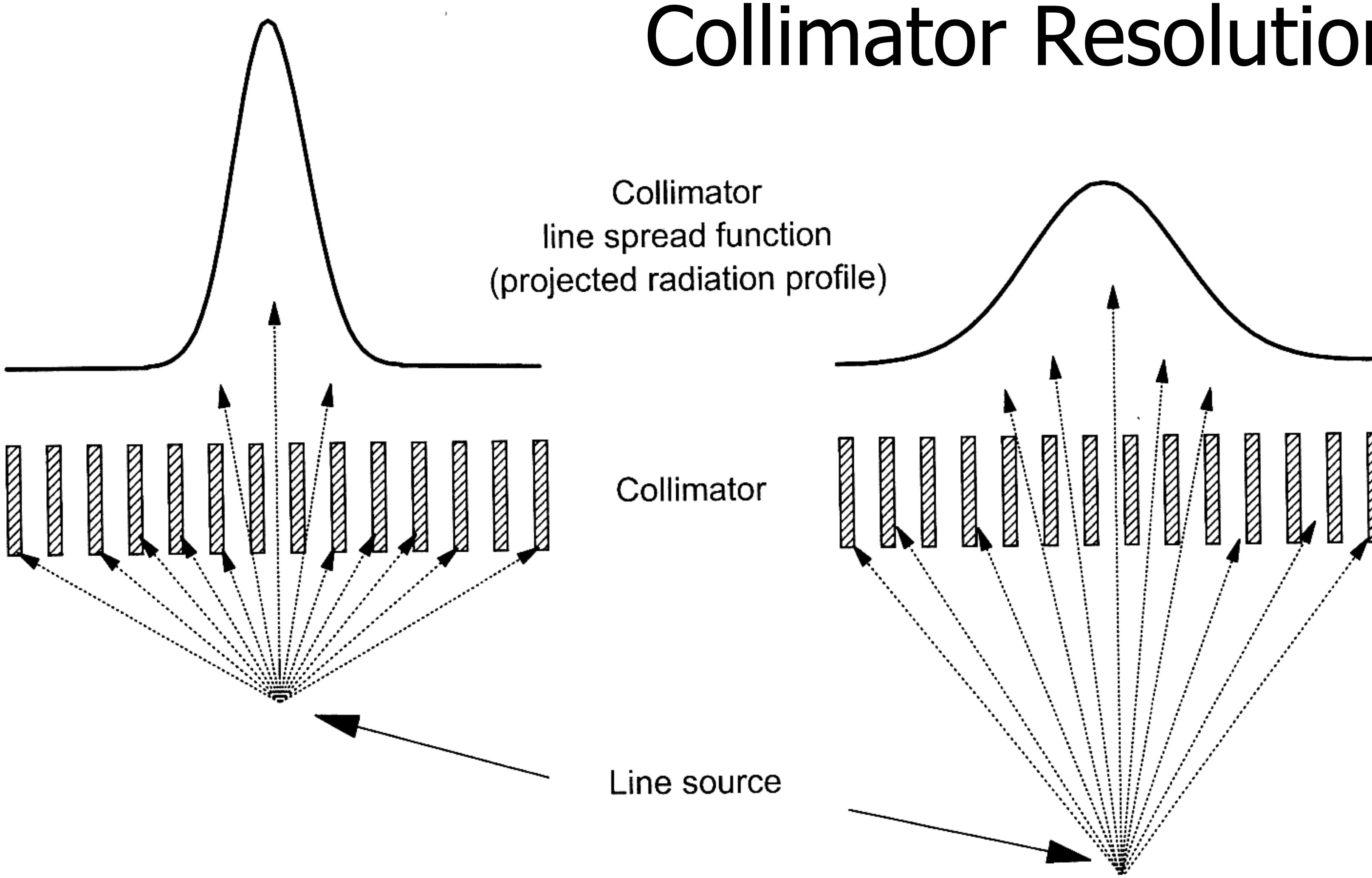
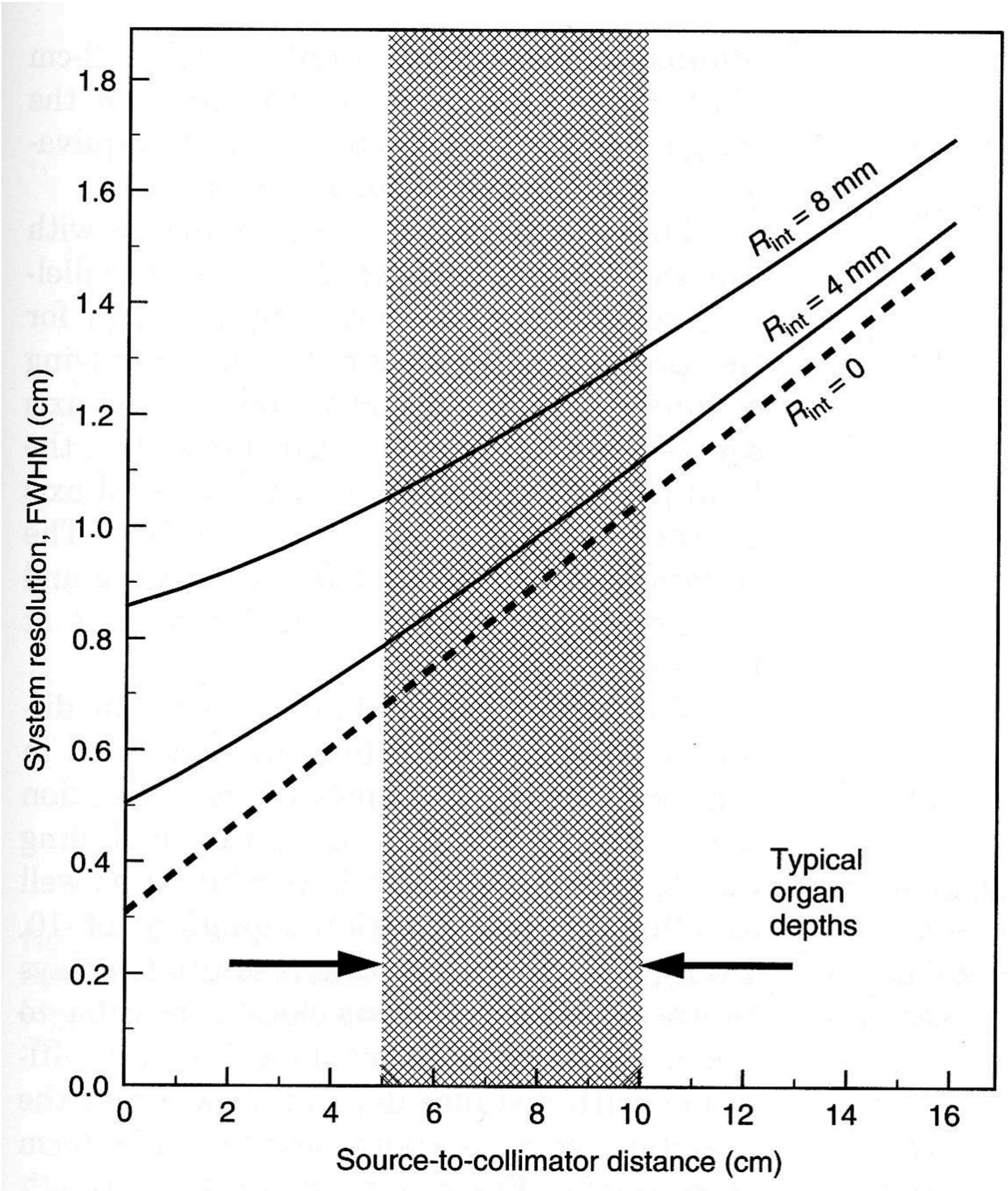
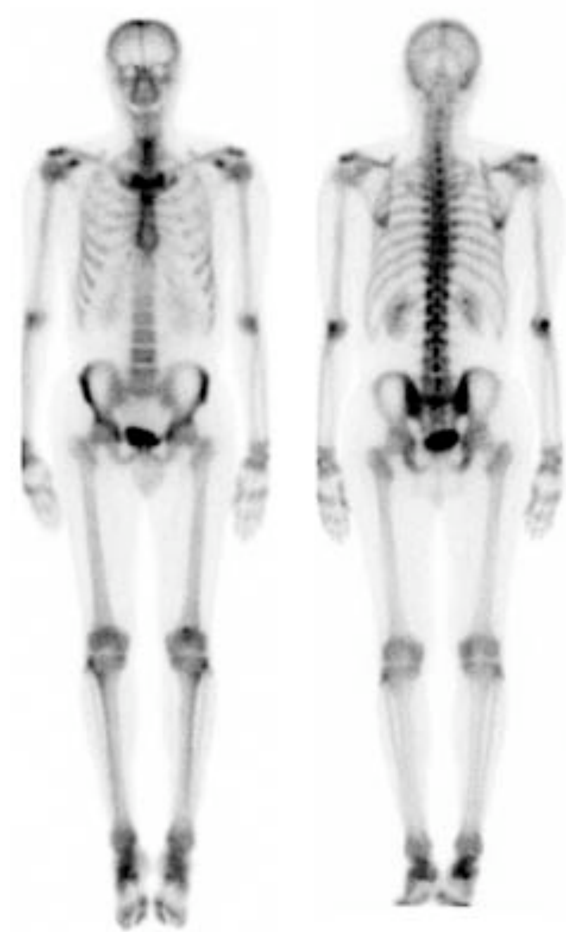


