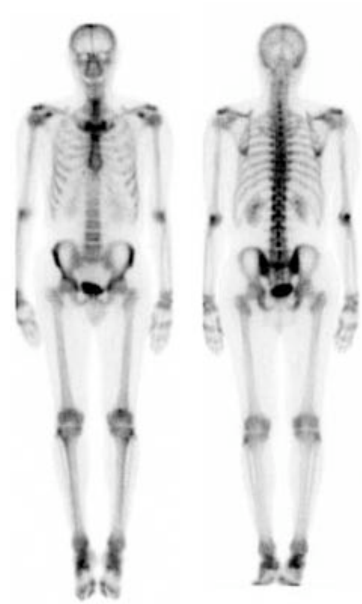
Overview of today's lecture

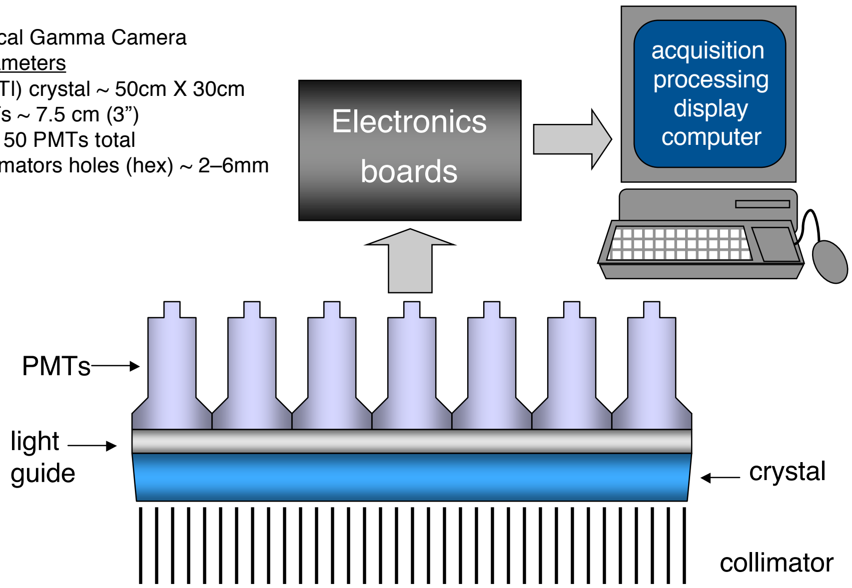
- Nature of nuclear radiation
  - Isotopes used in nucl. med.
- Detection methods
- Counting statistics
- **Imaging systems**
  - **Planar gamma scintigraphy**

The Planar Gamma Camera

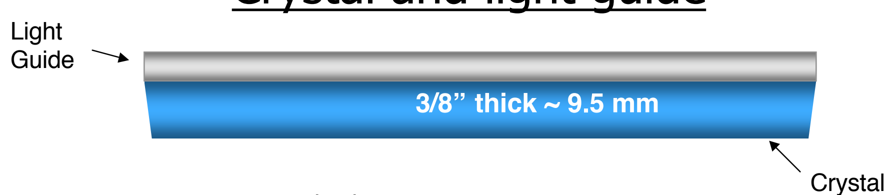


Gamma Camera Instrumentation

Typical Gamma Camera
Parameters
NaI(Tl) crystal ~ 50cm X 30cm
PMTs ~ 7.5 cm (3")
30 – 50 PMTs total
Collimators holes (hex) ~ 2–6mm



