Nuclear Medicine Imaging Systems: The Scintillation Camera

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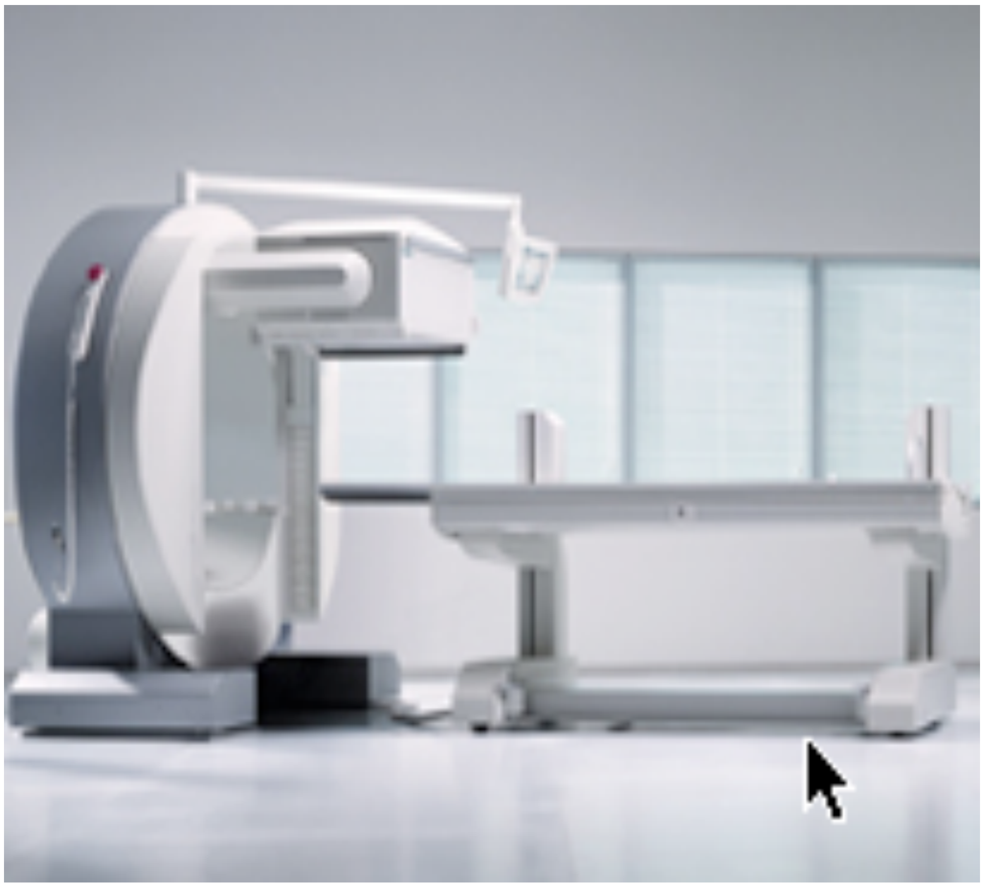
List of Nuclear Medicine Radionuclides

• 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

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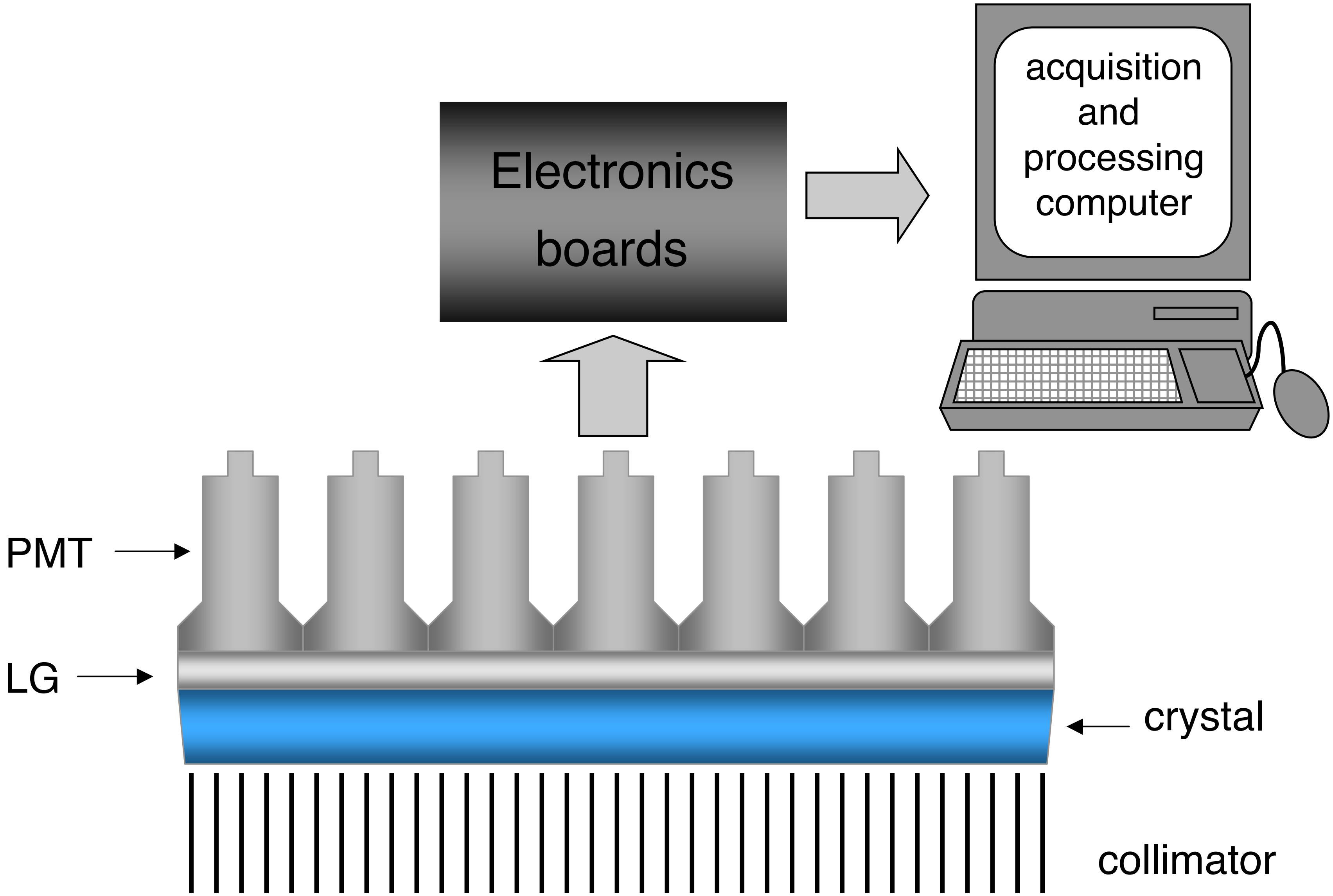
Gamma Camera Instrumentation



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The Scintillation Camera: Detector System

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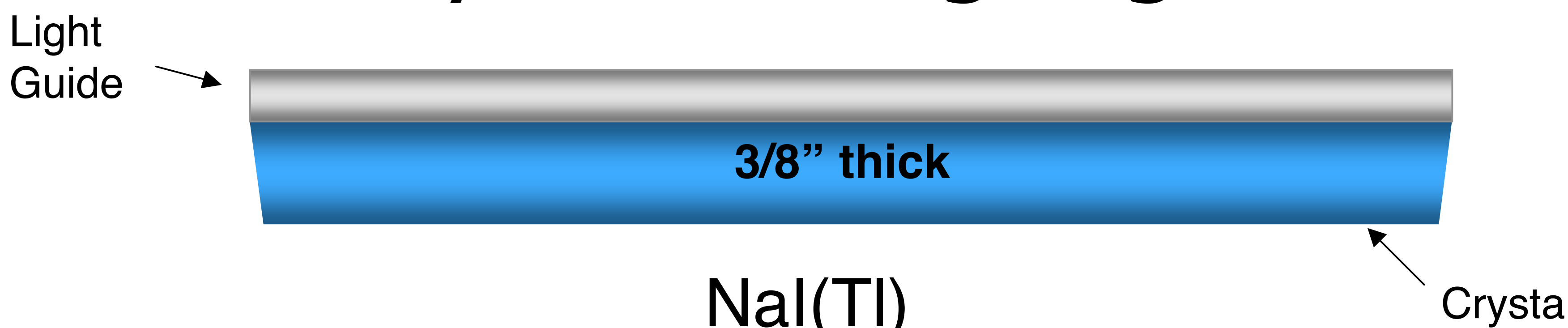
Crystal and light guide