FIGURE 21-12. Line spread function (LSF) of a parallel-hole collimator as a function of source-to-collimator distance. The full-width-at-half-maximum (FWHM) of the LSF increases linearly with distance from the source to the collimator; however, the total area under the LSF (photon fluence through the collimator) decreases very little with source to collimator distance. (In both figures, the line source is seen "end-on.")

Gamma Camera - spatial resolution





$$R_s = \sqrt{\left(R_i^2 + R_c^2\right)}$$

From: Physics in Nuclear Medicine (Cherry, Sorenson and Phelps)

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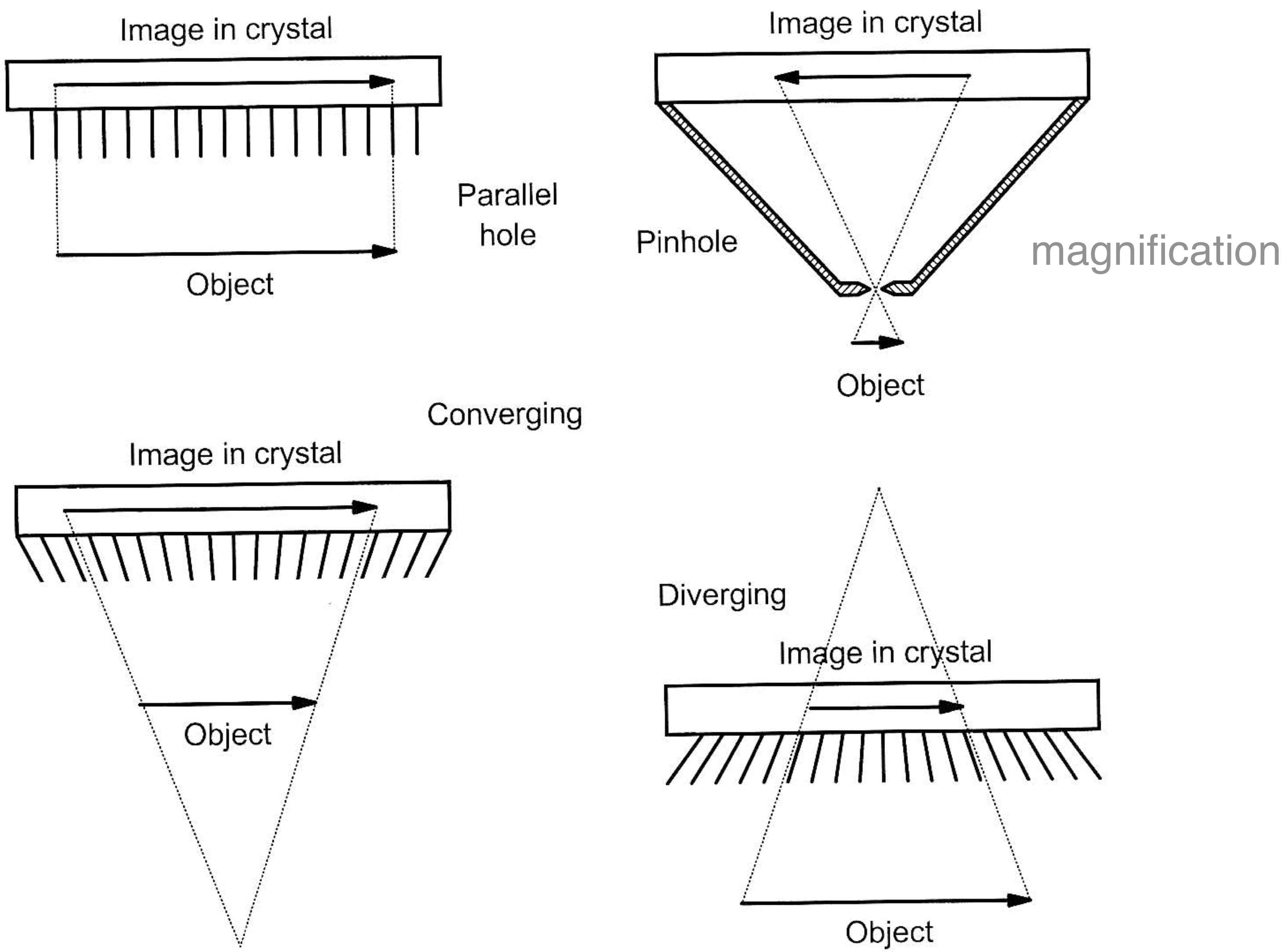
Types of Collimators



From: The Essential Physics of Medical Imaging (Bushberg, et al)