Crystal and light guide



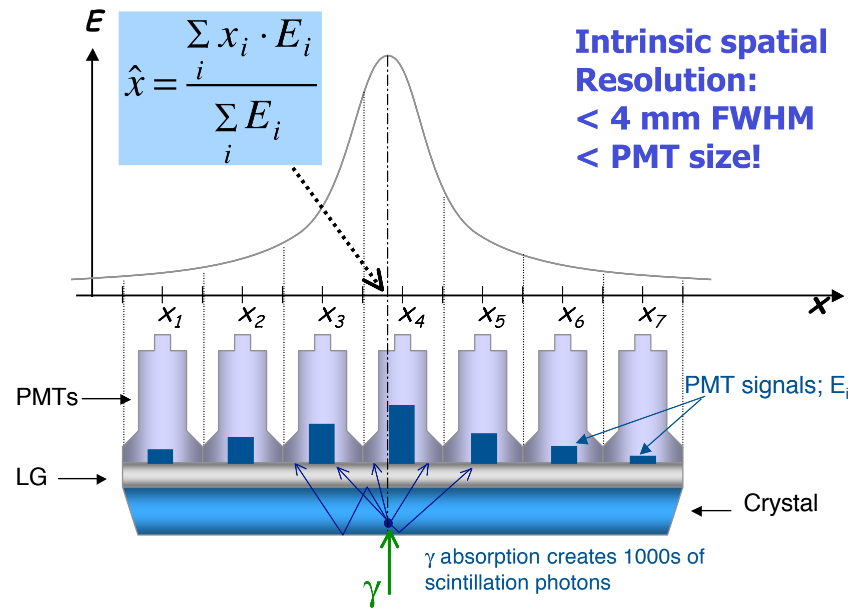
NaI(Tl)

Density	3.67 g/cm^3
Attenuation Coefficient μ (@140 keV)	2.64 cm^{-1} —-> 1-e$^{-(2.64/cm)(0.95cm)}$ = 92%
PE fraction	~80%
Light output	40/keV —-> 40*140 = 5,600 scint. photons
Decay time	230 nsec
Wavelength	410 nm

Light guide distributes scintillation light over PMT array

Light response function versus position

(light sharing —-> spatial resolution)



Spatial Positioning

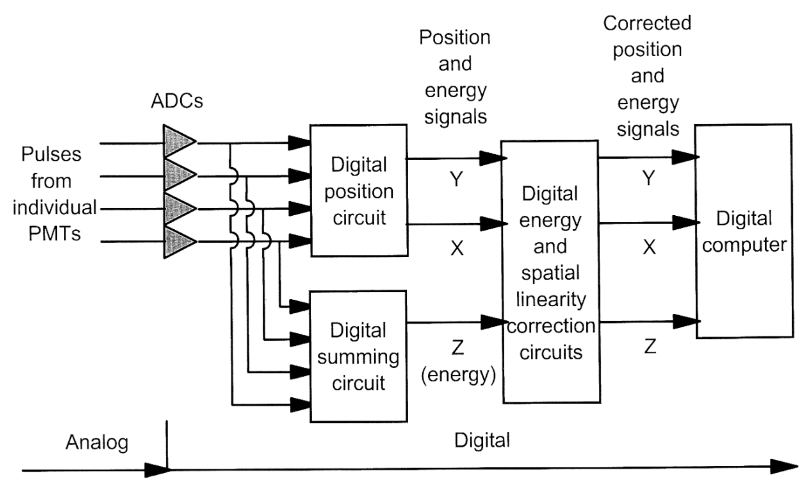
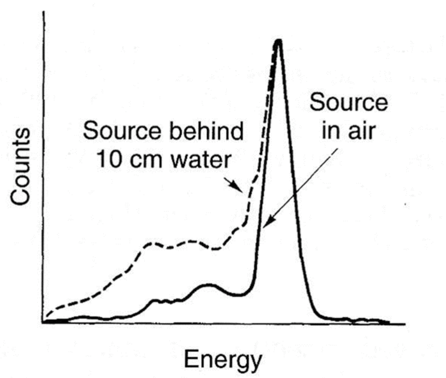


FIGURE 21-5. Electronic circuits of a modern digital scintillation camera.