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

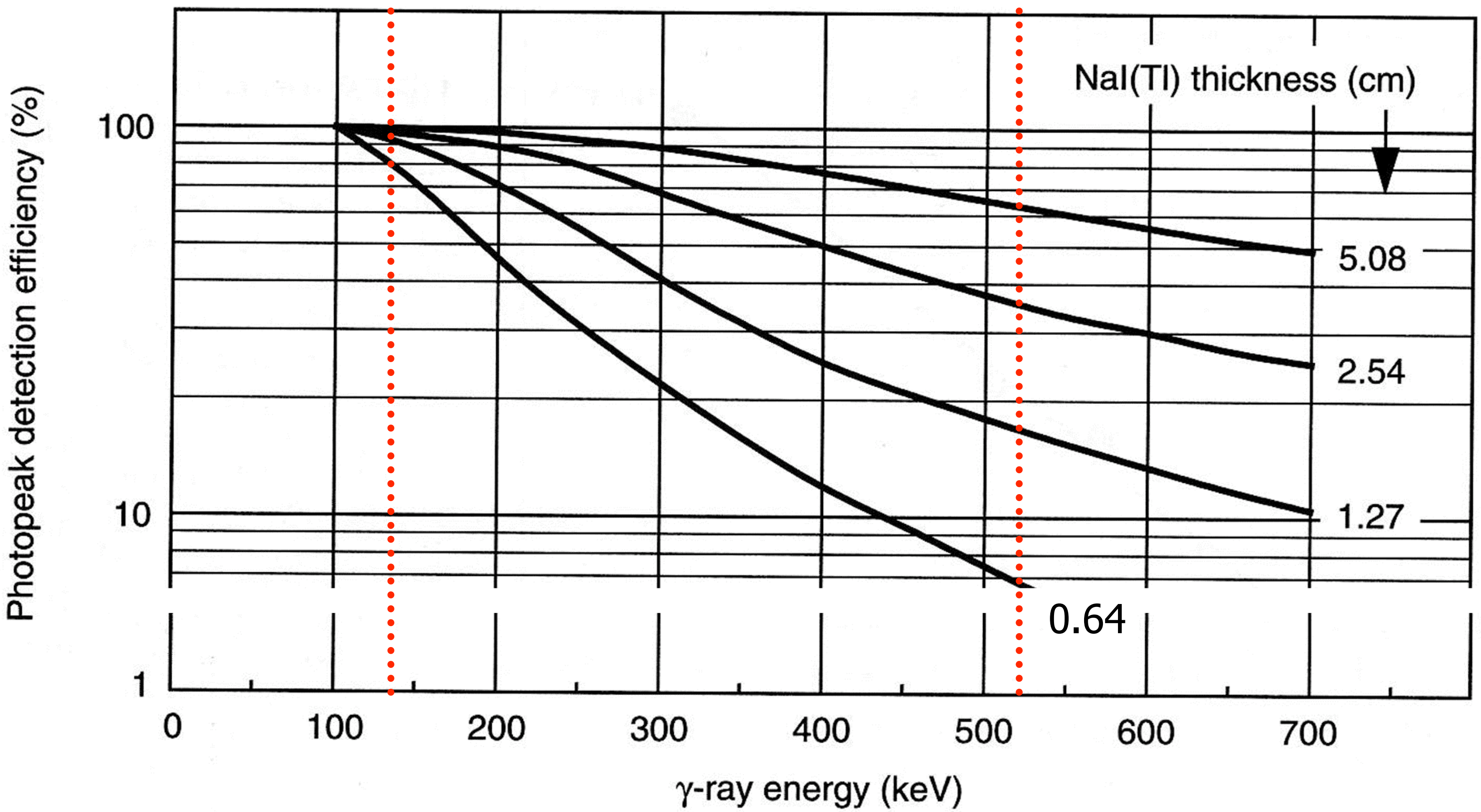
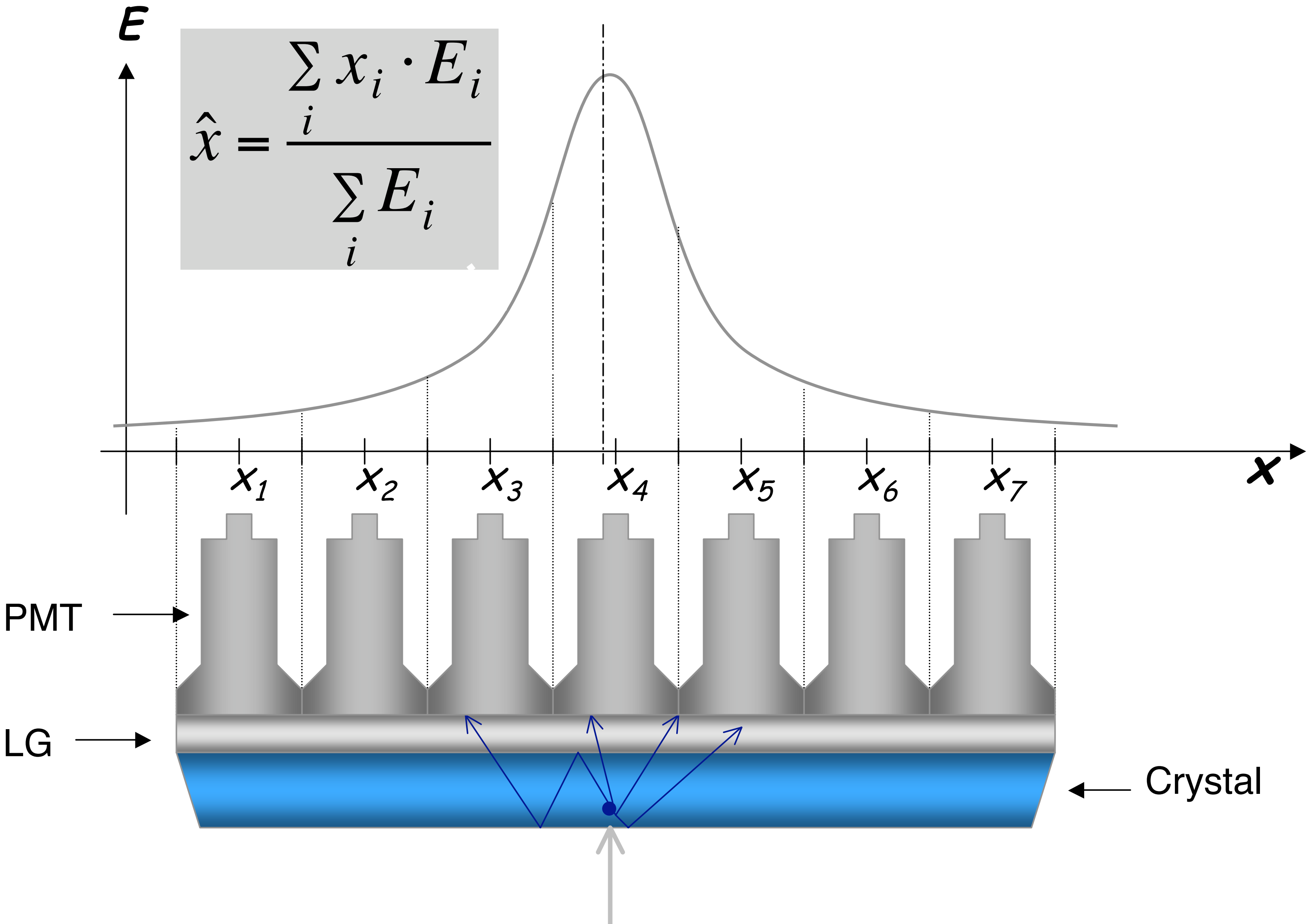


Figure 14–3. Photopeak detection efficiency versus γ-ray energy for NaI(Tl) detectors of different thicknesses. (Adapted from Anger HO: Radioisotope cameras. In Hine GJ [ed]: Instrumentation in Nuclear Medicine, Vol 1. New York, Academic Press, 1967, p 506.)

Light response function versus position
(spatial resolution)



Spatial Positioning

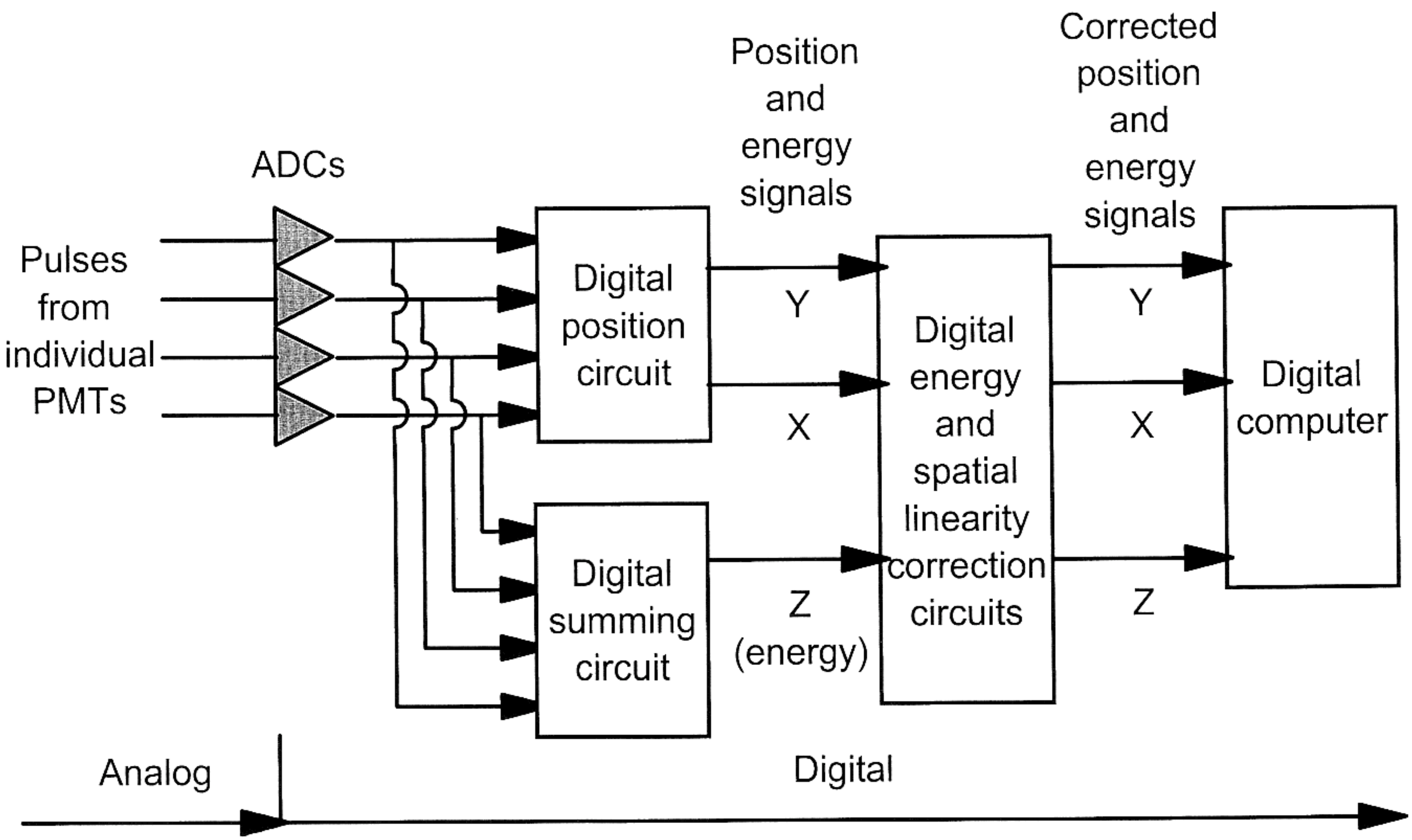
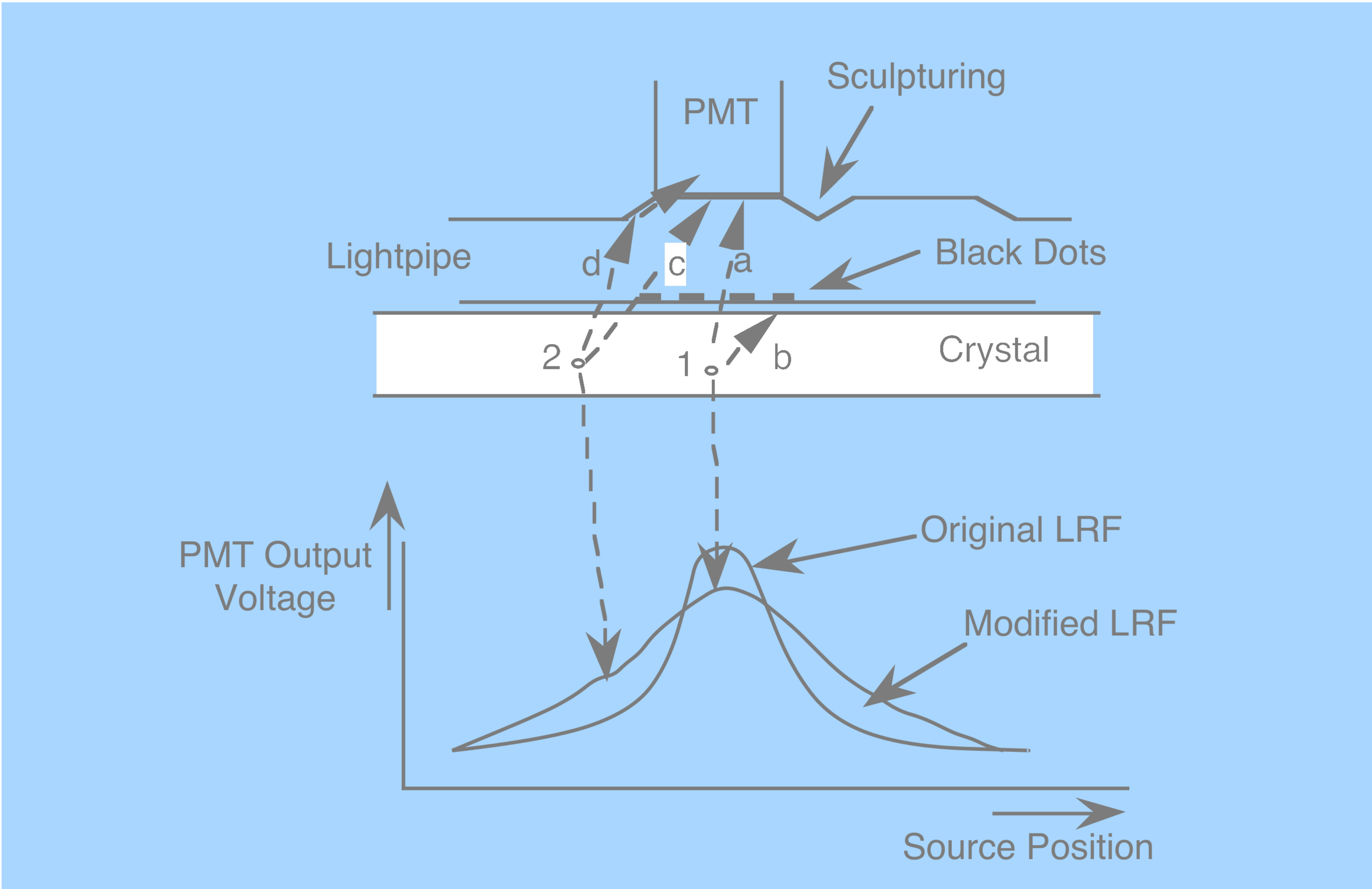


FIGURE 21-5. Electronic circuits of a modern digital scintillation camera.