Collimator: Resolution and Sensitivity

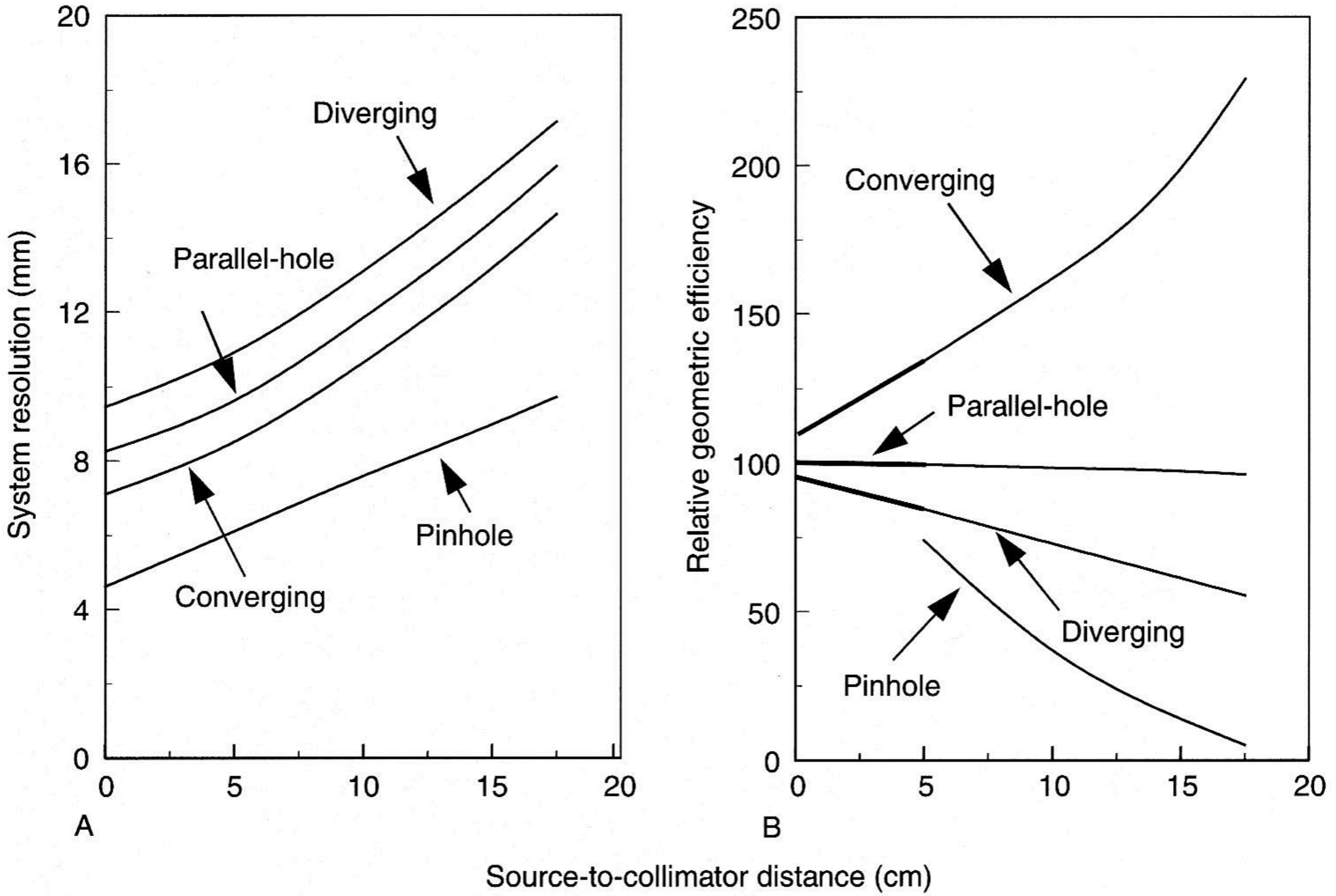


Figure 14–21. Performance characteristics (*A*, system resolution; *B*, point-source geometric efficiency in air) versus source-to-collimator distance for four different types of gamma camera collimators. (Reprinted by permission of the Society of Nuclear Medicine from Moyer RA: A low-energy multihole converging collimator compared with a pinhole collimator. J Nucl Med 15:59–64, 1974.)

From: Physics in Nuclear Medicine (Cherry, Sorenson and Phelps)

Collimator: Resolution and Sensitivity

TABLE 21-3. THE EFFECT OF INCREASING COLLIMATOR-TO-OBJECT DISTANCE ON COLLIMATOR PERFORMANCE PARAMETERS

Collimator	Spatial resolution[a]	Efficiency	Field size	Magnification
Parallel hole	Decreases	Approximately constant	Constant	Constant (*m* = 1.0)
Converging	Decreases	Increases	Decreases	Increases (*m* >1 at collimator surface)
Diverging	Decreases	Decreases	Increases	Decreases (*m* <1 at collimator surface)
Pinhole	Decreases	Decreases	Increases	Decreases (*m* largest near pinhole)

[a]Spatial resolution corrected for magnification.

From: The Essential Physics of Medical Imaging (Bushberg, et al)

Raphex Question

D67. A patient with a history of thyroid cancer has suspected bone marrow metastases in the cervical spine. It is recommended to perform both an I-131 radioiodine scan as well as a bone scan using the Tc-99m-MDP. Which would be the optimum sequence to perform unambiguous scans in the ***shortest*** time?

A. Administer the I-131 and Tc-99m simultaneously. Perform the bone scan first and recall the patient after 24 hours for the radioiodine scan.
B. Administer the I-131 first. Perform the I-131 thyroid scan at 24 hours, then inject Tc-99m MDP and perform the bone scan shortly afterwards.
C. Administer the I-131 first. Perform the I-131 thyroid scan at 24 hours, then ask the patient to wait 3 to 6 weeks until the I-131 has fully decayed before performing the bone scan.
D. Administer the Tc-99m MDP first. Perform the bone scan. Then administer the I-131, and perform the thyroid scan after 24 hours.
E. Administer the Tc-99m MDP first, followed shortly thereafter by the I-131. Then perform the bone scan followed by the thyroid scan after 24 hours.

Raphex Question

D75. In an anterior spot image of the thyroid, a starburst artifact may be seen. The cause of this artifact is:

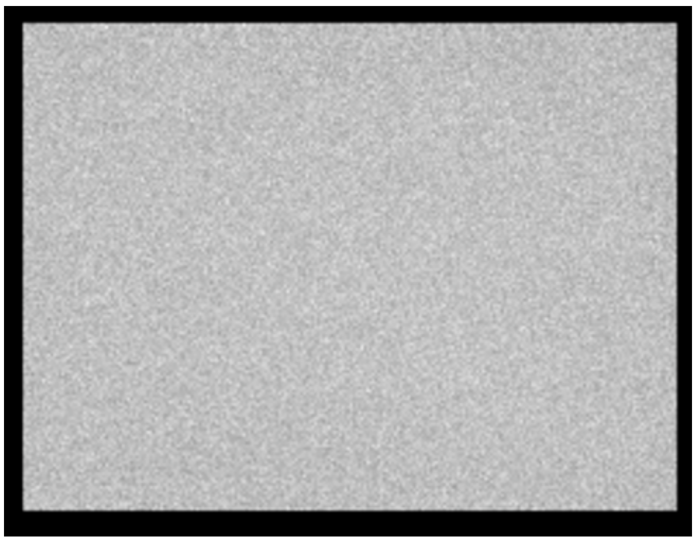
A. Contamination of the collimator.
B. Imperfections in the evenness of the collimator holes.
C. An image reconstruction artifact caused by filtered back projection.
D. Local photomultiplier tube dead time.
E. Septal penetration.

Raphex Question

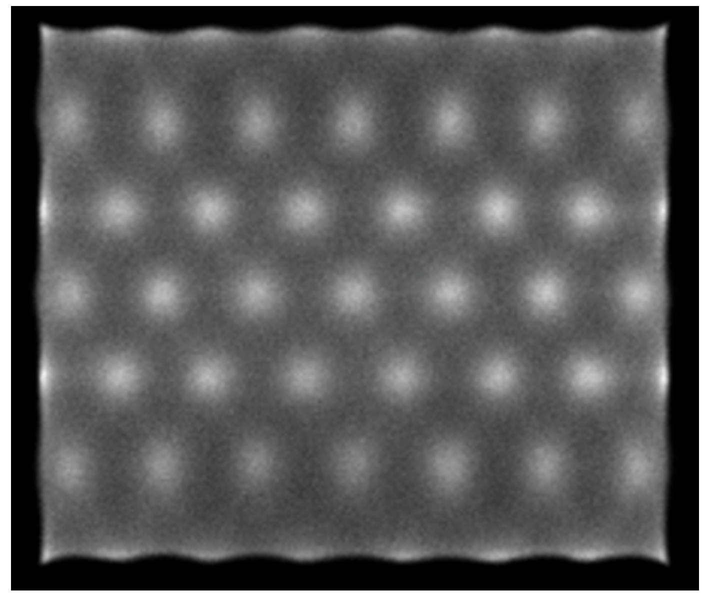
D64. What would be the appearance of a gamma camera image if a Tc-99m isotope scan were performed for the same duration but with the wrong collimator: a medium-energy general-purpose instead of a low-energy general-purpose collimator ?

A. There would be absolutely no effect.
B. The image will be more noisy, but probably clinically acceptable.
C. The image quality would be poor due to septal penetration. The study would need to be repeated.
D. There would be so few counts that the study would need to be repeated.
E. This mistake could never happen, because instrument interlocks would prevent a Tc-99m study being performed with the wrong collimator.