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

Gamma Camera Energy Spectra

Summed signal from all PMTs

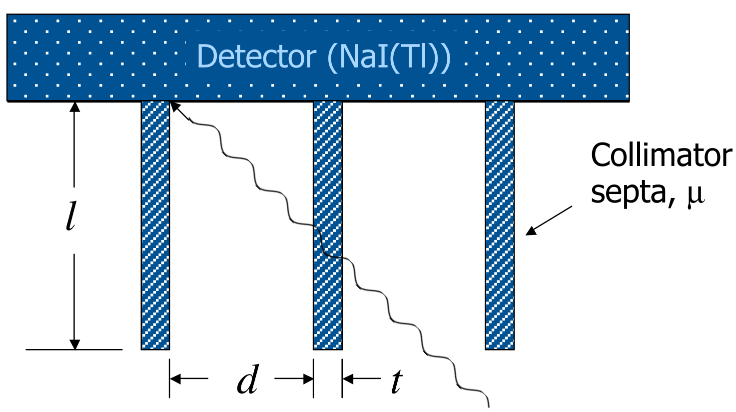


Scattered events have changed direction, hence, they will be mis-positioned by the image generation algorithm
---> this tends to diffuse sources and reduce image contrast

Energy Windows

- Balance between accepting all good events (importance of sensitivity) and rejecting scattered events.
- Most gamma cameras can acquire data using multiple energy windows. Allows for simultaneous imaging of different radioisotopes, for example Tc-99m (140 keV) and I-131 (364 keV).

Collimators - Septal Penetration



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

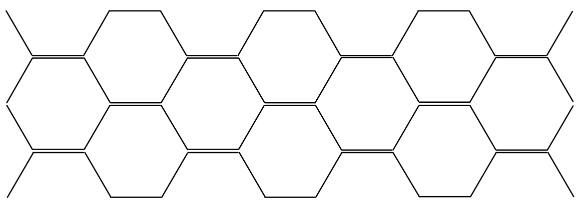
$$t \geq \frac{6d/\mu}{l - \left(3/\mu\right)}$$

Collimator Efficiency

Collimators typically absorb well over 99.95% of all photons incident on them.

Trade-off between spatial resolution (small collimator holes) and detection efficiency (large collimator holes).

Hexagonal holes: good symmetry, good packing fraction, foil fabrication ---> 2 /6 are double walls



Collimator Resolution

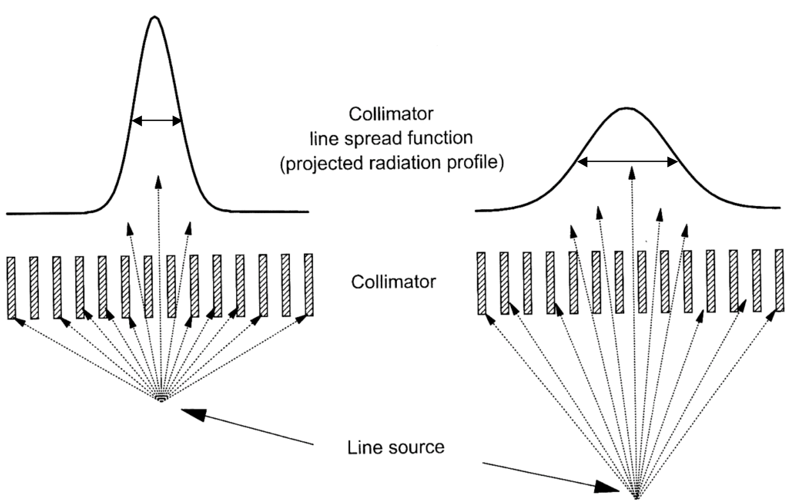
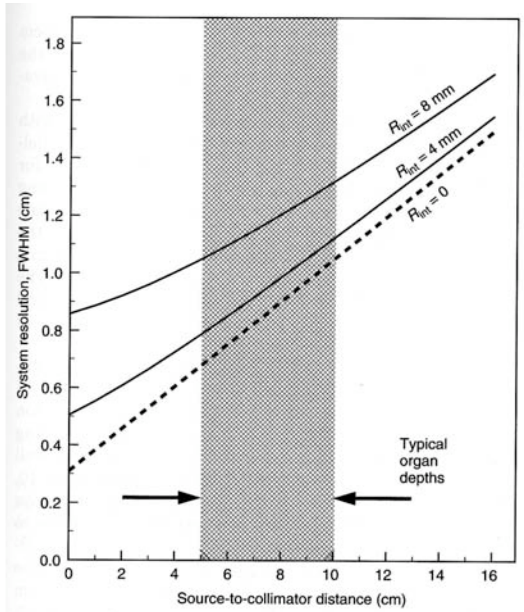