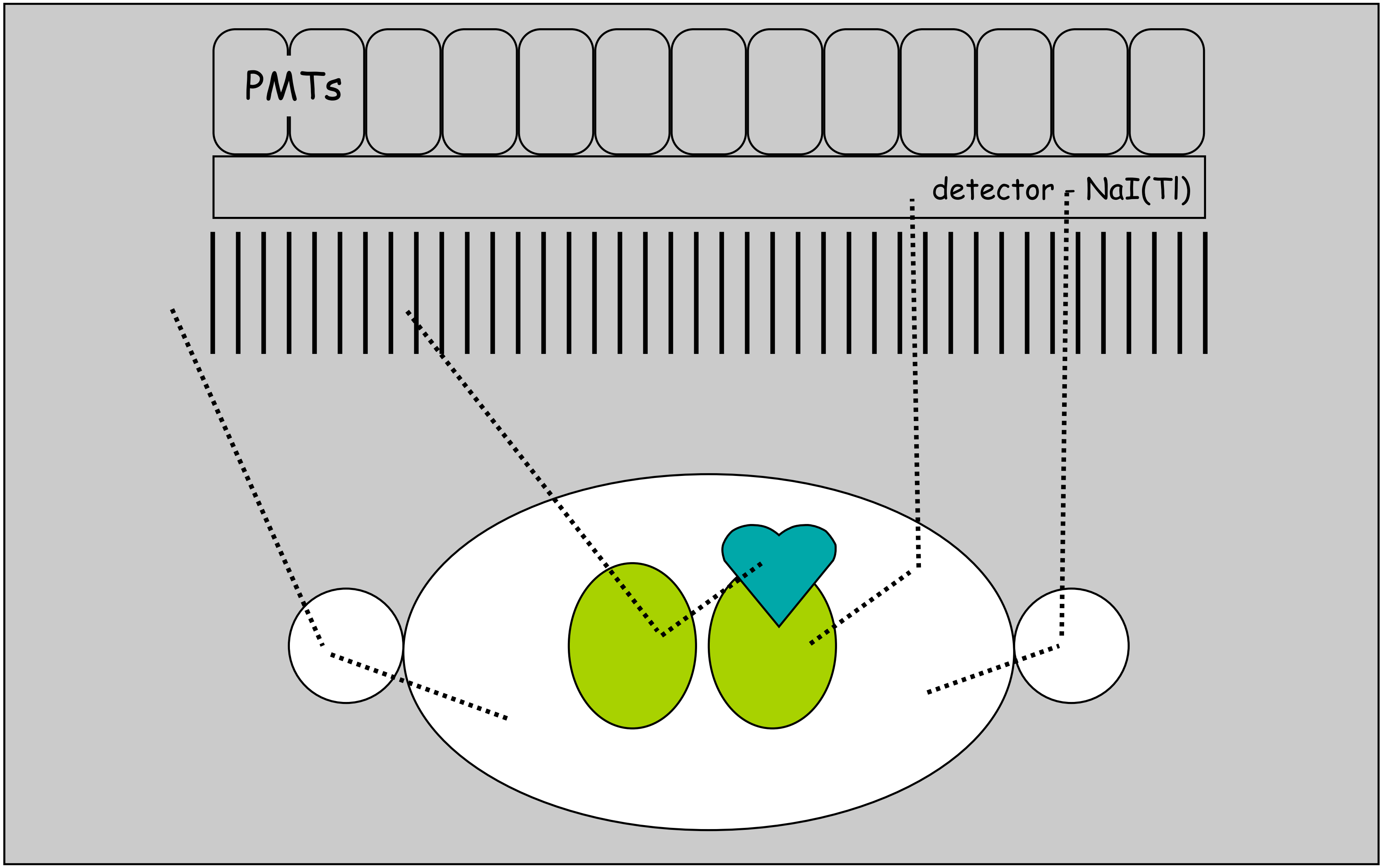
From: The Essential Physics of Medical Imaging (Bushberg, et al)

Techniques to optimize shape of light response function



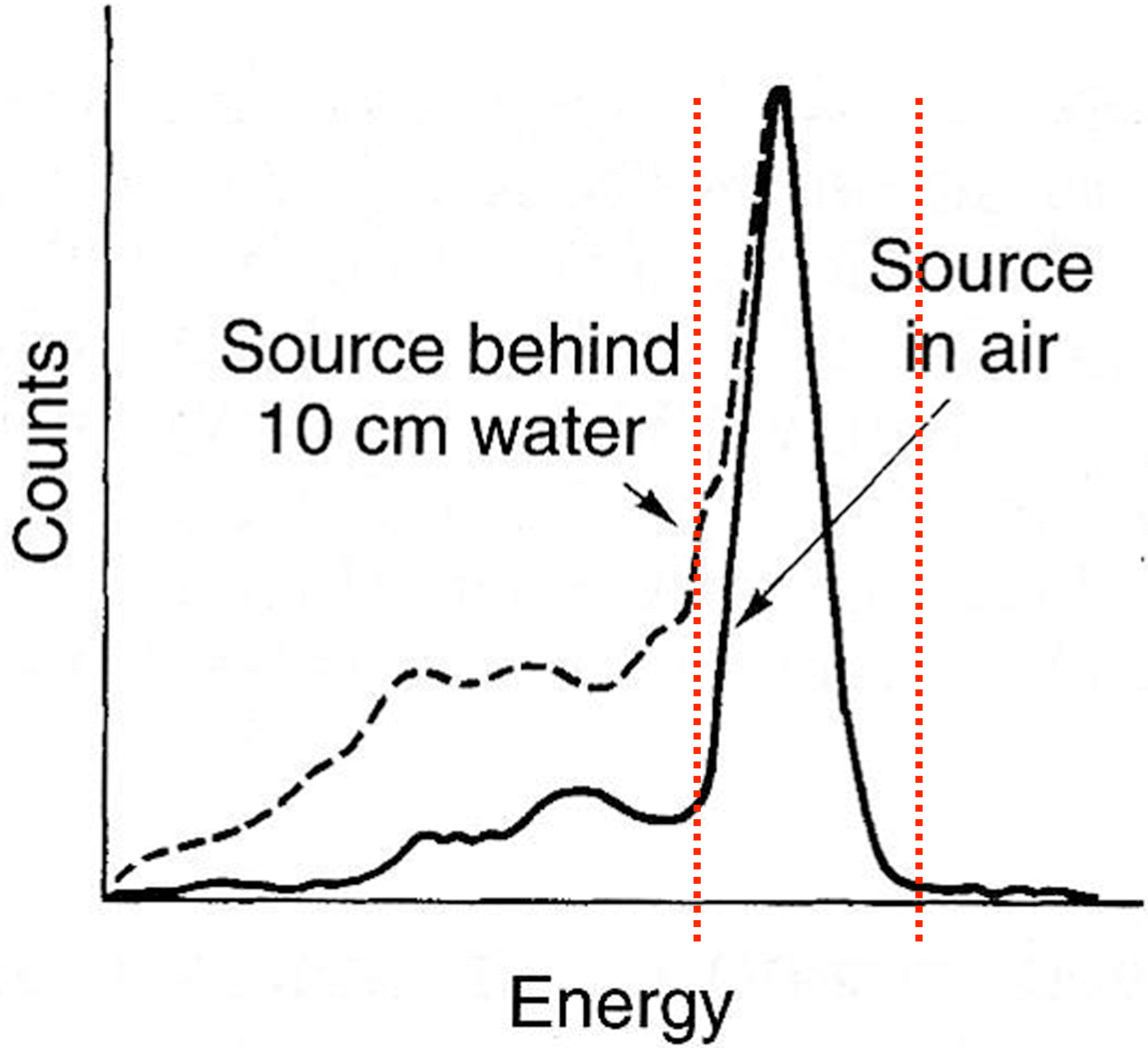
Siemens Medical Solutions product literature

Scatter

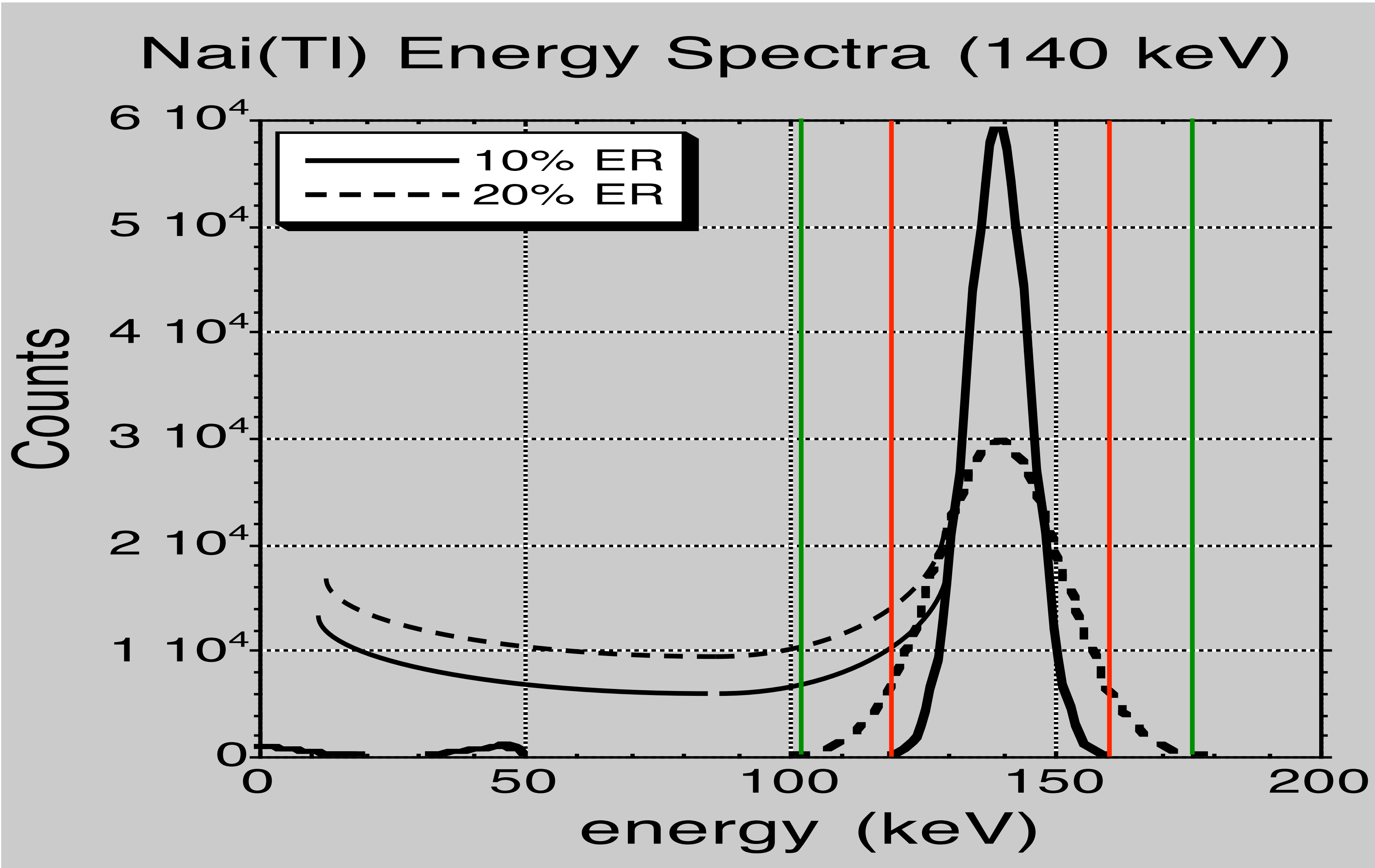


All scatter counts are within the object (unlike in PET)

Gamma Camera Energy Spectra



Gamma Camera Energy Spectra



140 keV photons, 9.5 mm crystal

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The Scintillation Camera: Collimators