The Scintillation Camera: Corrections and QA



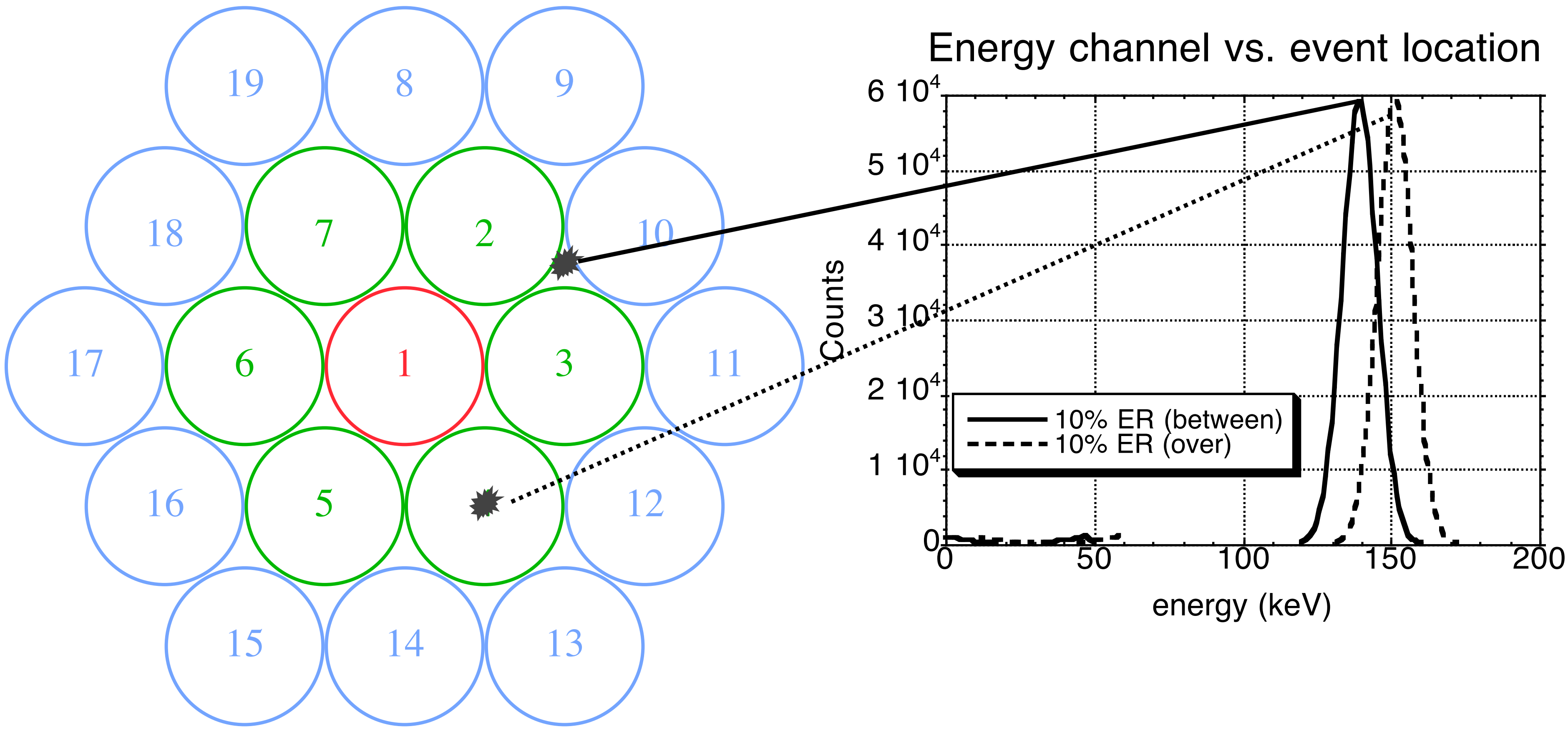
With corrections



Without corrections

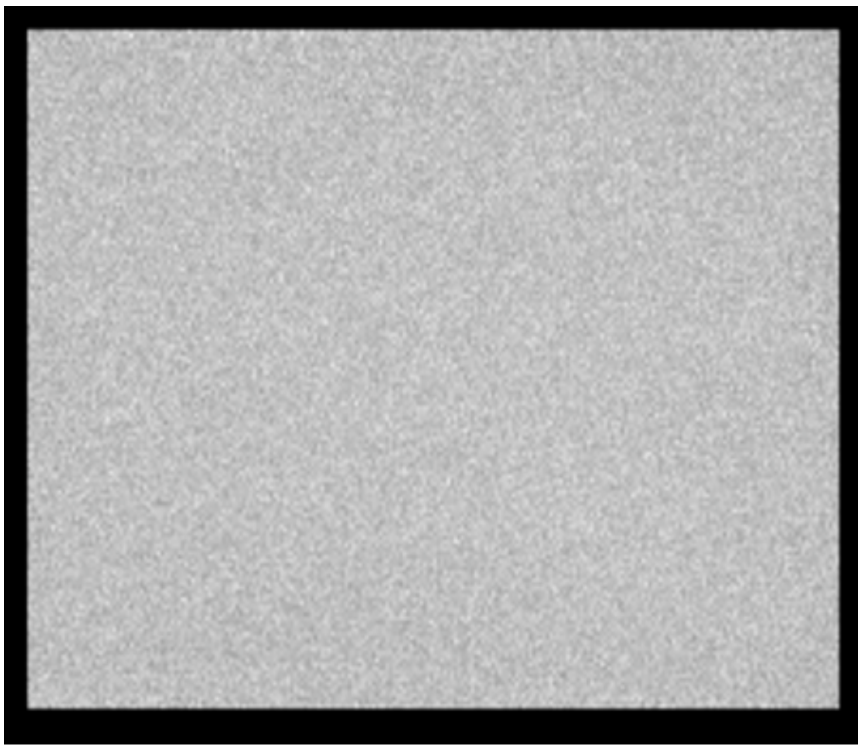
Gamma Camera Processing Electronics

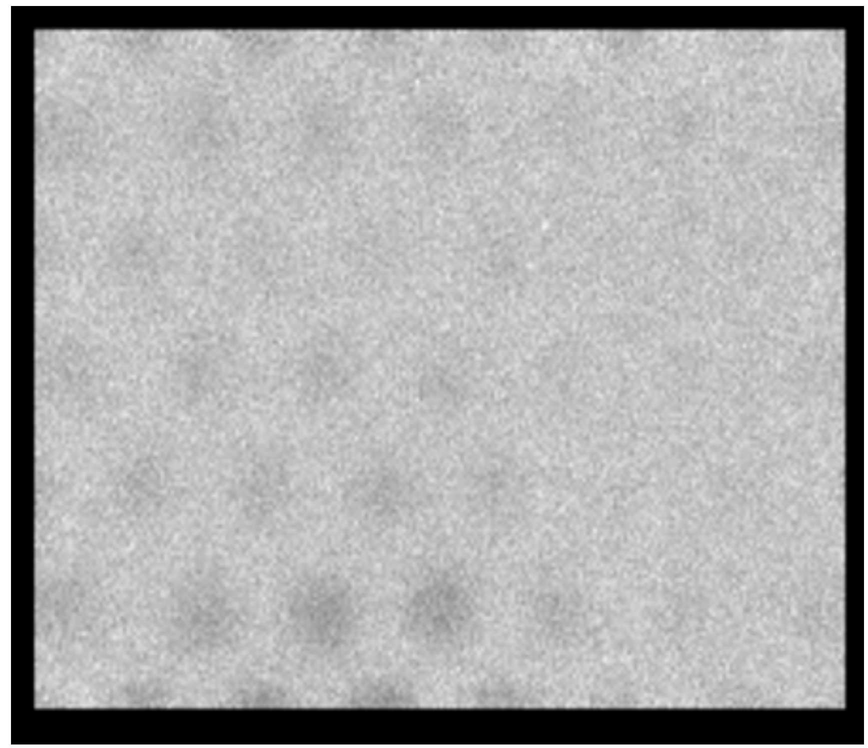
(energy correction)



Gamma Camera Processing Electronics

(with and without energy correction)