FIGURE 21-12. Line spread function (LSF) of a parallel-hole collimator as a function of source-to-collimator distance. The full-width-at-half-maximum (FWHM) of the LSF increases linearly with distance from the source to the collimator; however, the total area under the LSF (photon fluence through the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

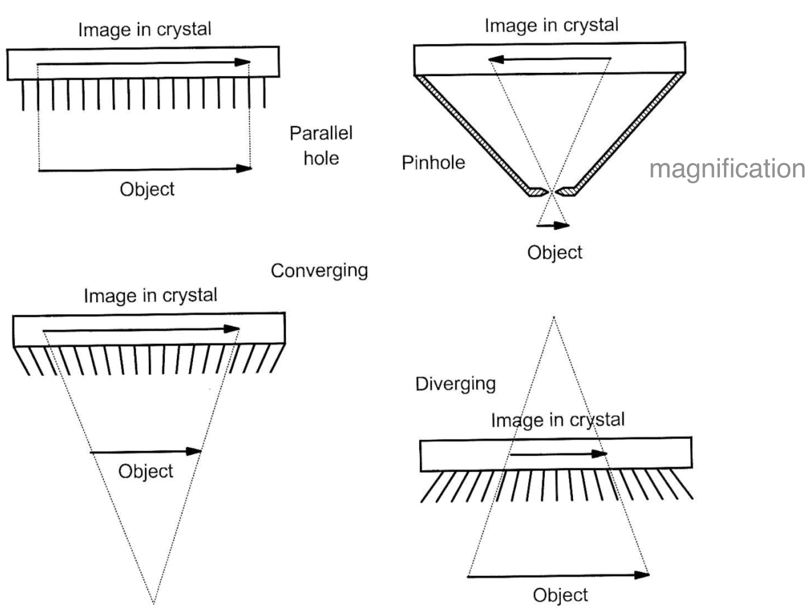
From: The Essential Physics of Medical Imaging (Bushberg, et al)