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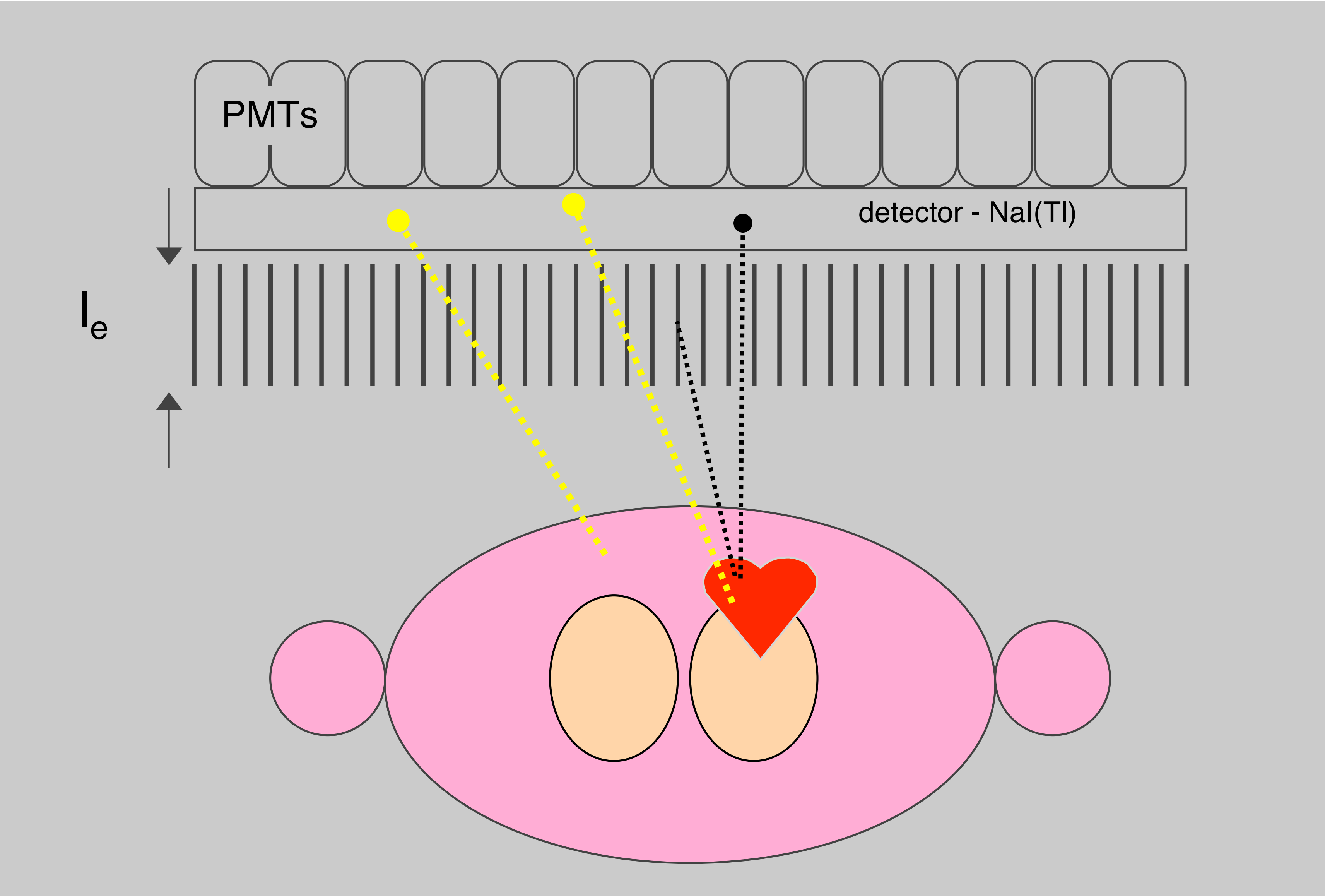
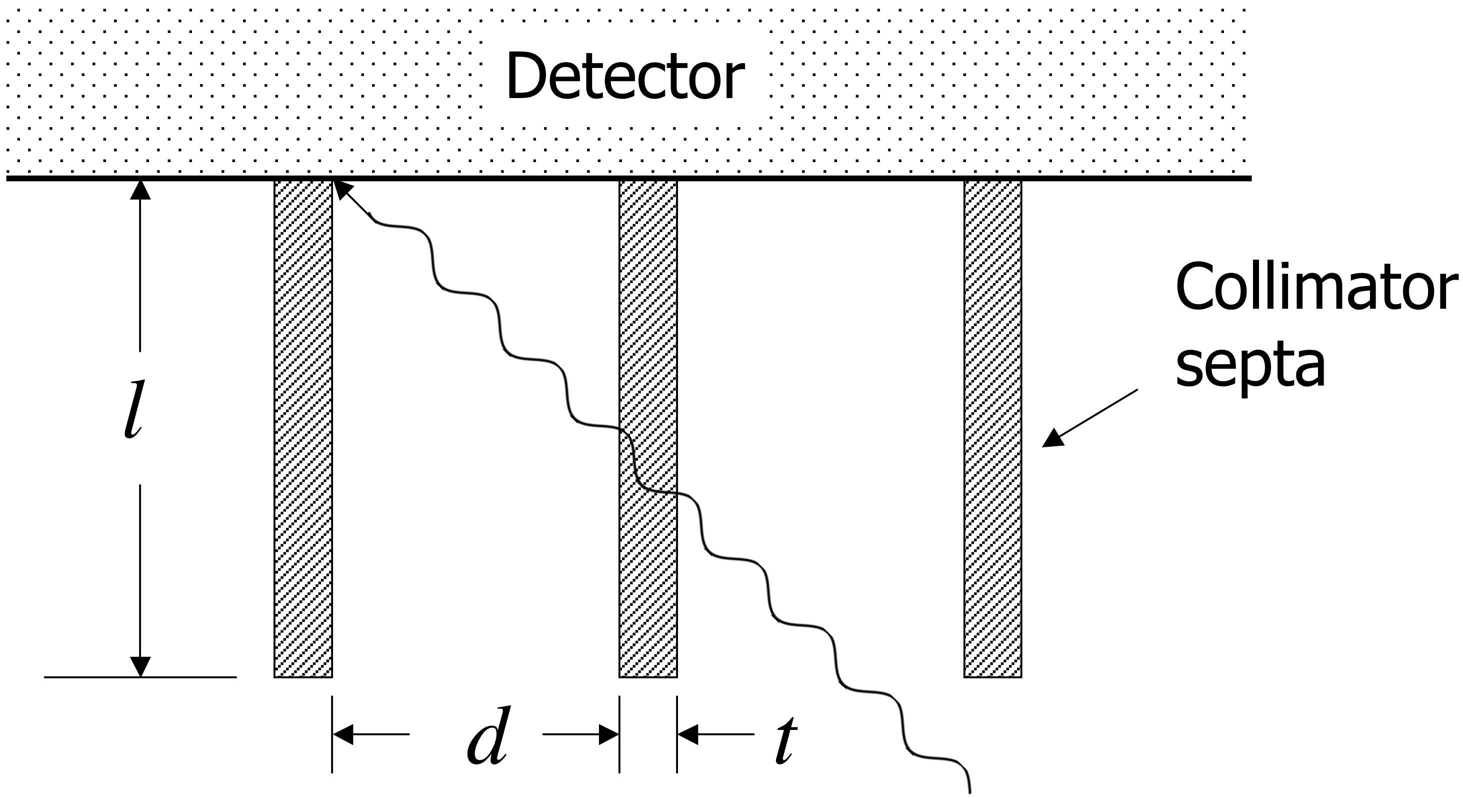
Parallel Hole Collimator



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

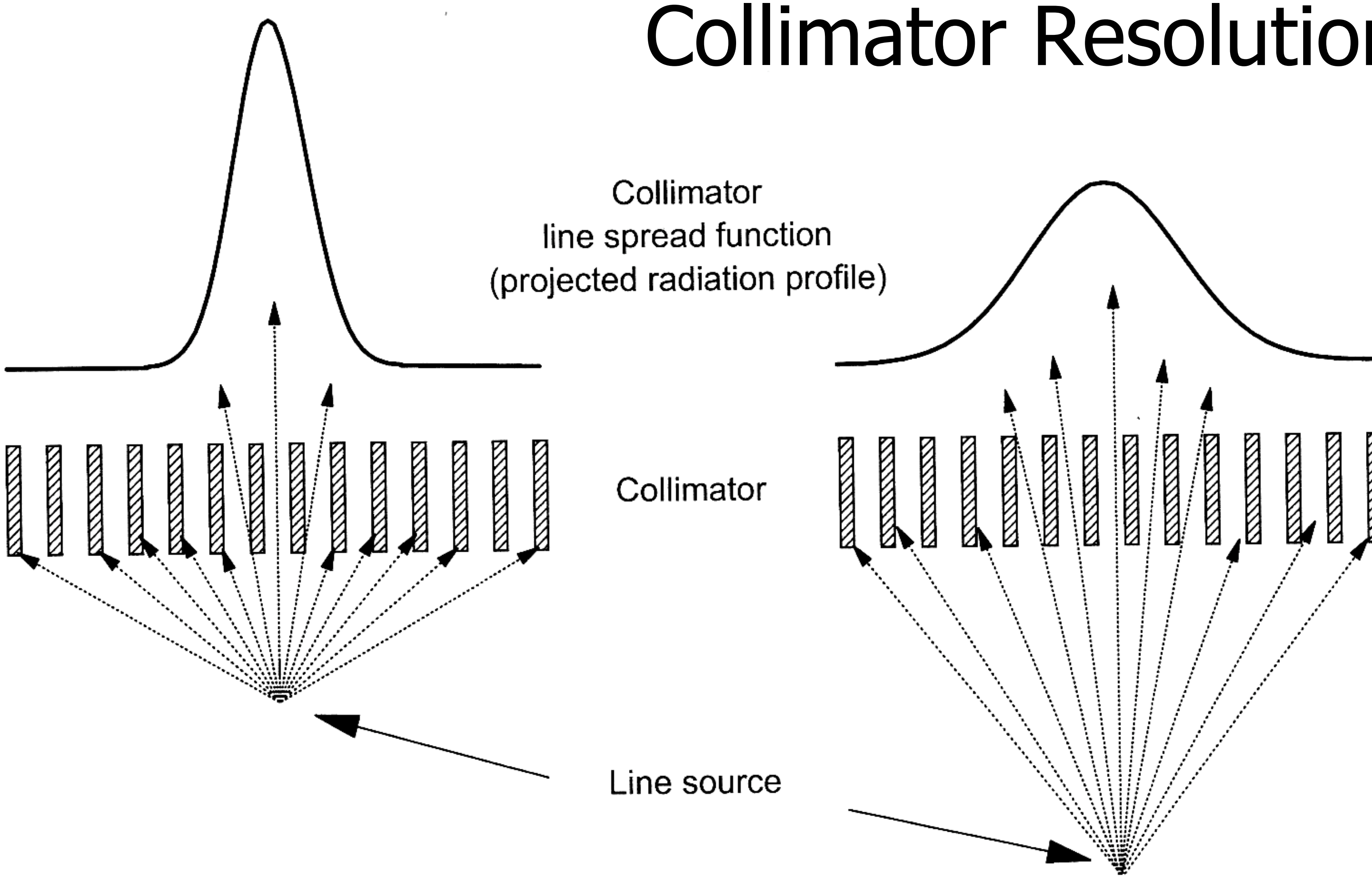
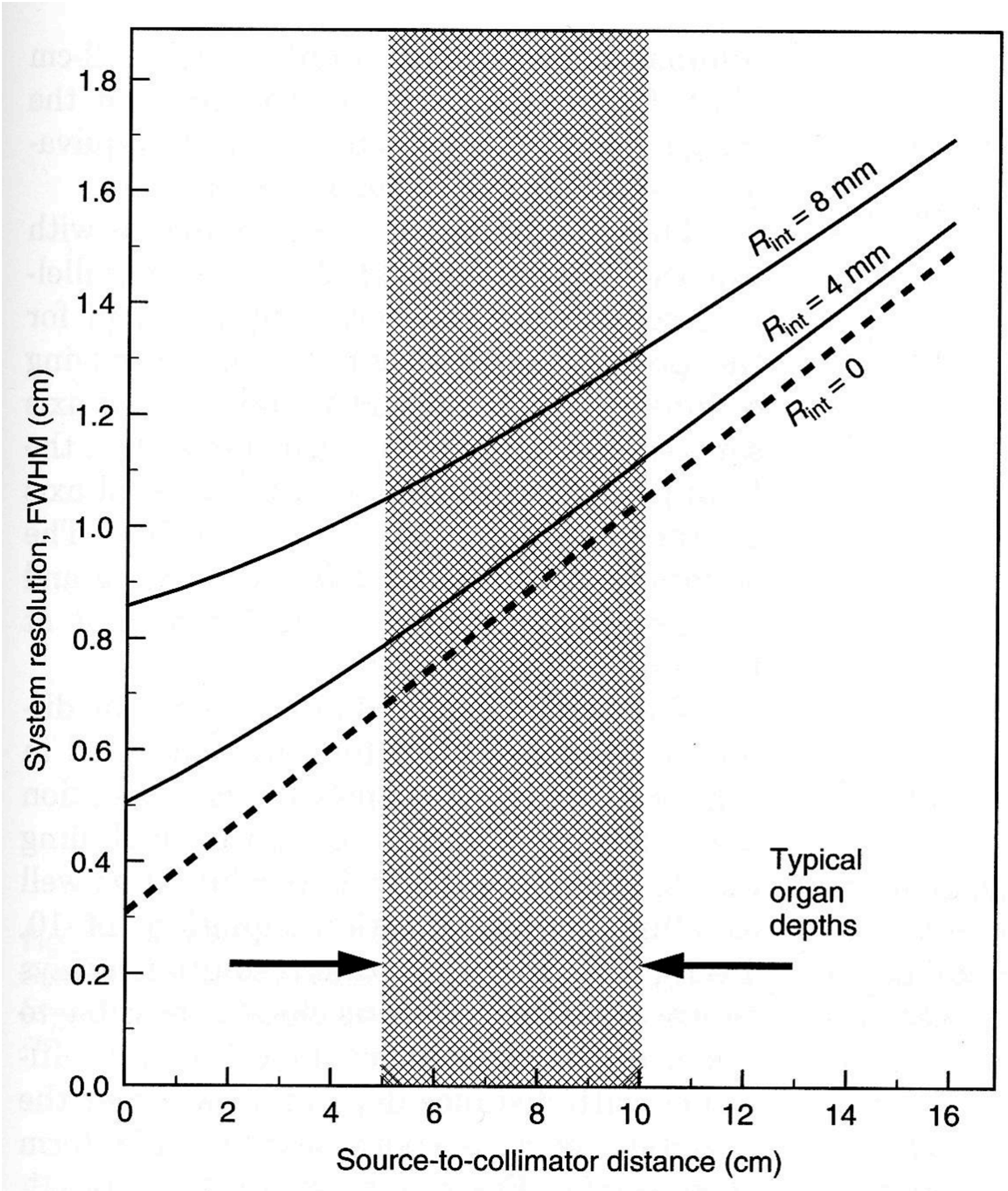