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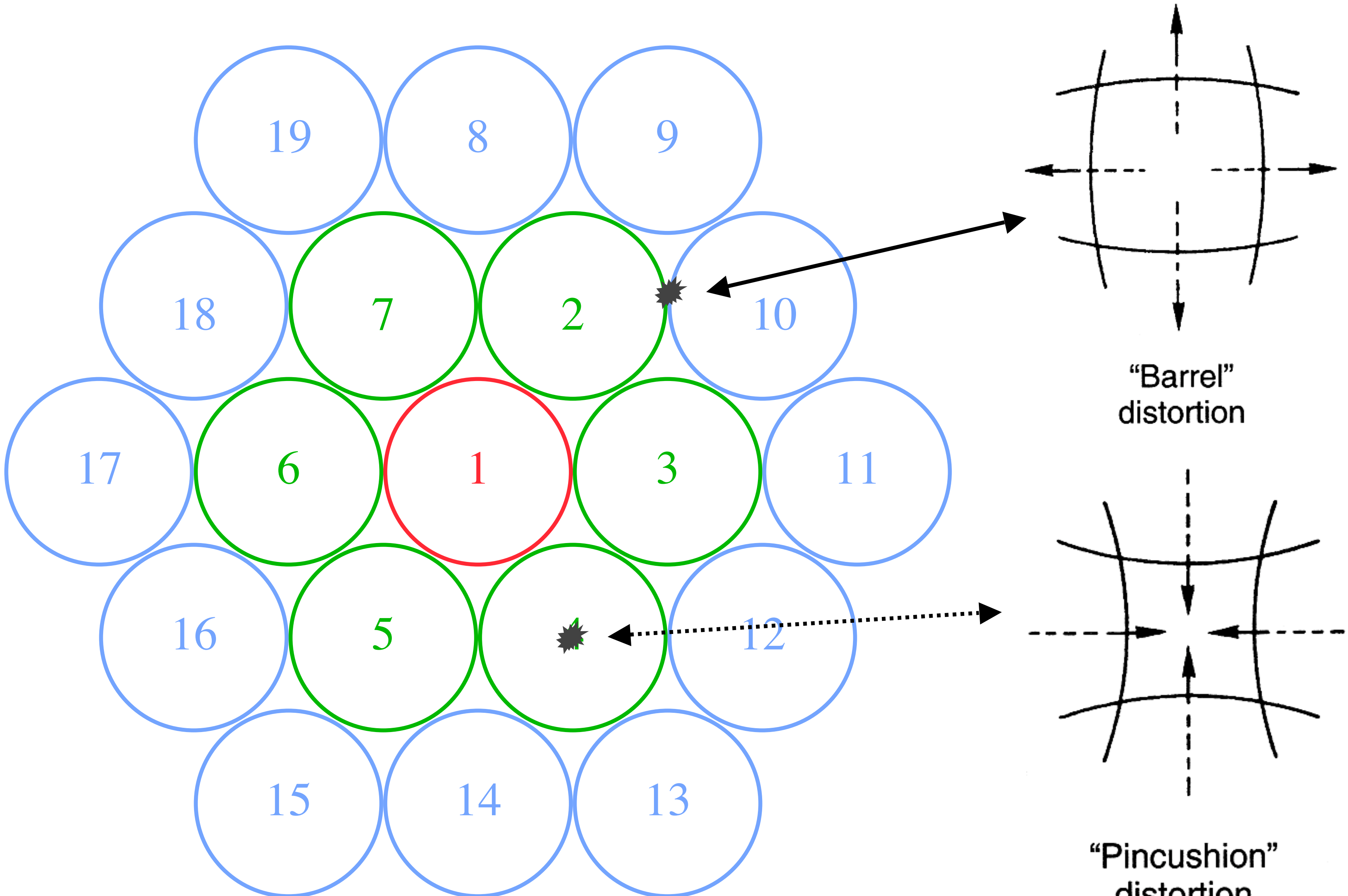
Gamma Camera Processing Electronics

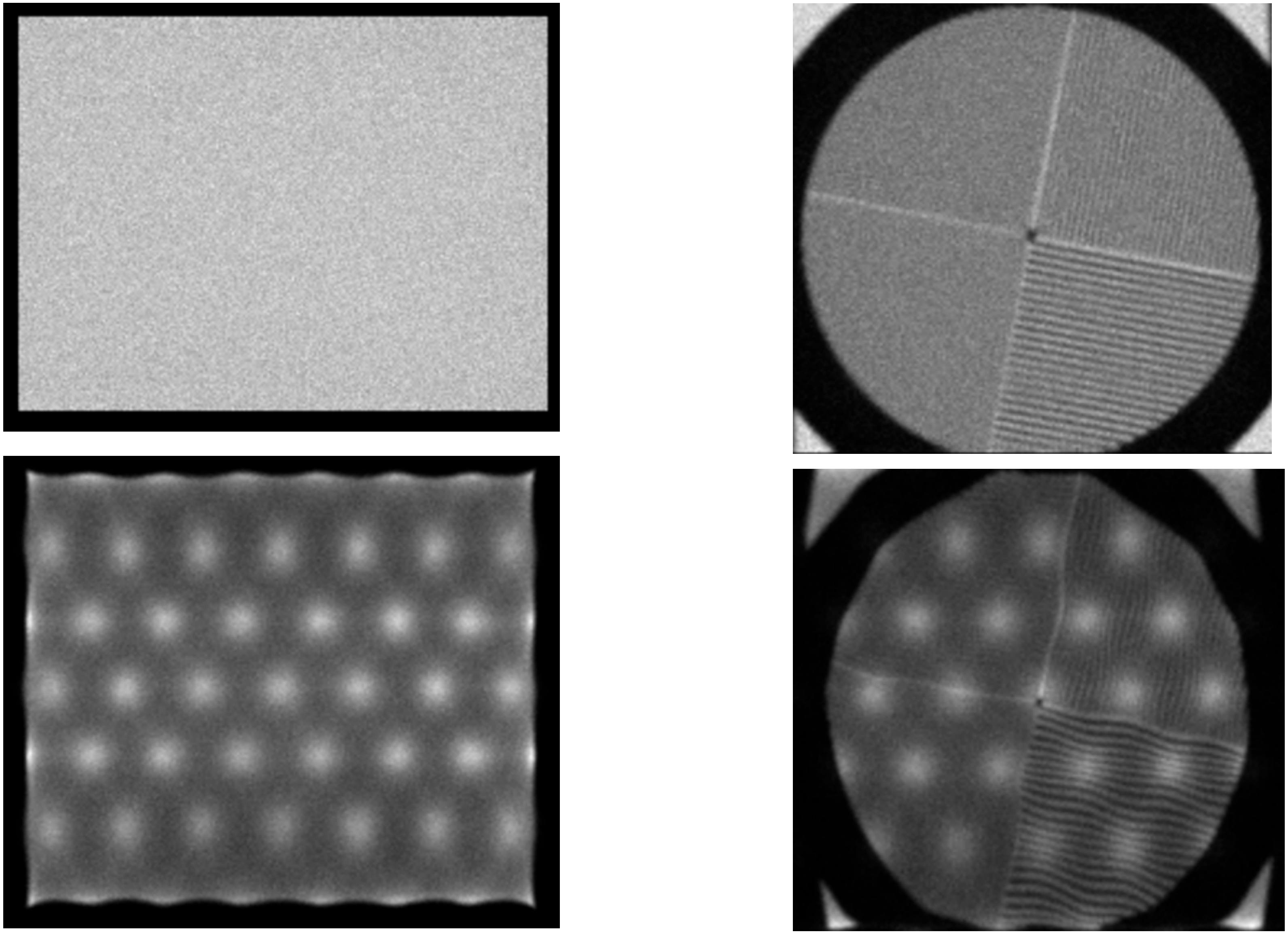
(linearity correction)



From: Physics in Nuclear Medicine (Cherry, Sorenson and Phelps)

Gamma Camera Processing Electronics

(linearity correction)



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Additional Gamma Camera Correction

(sensitivity / uniformity correction)

Acquired from long uniform flood after energy and linearity corrections have been applied