Gamma Camera - spatial resolution



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

Types of Collimators



Collimator: Resolution and Sensitivity

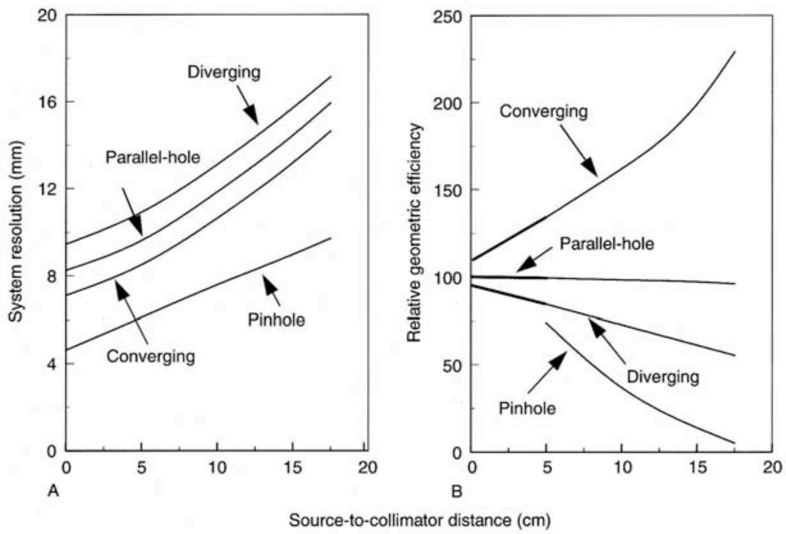


Figure 14–21. Performance characteristics (*A*, system resolution; *B*, point-source geometric efficiency in air) versus source-to-collimator distance for four different types of gamma camera collimators. (Reprinted by permission of the Society of Nuclear Medicine from Moyer RA: A low-energy multihole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

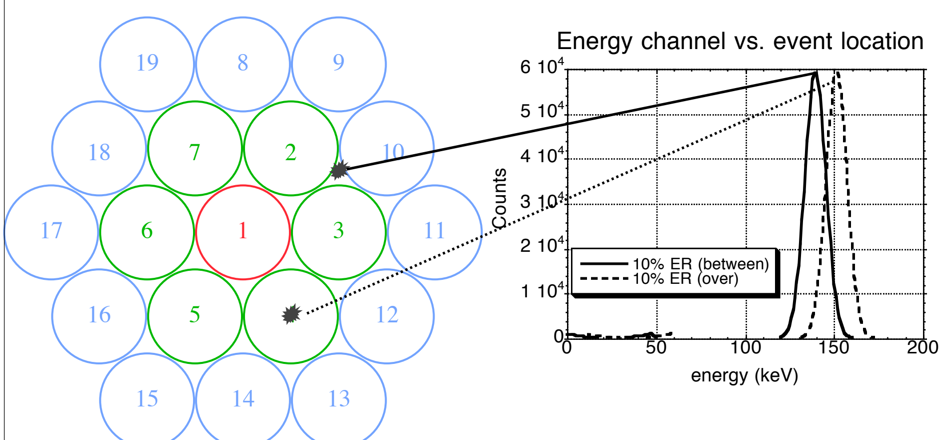
Collimator	Spatial resolution[a]	Efficiency	Field size	Magnification
Parallel hole	Decreases	Approximately constant	Constant	Constant (m = 1.0)
Converging	Decreases	Increases	Decreases	Increases (m >1 at collimator surface)
Diverging	Decreases	Decreases	Increases	Decreases (m <1 at collimator surface)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

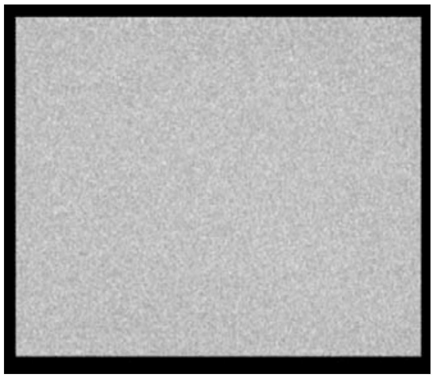
The Scintillation Camera: Corrections and QA

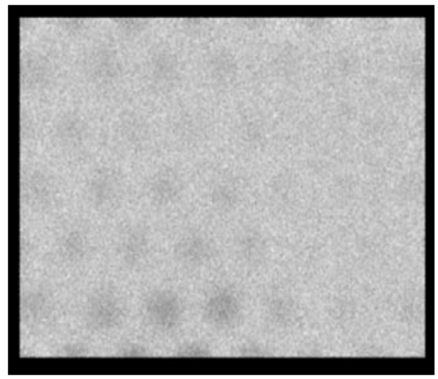
Gamma Camera Processing Electronics
(energy correction)