FIGURE 21-12. Line spread function (LSF) of a parallel-hole collimator as a function of source-to-collimator distance. The full-width-at-half-maximum (FWHM) of the LSF increases linearly with distance from the source to the collimator; however, the total area under the LSF (photon fluence through the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

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

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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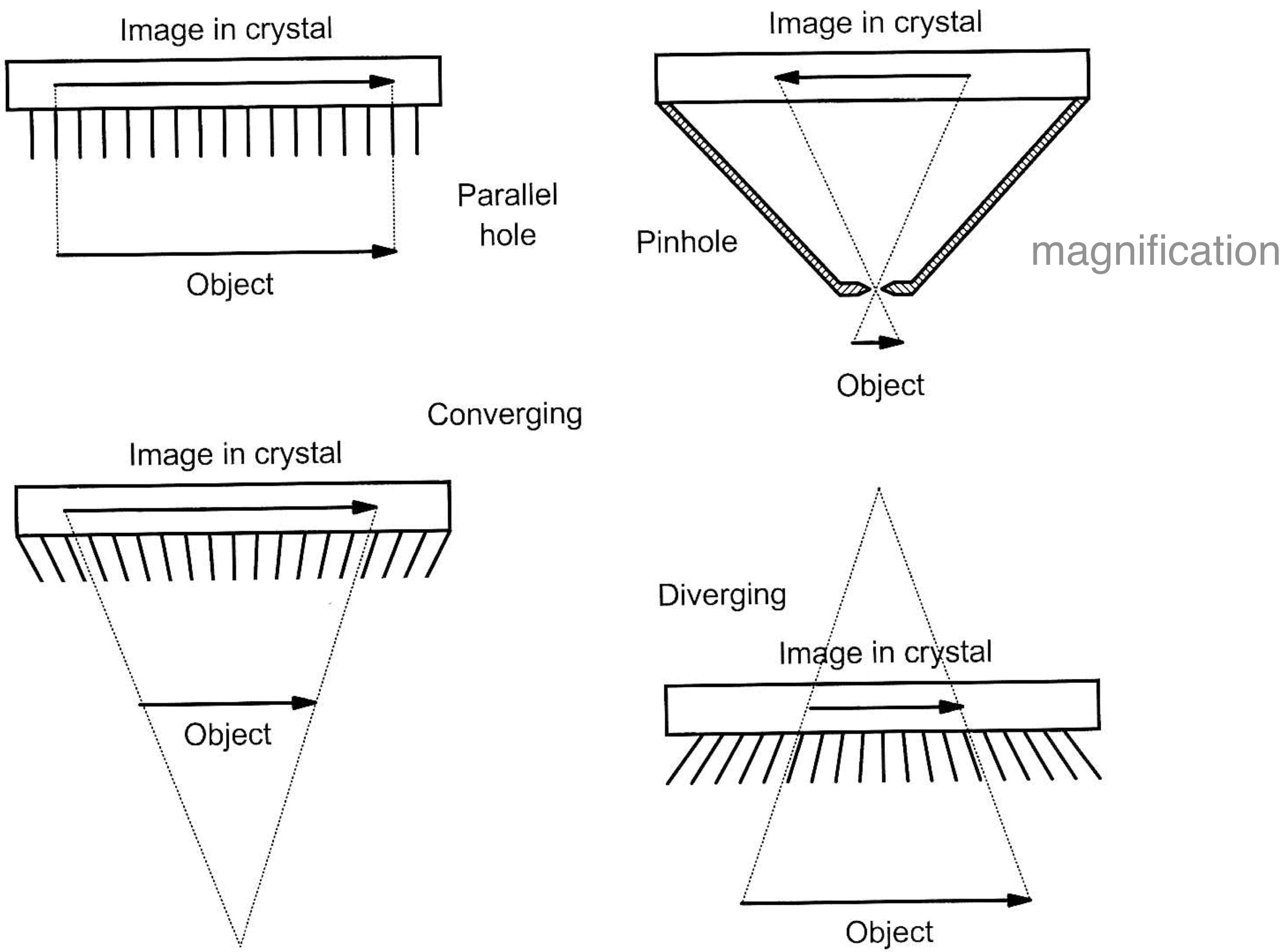
Types of Collimators



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

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Collimator: Resolution and Sensitivity

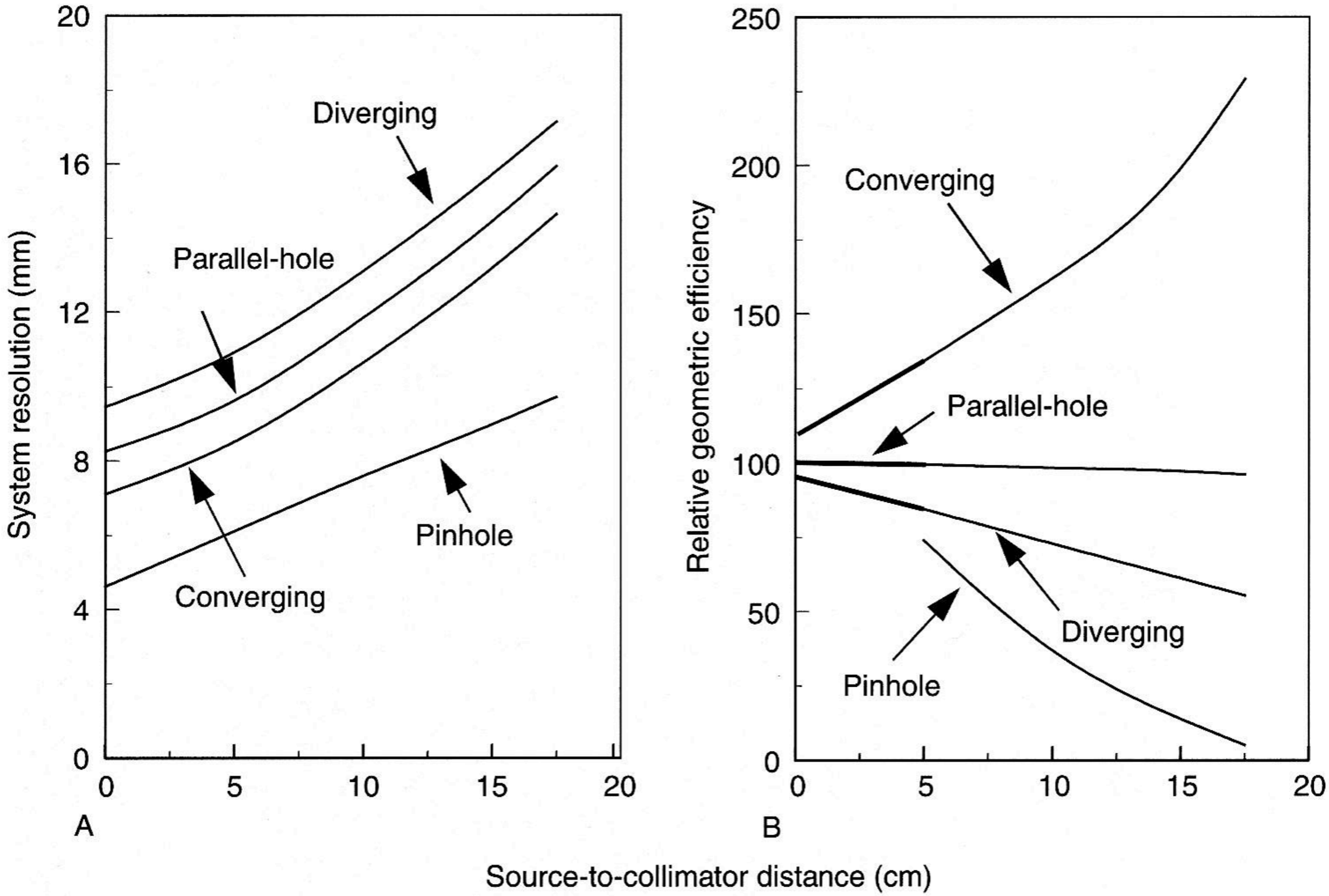

Figure 14–21. Performance characteristics (*A,* system resolution; *B,* point-source geometric efficiency in air) versus source-to-collimator distance for four different types of gamma camera collimators. (Reprinted by permission of the Society of Nuclear Medicine from Moyer RA: A low-energy multihole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