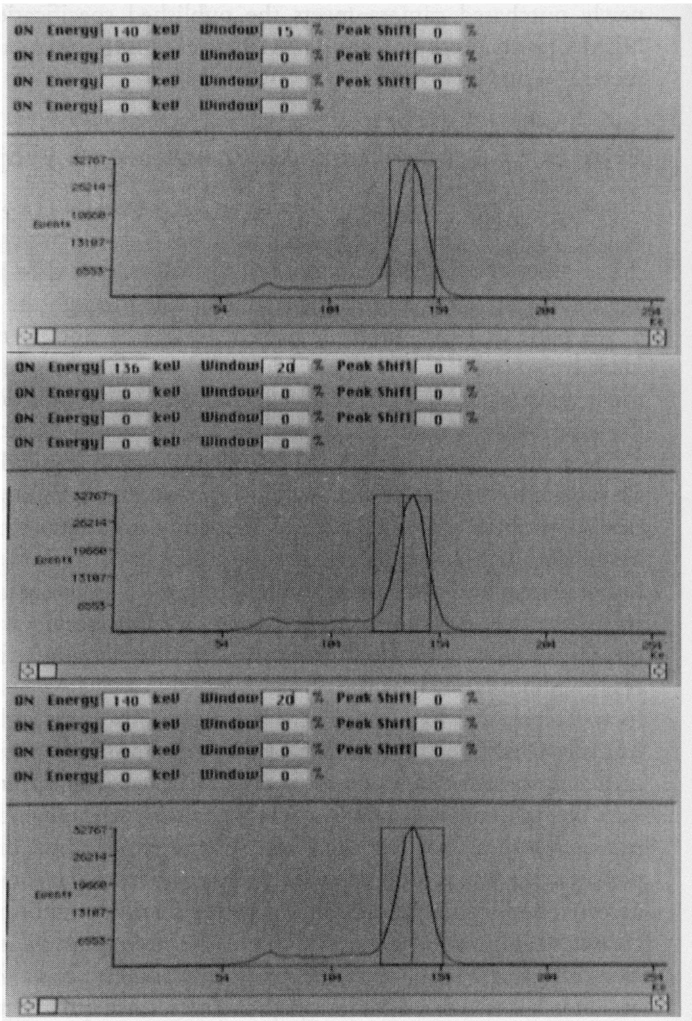
Multiplicative correction

Adjusts for slight variation in the detection efficiency of the crystal

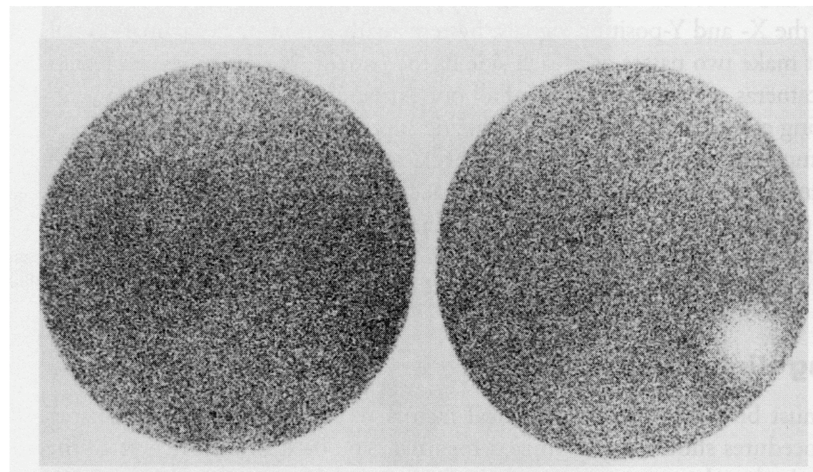
Compensates for small defects or damage to the collimator

Should not be used to correct for large irregularities

Daily Gamma Camera QA Tests



Photopeak window



Flood uniformity

From: The Essential Physics of Medical Imaging (Bushberg, et al)

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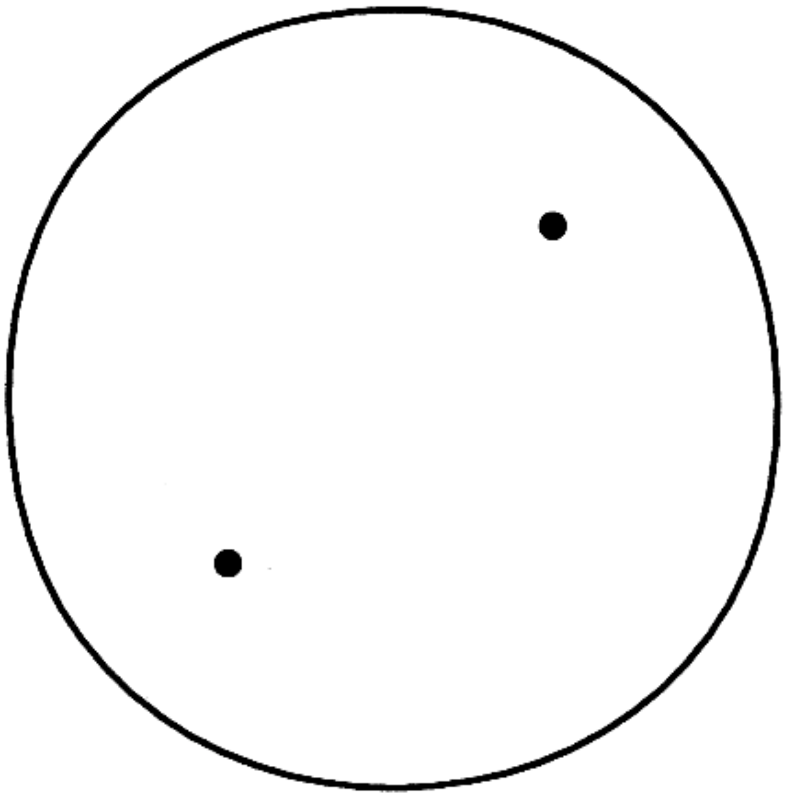
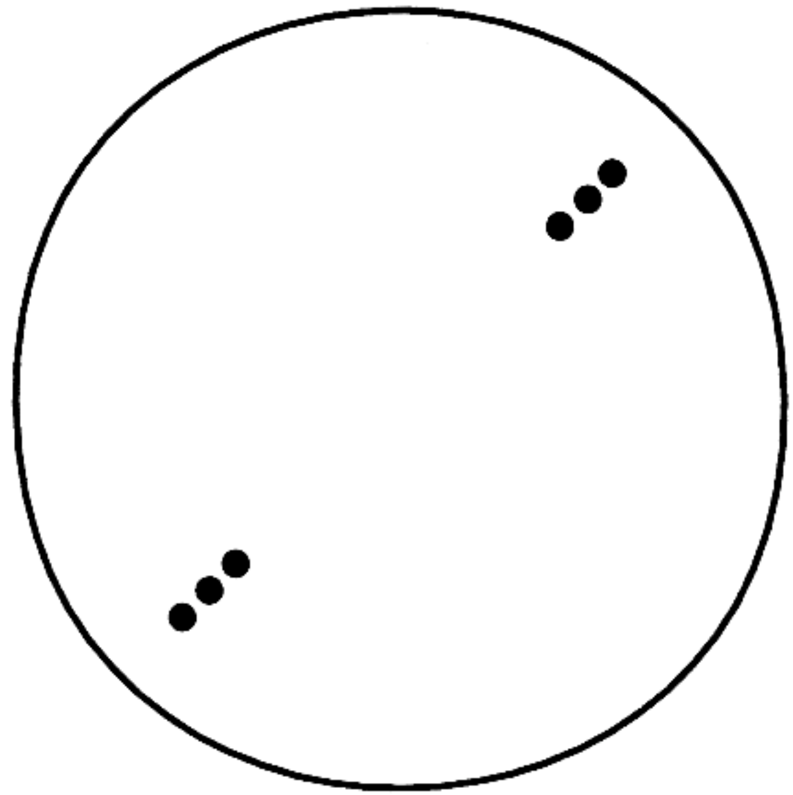
Multienergy spatial registration

(e.g., Ga-67 (93-, 185-, and 300 keV) gamma rays)



properly adjusted



improperly adjusted

From: The Essential Physics of Medical Imaging (Bushberg, et al)