Gamma Camera Processing Electronics

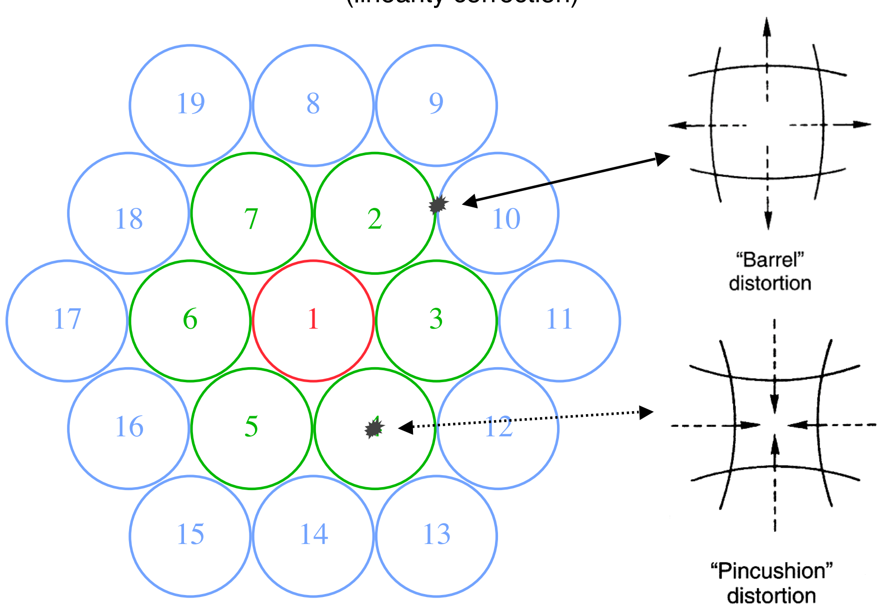
(with and without energy correction)





Gamma Camera Processing Electronics

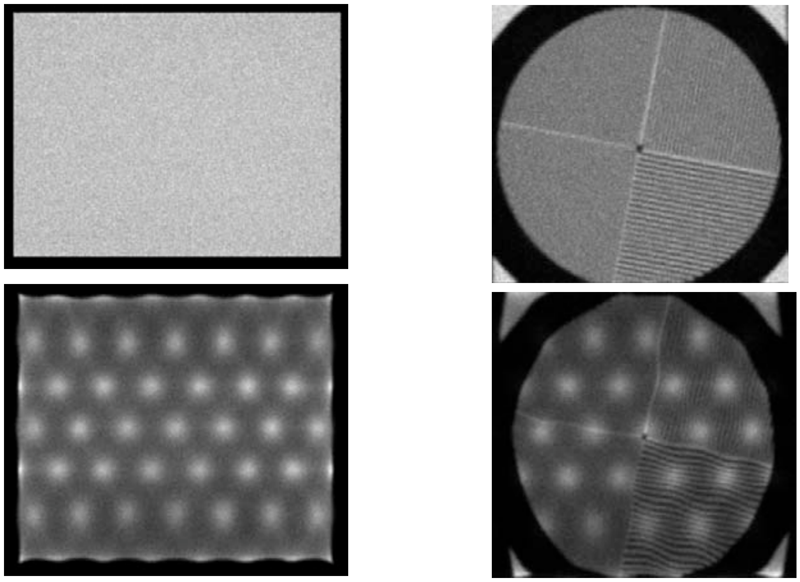
(linearity correction)



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

Gamma Camera Processing Electronics

(linearity correction)



Additional Gamma Camera Corrections

(sensitivity / uniformity)

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

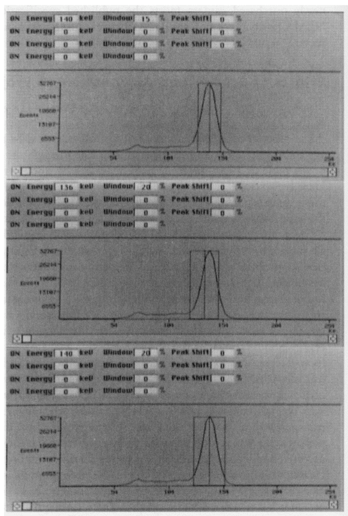
Multiplicative correction

Adjusts for slight variation in the detection efficiency of the crystal

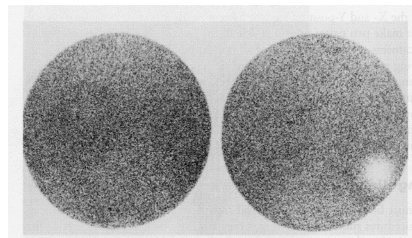
Compensates for small defects or damage to the collimator