The Scintillation Camera: Corrections and QA

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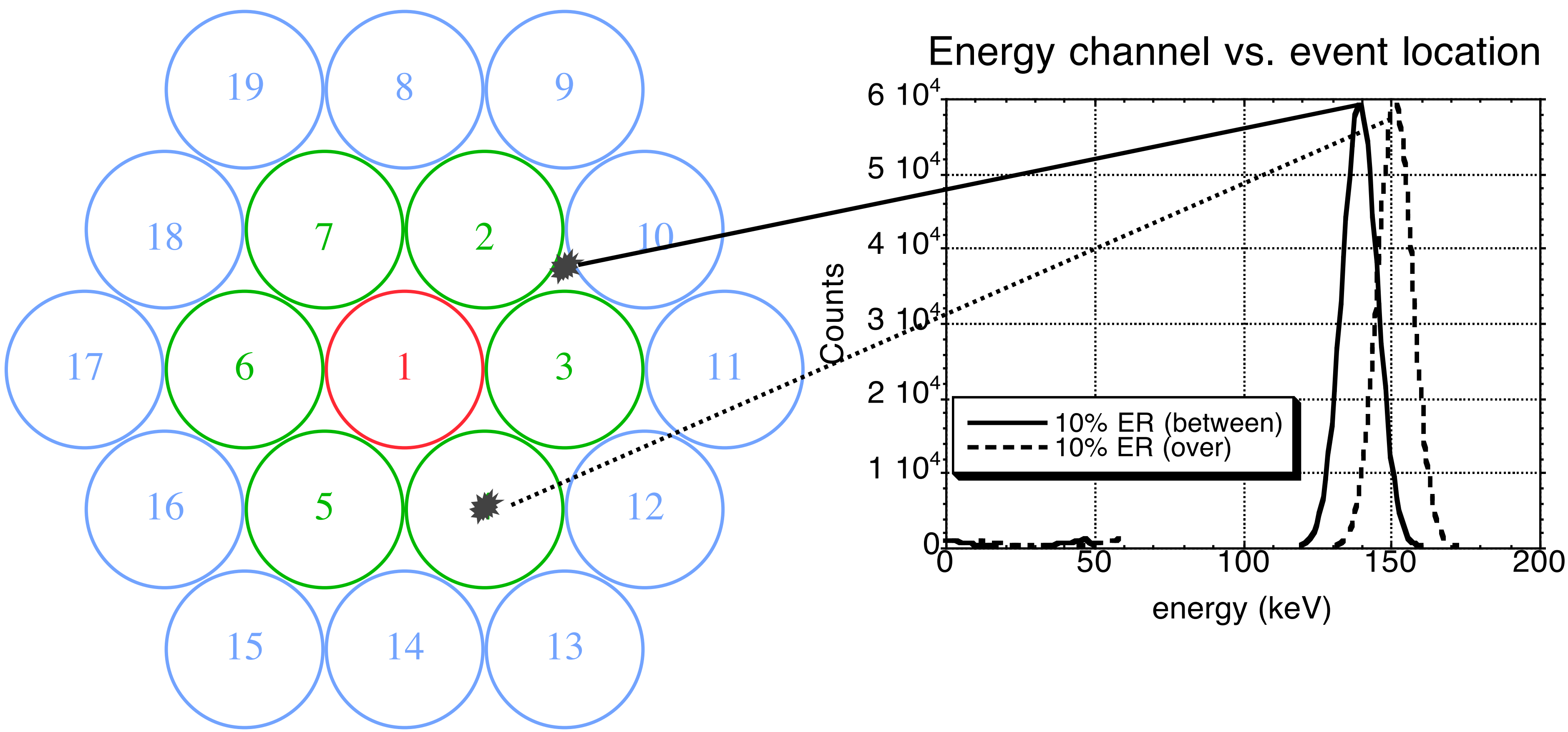
Gamma Camera Processing Electronics

(energy correction)



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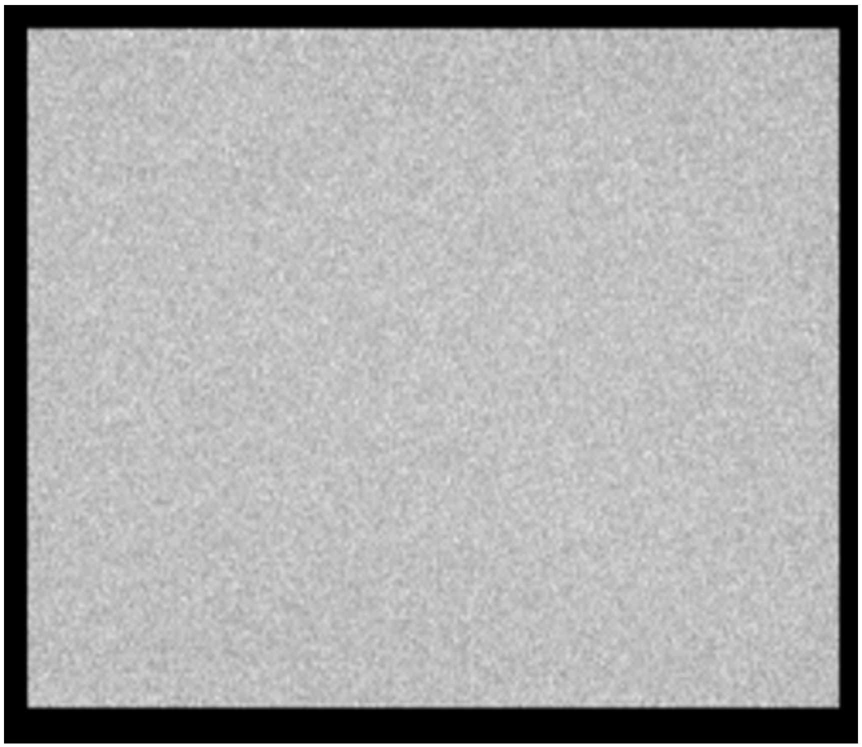
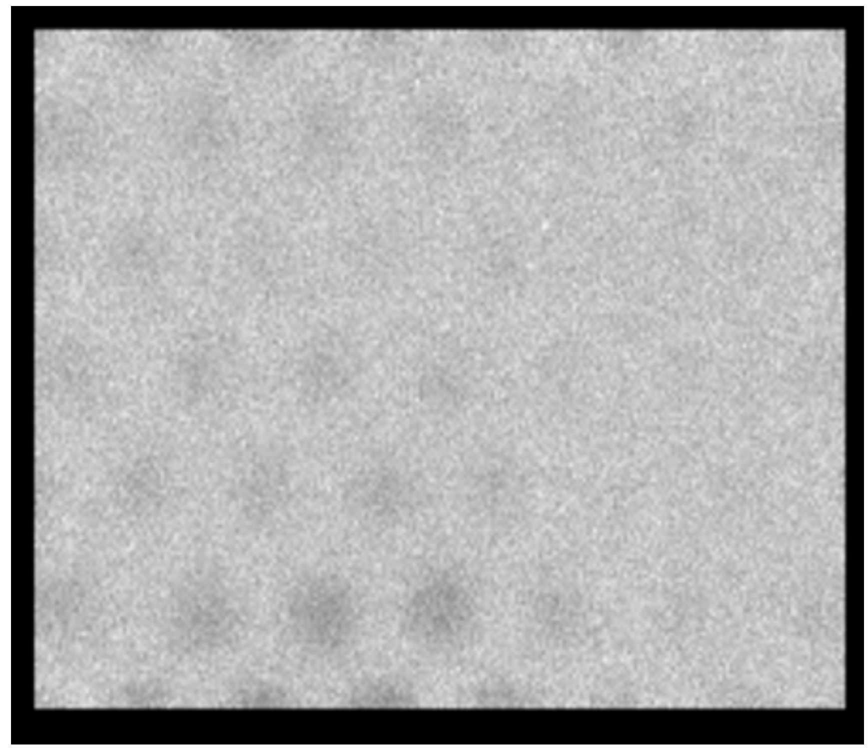
Gamma Camera Processing Electronics

(with and without energy correction)





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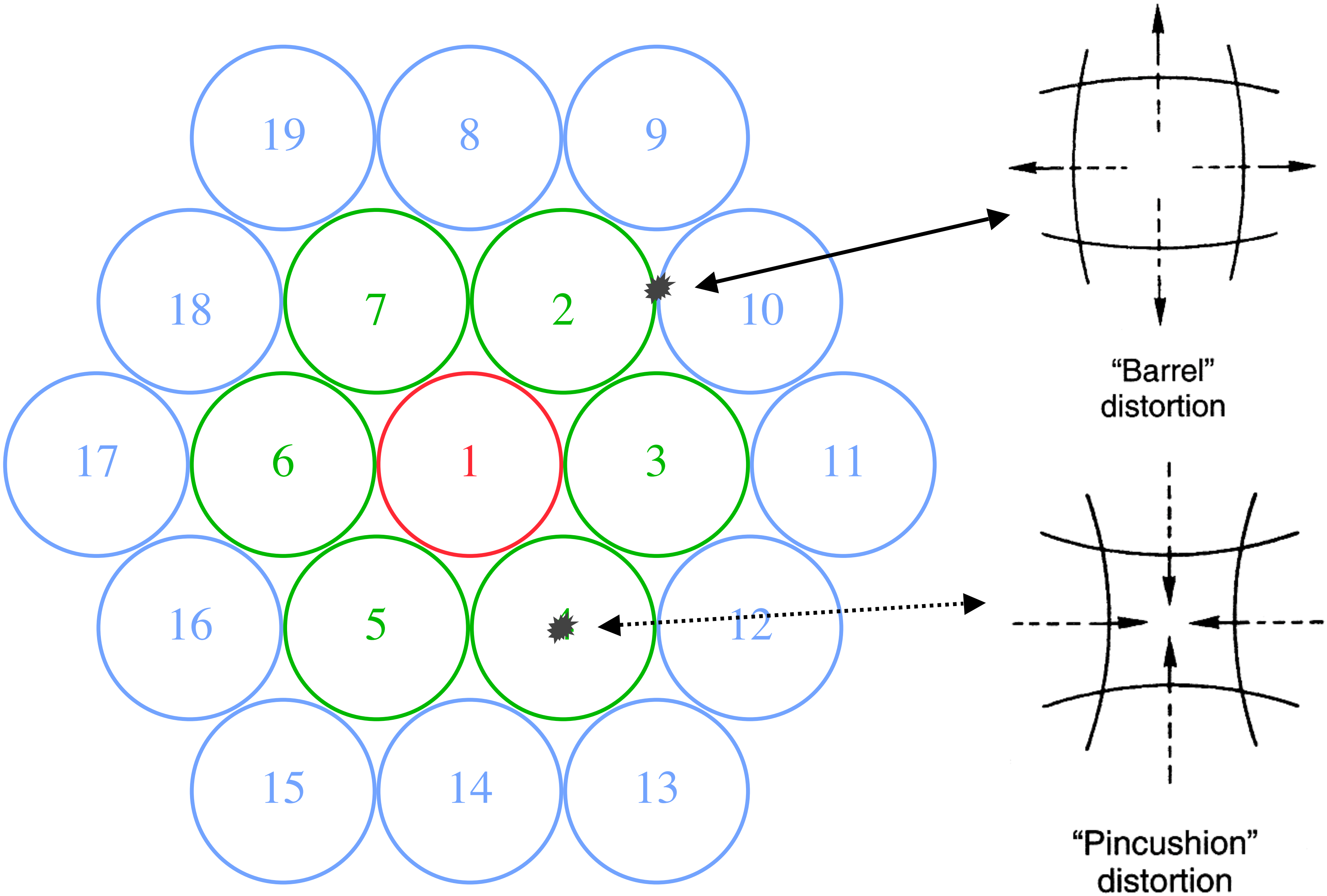
Gamma Camera Processing Electronics

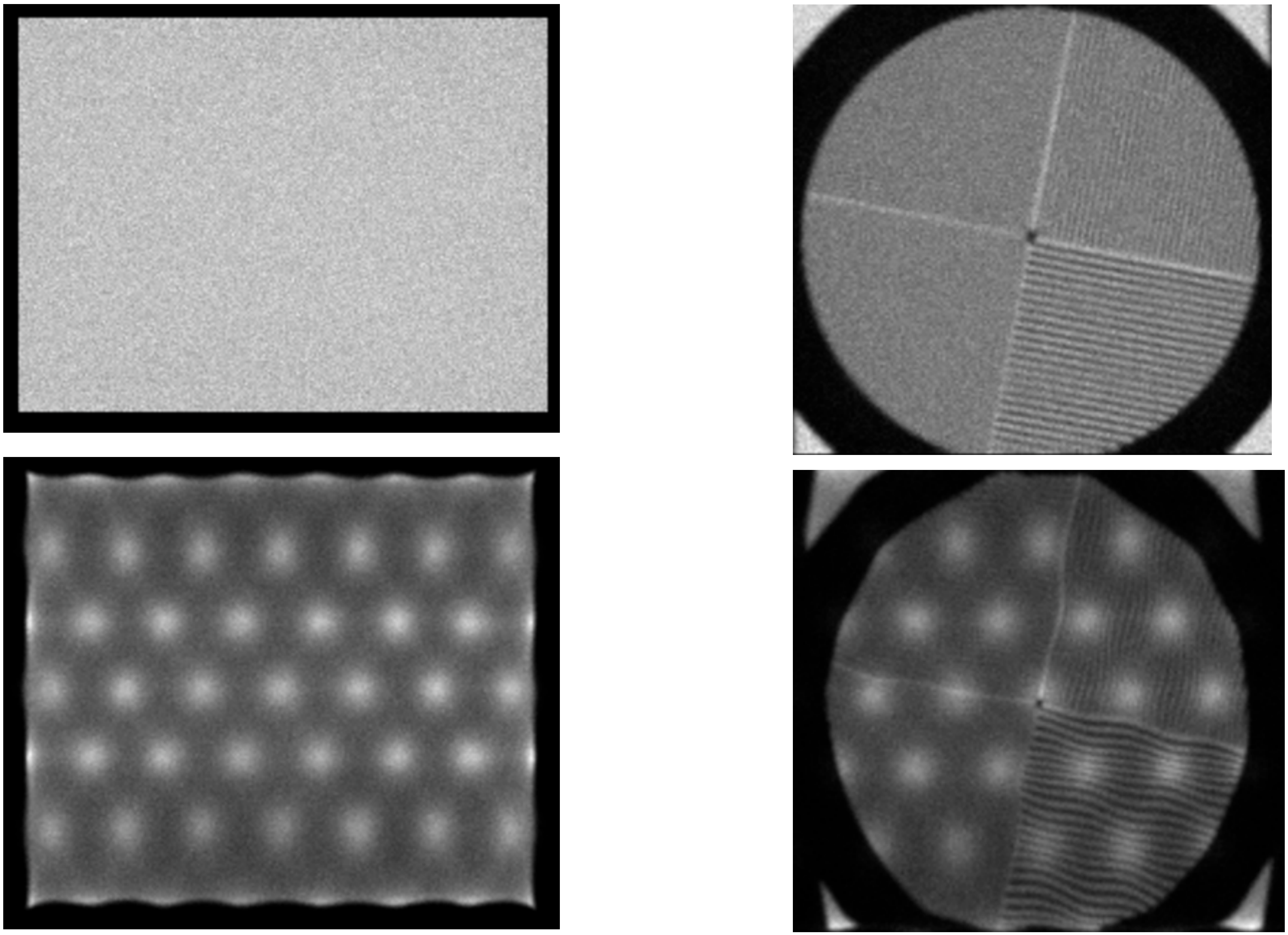
(linearity correction)