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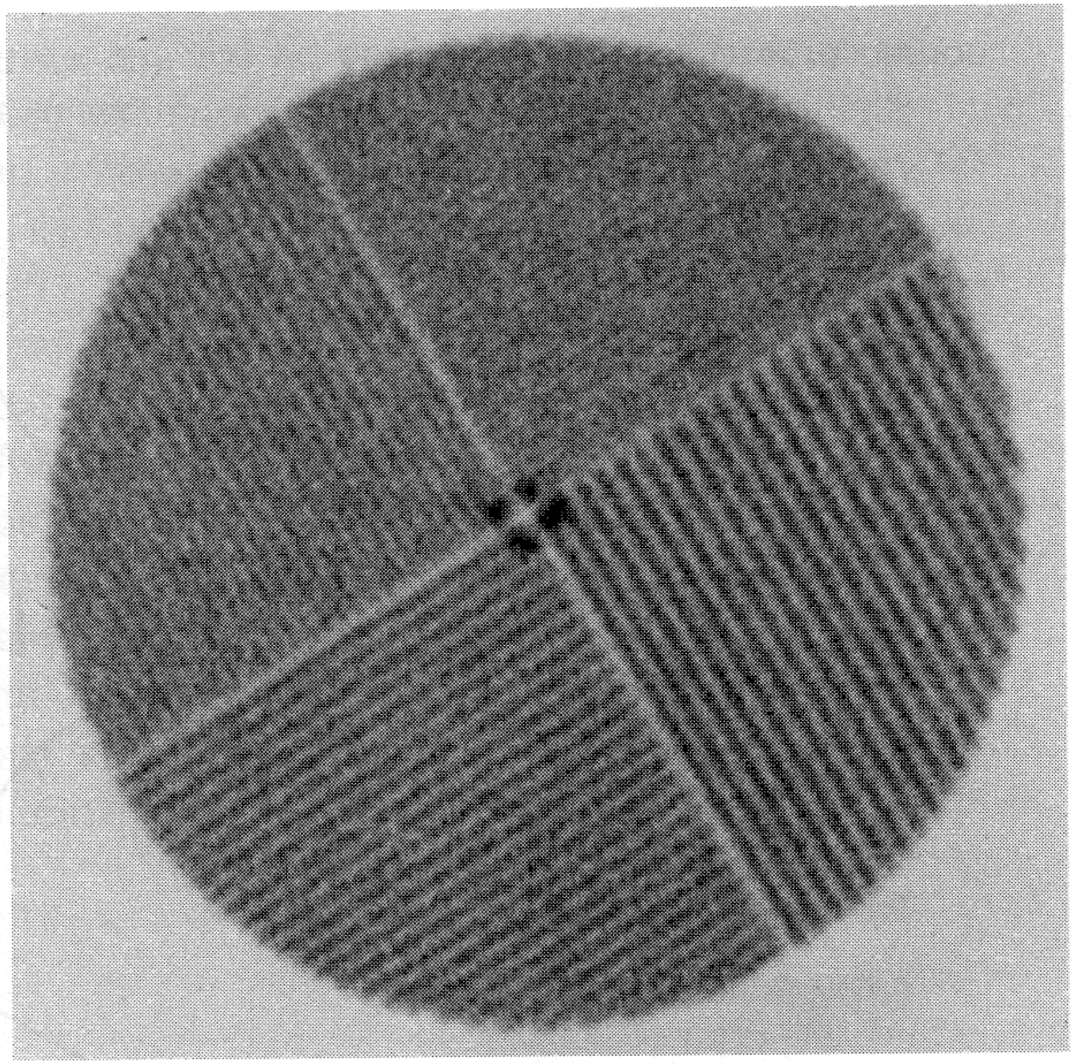
Spatial Resolution Test



FWHM of LSF = 1.7 x (size of smallest bar resolved)

Pulse Pile-up

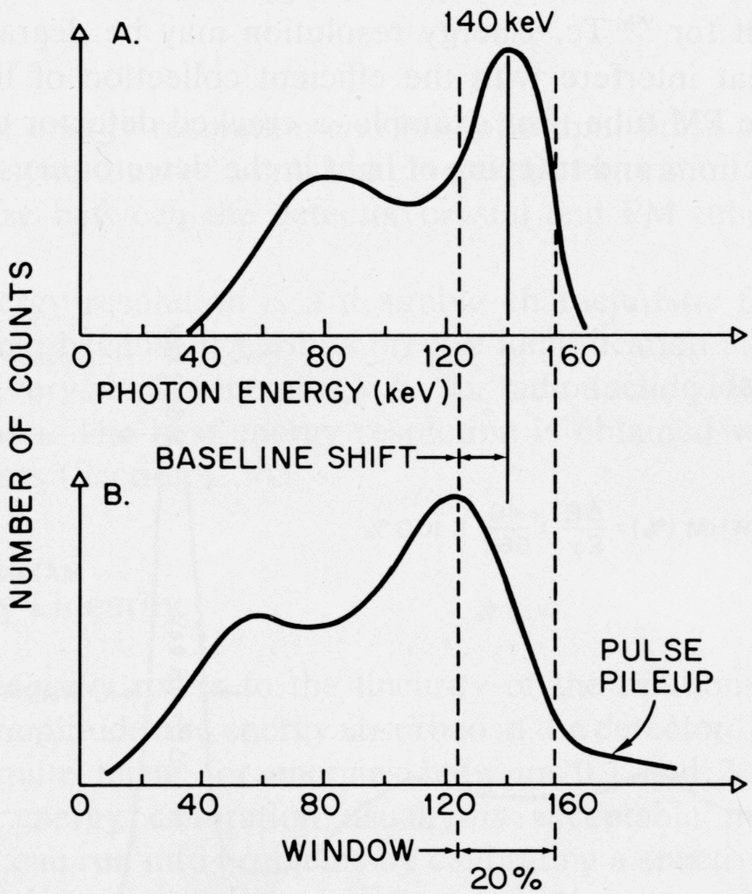


Fig. 11-10. (A) ^{99m}Tc spectrum at low counting rate. (B) Spectral broadening and shift in apparent photopeak energy due to pulse pileup and baseline shift in the spectrometer amplifier at high counting rate.

Energy spectra

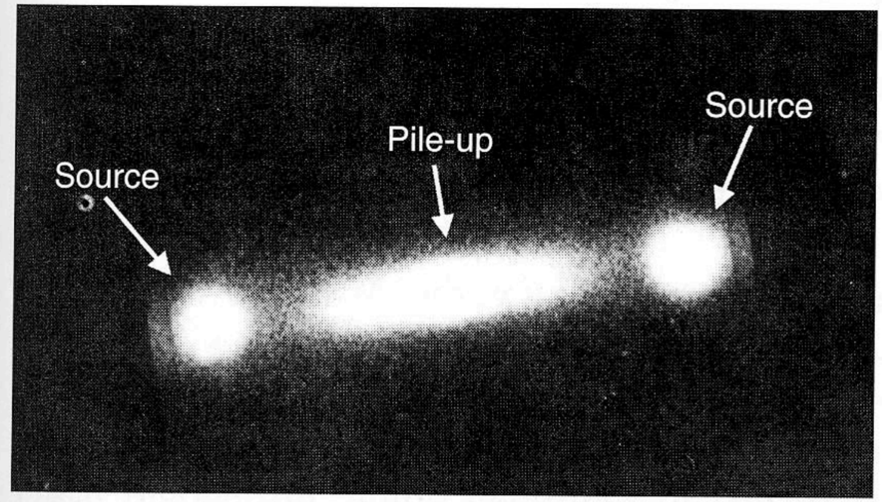


Figure 14–6. Images of two ^{99m}Tc point sources of relatively high activities (~370 MBq each). Events appearing in the band between the two point-source locations are mispositioned events due to pulse pile-up.