Should not be used to correct for large irregularities

Daily Gamma Camera QA Tests



Photopeak window

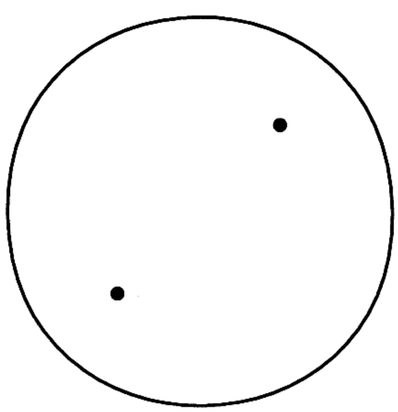


Flood uniformity

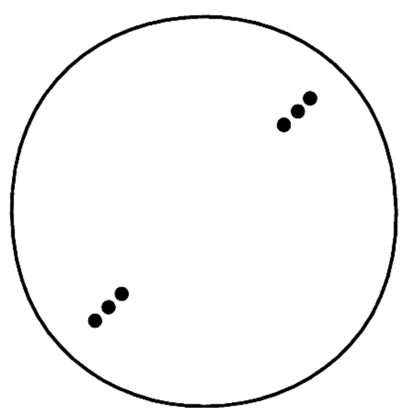
From: The Essential Physics of Medical Imaging (Bushberg, et al)

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)

Pulse Pile-up

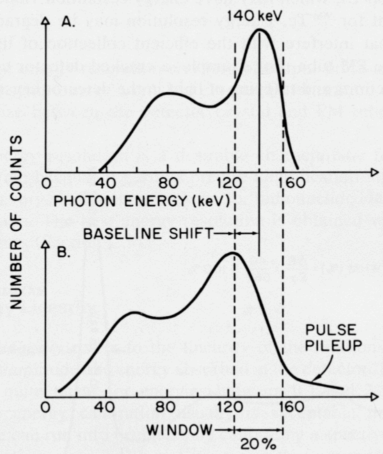


Fig. 11-10. (A) ^{99m}Tc spectrum at low counting rate. (B) Spectral broadening and shift in apparent photopeak energy due to pulse pileup and baseline shift in the spectrometer amplifier at high counting rate.

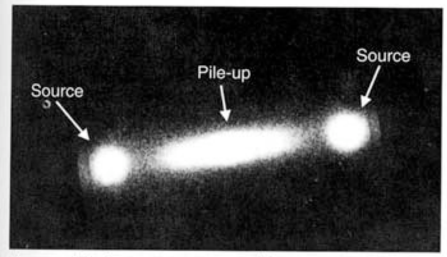


Figure 14–6. Images of two ^{99m}Tc point sources of relatively high activities (~370 MBq each). Events appearing in the band between the two point-source locations are mispositioned events due to pulse pile-up.

Pile-up in image

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

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

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

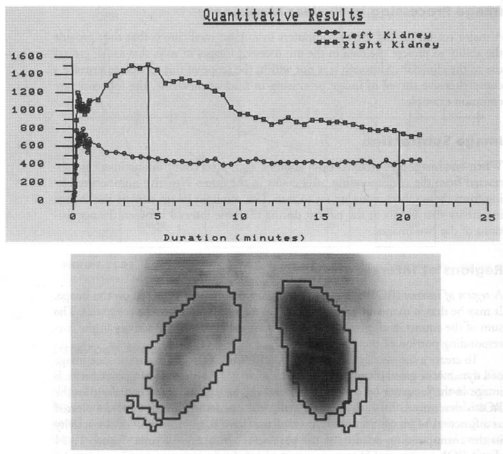
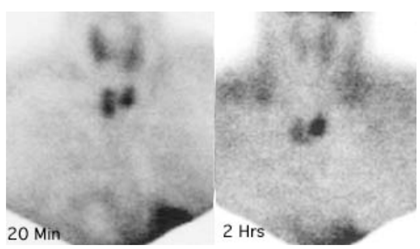