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

Gamma Camera Processing Electronics

(linearity correction)



Additional Gamma Camera Correction

(sensitivity / uniformity)

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

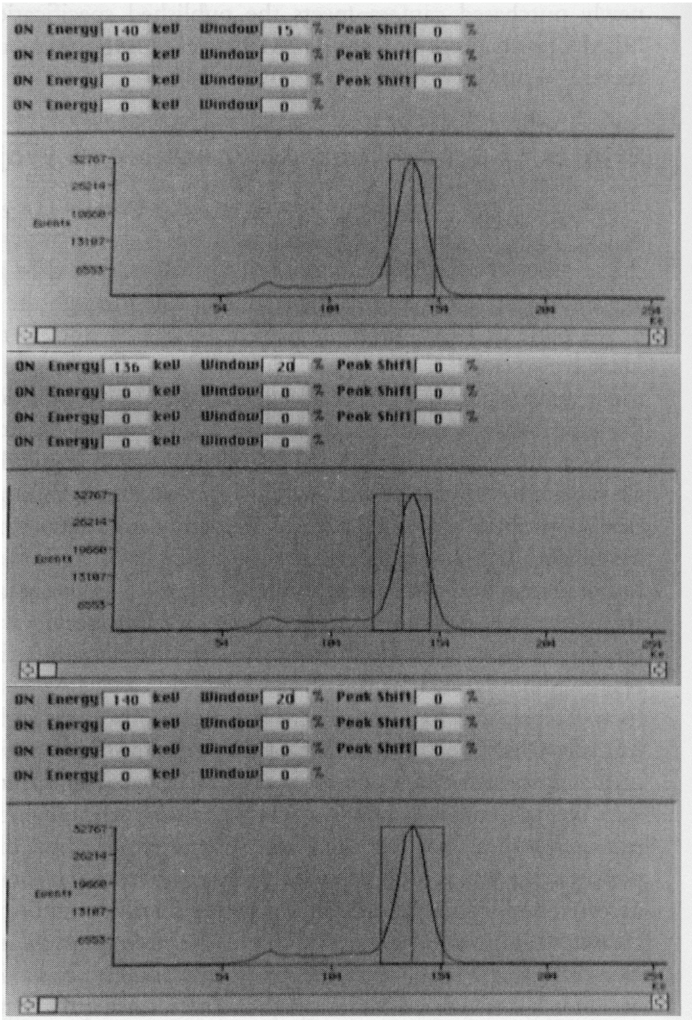
Multiplicative correction

Adjusts for slight variation in the detection efficiency of the crystal

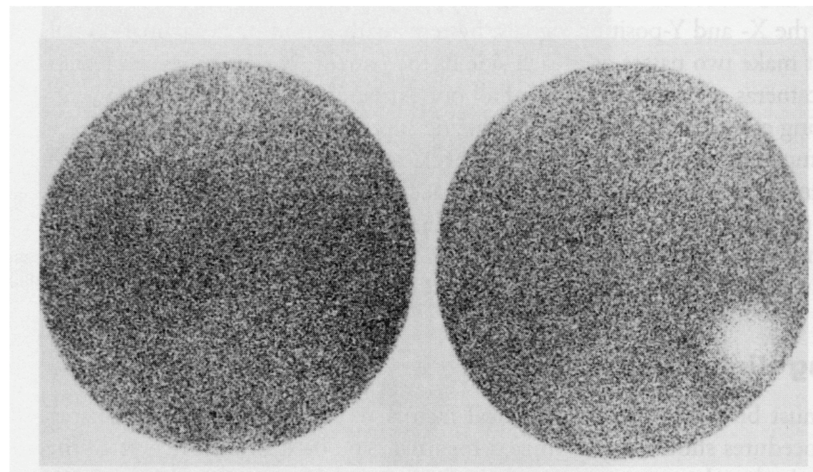
Compensates for small defects or damage to the collimator

Should not be used to correct for large irregularities

Daily Gamma Camera QA Tests



Photopeak window

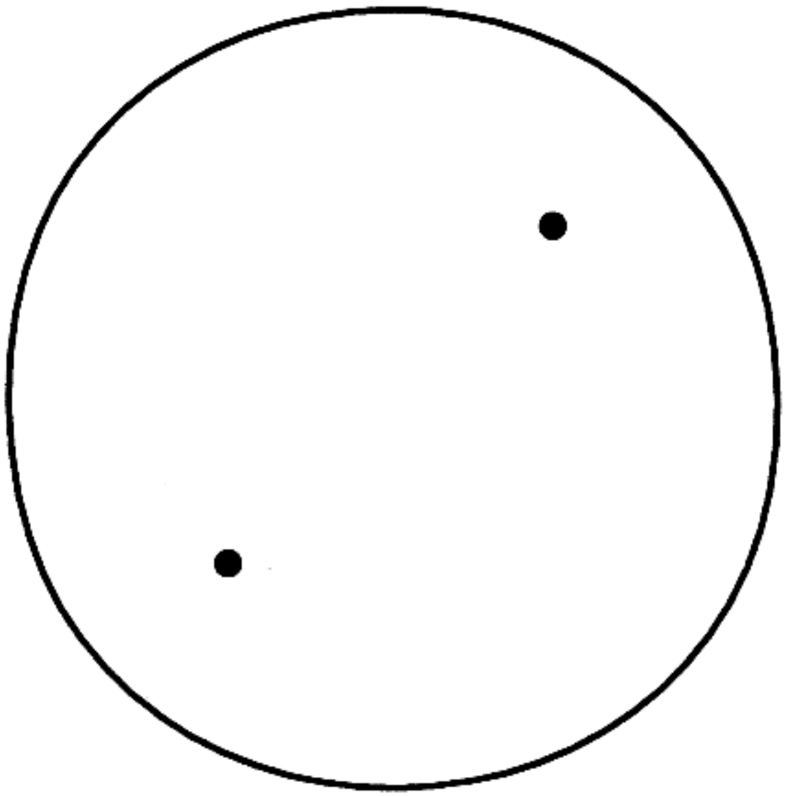


Flood uniformity

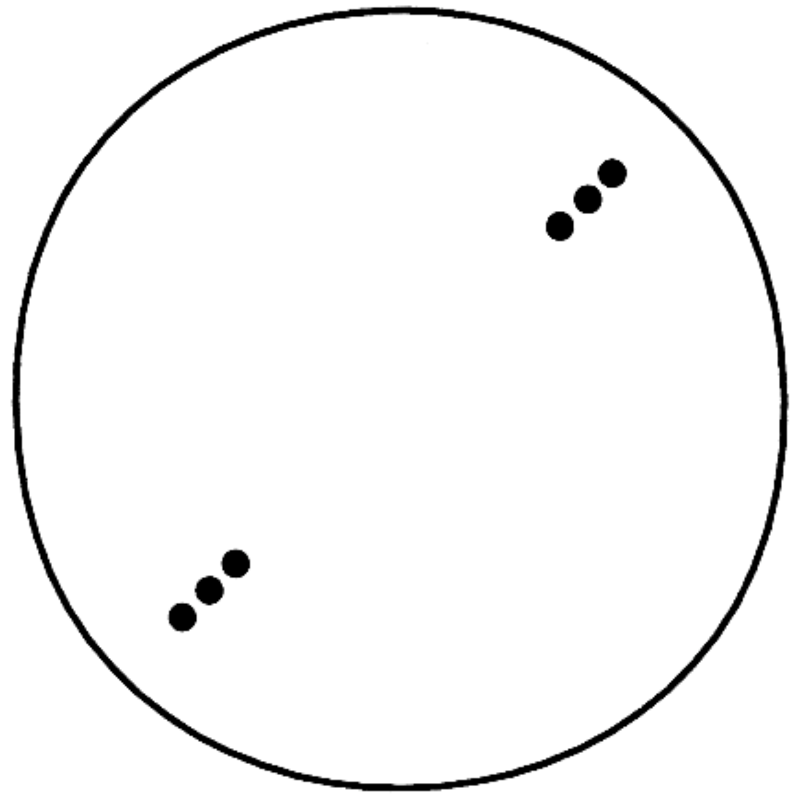
From: The Essential Physics of Medical Imaging (Bushberg, et al)