Pile-up in image

From: Physics in Nuclear Medicine (Sorenson and Phelps) and (Cherry, Sorenson and Phelps)

The Scintillation Camera: Image Acquisition

Image Acquisition

- Frame mode (data stored as an image)
  - static
    - single image acquisition
    - can have multiple energy windows
  - dynamic
    - series of images acquired sequentially
  - gated
    - repetitive, dynamic imaging
    - used for cardiac imaging
- List-mode (data stored event by event)
  - time stamps are included within data stream
  - allows for flexible post-acquisition binning
  - can result in very large data files

Gated Acquisition

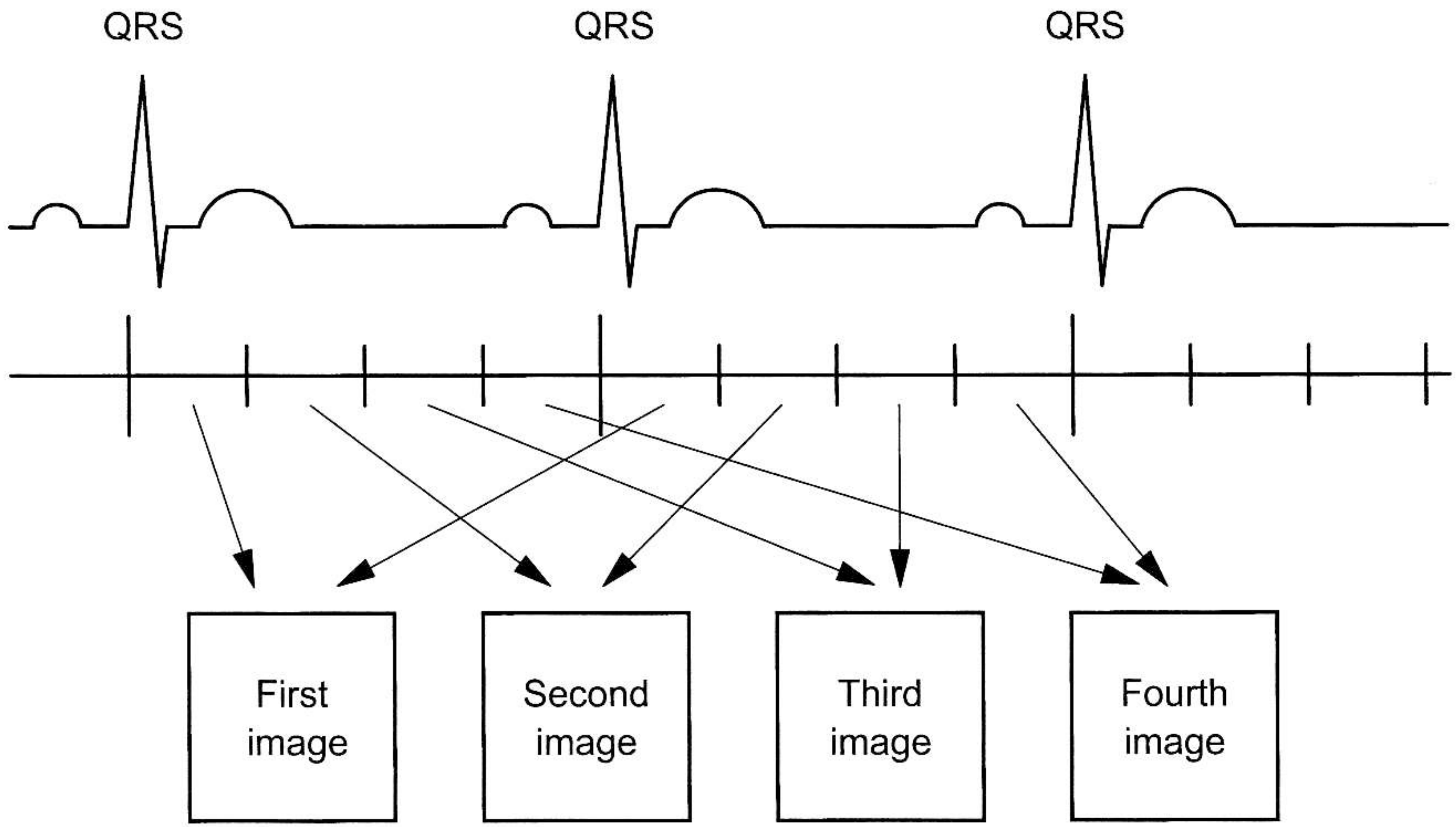


FIGURE 21-22. Acquisition of a gated cardiac image sequence. Only four images are shown here. Sixteen to 24 images are typically acquired.

Region of Interest (ROI) and Time-Activity Curves (TAC)

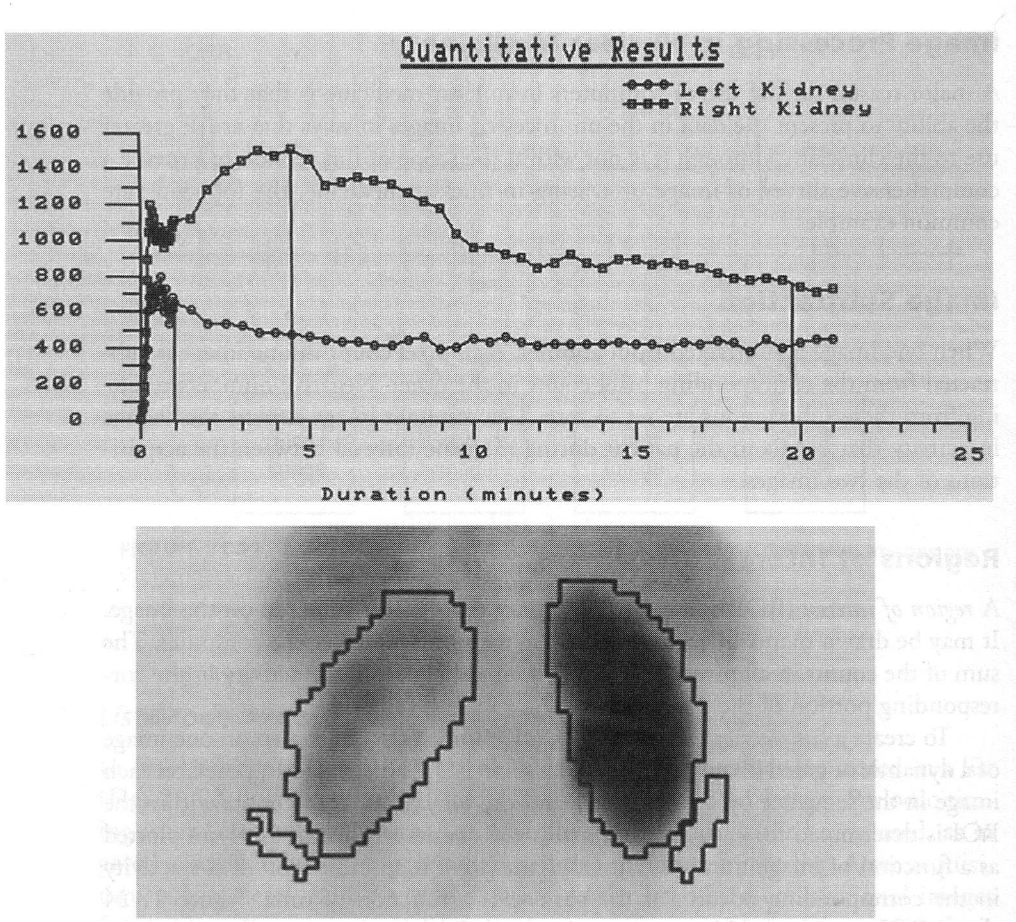


FIGURE 21-24. Regions of interest (ROIs) **(bottom)** and time-activity curves (TACs) **(top)**.

Raphex Question

D81. A cold spot artifact appears in a scintillation camera image. The artifact could be caused by all of the following ***except:***

A. The camera is incorrectly peaked for the radionuclide in the study.
B. The photomultiplier tube is defective.
C. The patient is wearing metallic jewelry.
D. An out-dated uniformity correction is used.
E. The wrong collimator was used.

Raphex Question

2-4. In nuclear medicine imaging, match the following quality control procedures with the relevant choice:

a. *Gamma camera resolution*
b. *Gamma camera field uniformity*
c. *Photopeak window of the pulse height analyzer*

2. *Checked daily using a uniform flood source.* _____
3. *Checked daily by placing a small amount of a known source of radioisotope in front of the camera.* _____
4. *Checked weekly using a bar phantom.* _____