FIGURE 21-24. Regions of interest (ROIs) **(bottom)** and time-activity curves (TACs) **(top)**.

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

Example Clinical Images



To evaluate the hyperparathyroidism double phase technetium-99m sestamibi parathyroid scintigraphy was performed.

Parathyroid Scintigraphy was performed 20 minutes and 2 hours after injection of technetium-99m-sestamibi.

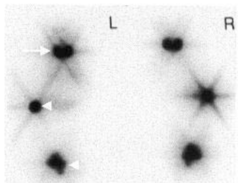
The 20 minute scan showed uptake in a normal appearing thyroid gland

as well as uptake in two ovoid areas in the upper mediastinum.

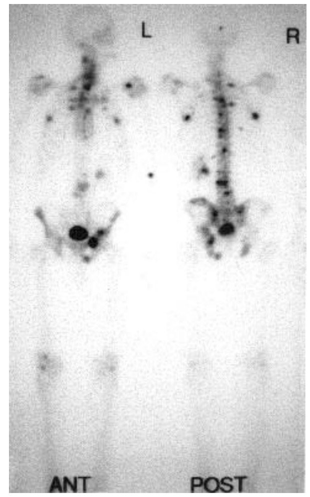
The 2 hour image showed wash out of activity from the thyroid, and persistence of activity in the upper mediastinum

Example Clinical Images

Collimator artifacts
(from high energy gammas
- 364 keV)

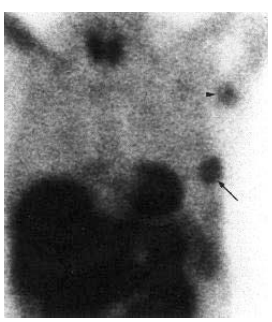


^{131}I uptake in primary differentiated thyroid carcinoma (arrow) and in rib and pelvic metastases (arrowheads)



^{99m}Tc-MDP bone scintigraphy demonstrating multi-focal increased uptake due to skeletal metastases from a renal carcinoma – note right nephrectomy

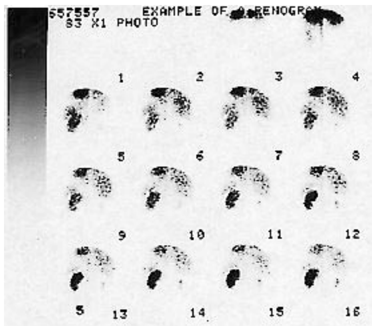
Example Clinical Images



^{99m}Tc-MIBI scintimammography (supine and prone left lateral views) showing a primary tumor in the left breast (arrow) and axillary lymph node metastases (arrowhead)

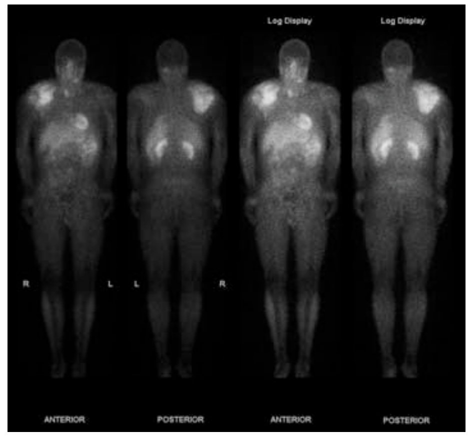
Example Clinical Images

renal excretion



^{99m}Tc

whole body



^{201}Tl