Multienergy spatial registration

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



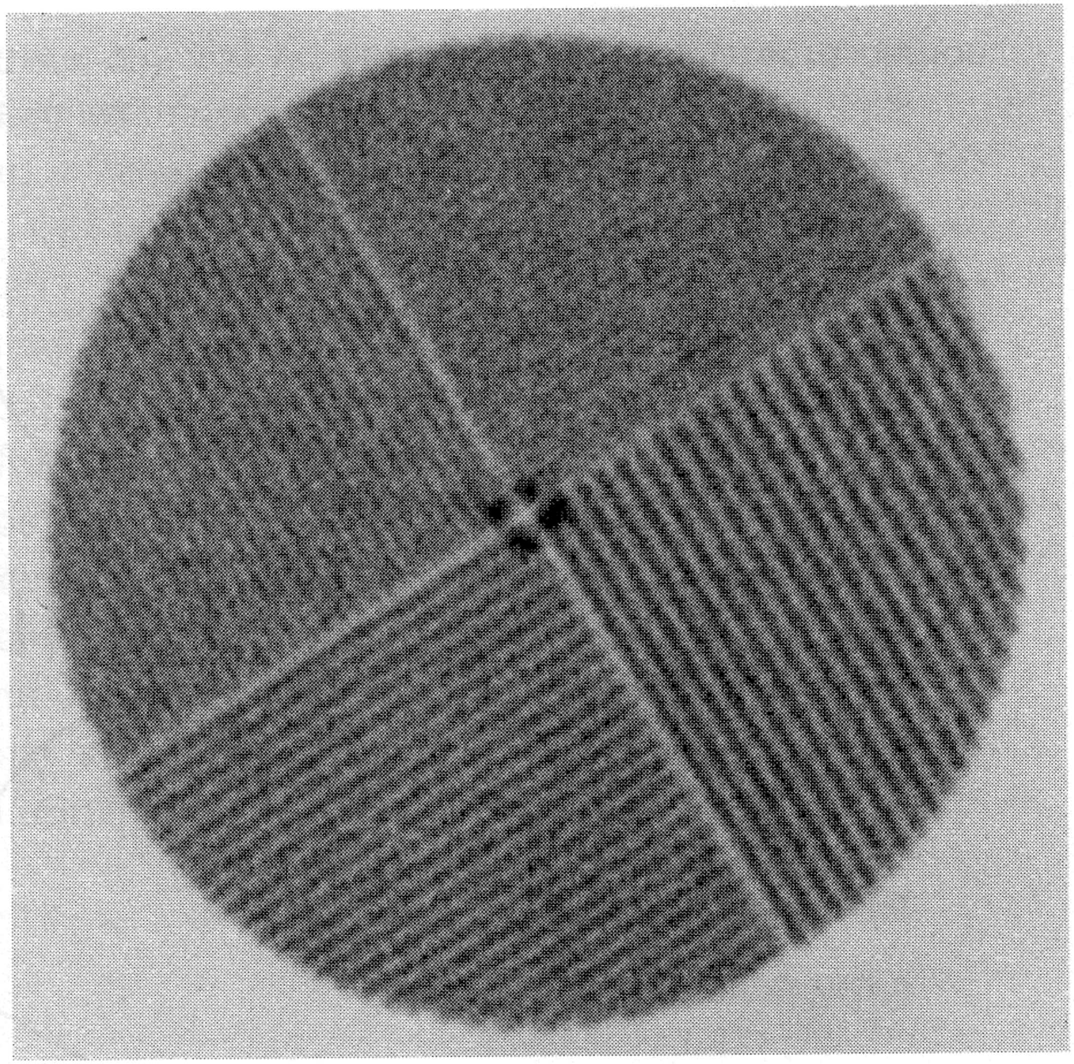
properly adjusted



improperly adjusted

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

Spatial Resolution Test



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

Pulse Pile-up

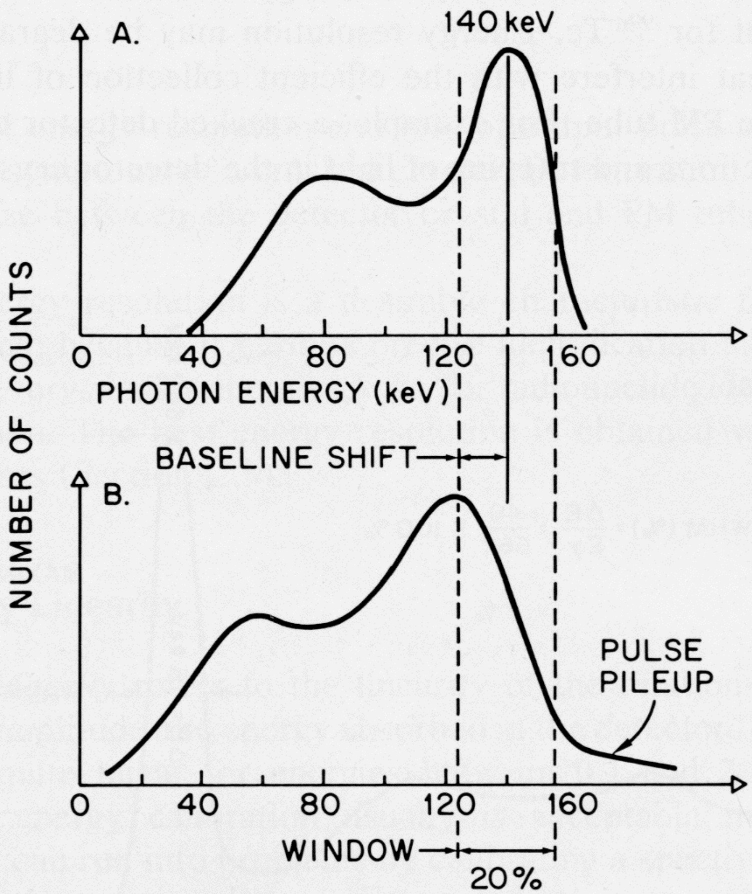


Fig. 11-10. (A) ^{99m}Tc spectrum at low counting rate. (B) Spectral broadening and shift in apparent photopeak energy due to pulse pileup and baseline shift in the spectrometer amplifier at high counting rate.

Energy spectra

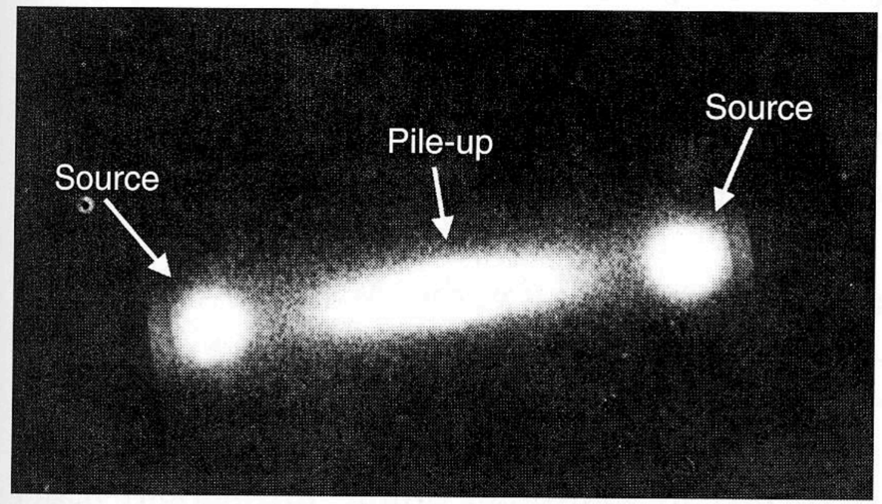


Figure 14–6. Images of two ^{99m}Tc point sources of relatively high activities (~370 MBq each). Events appearing in the band between the two point-source locations are mispositioned events due to pulse pile-up.

Pile-up in image

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

The Scintillation Camera: Image Acquisition

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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

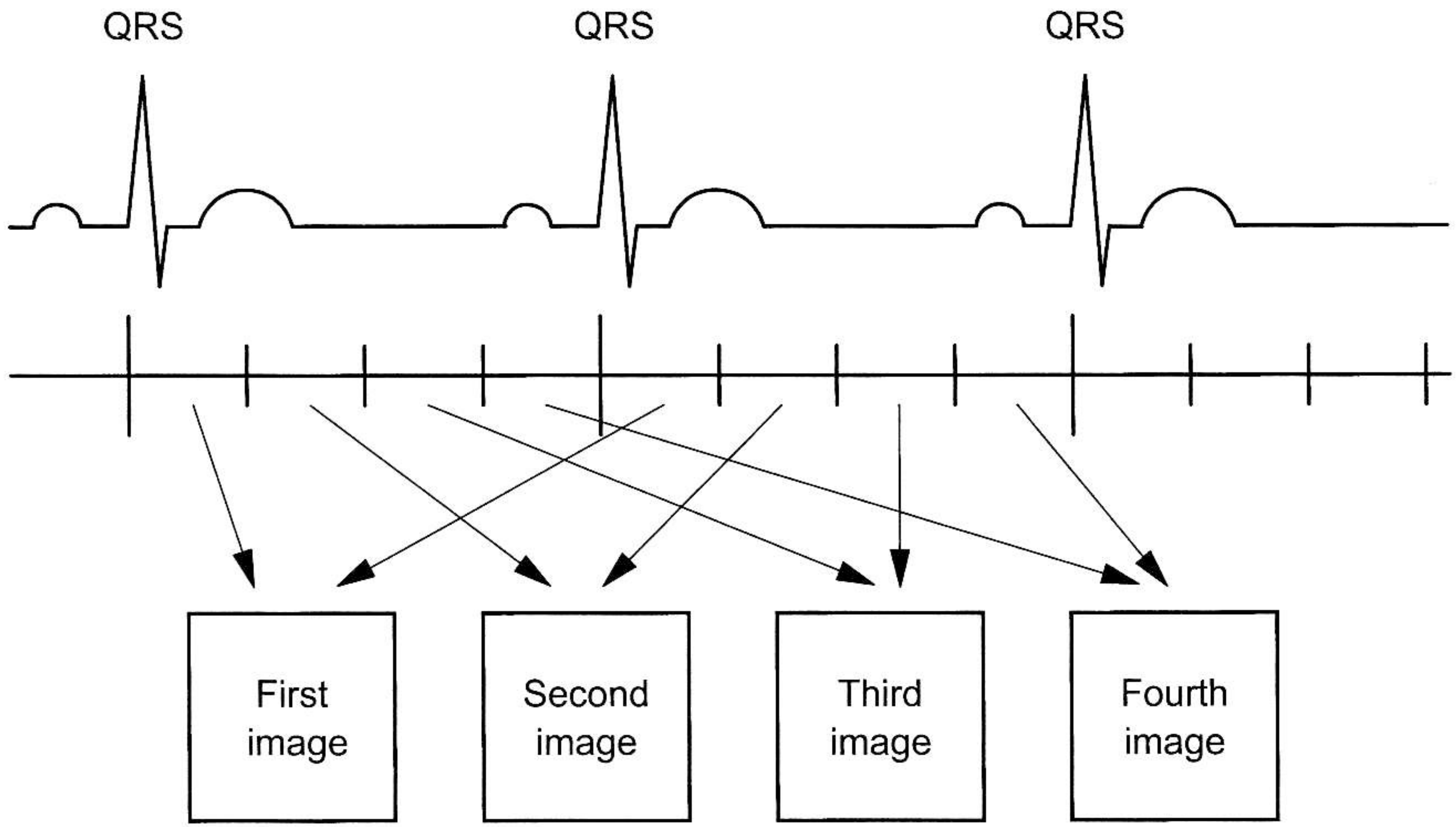

FIGURE 21-22. Acquisition of a gated cardiac image sequence. Only four images are shown here. Sixteen to 24 images are typically acquired.

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

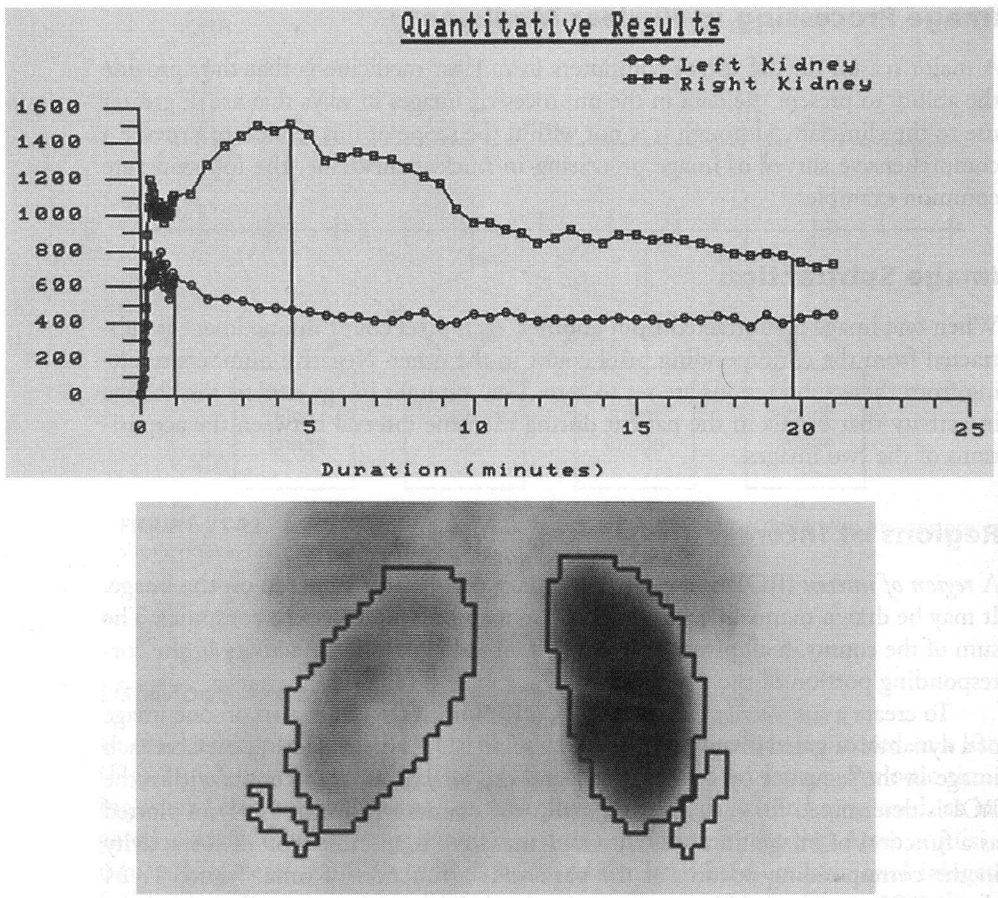

FIGURE 21-24. Regions of interest (ROIs) **(bottom)** and time-activity curves (TACs) **(top)**.

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