Nuclear Medicine Imaging Systems: The Scintillation Camera
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
The Scintillation Camera: Detector System - Crystal and Electronics
Crystal and light guide

Nal(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

Light Guide

3/8” thick

Crystal
Detection Efficiency

• What thickness of NaI(Tl) is needed to detect ~90% of 140 keV photons?

We need to find the thickness $x$, where only 10% of the photons pass through the detector without an interaction.

$I(x) = I_o \times e^{-\mu x}$

$\mu = \text{linear attenuation coefficient}$,
$x = \text{distance in cm}$,
$I(x) = 0.10 \times I_o$

So:

$x = (\ln(I_o / I(x))/\mu$

$x = (\ln(10))/2.64$

$x = 0.9\text{cm}$
Light response function versus position (spatial resolution)

\[ \hat{x} = \frac{\sum x_i \cdot E_i}{\sum E_i} \]
Techniques to optimize shape of light response function

Diagram showing lightpipe, PMT, black dots, crystal, and variations in light response function (LRF) before and after sculpturing.
Scatter

All scatter counts are within the object (unlike in PET)
Gamma Camera Energy Spectra

140 keV photons, 9.5 mm crystal

Energy Resolution - scatter rejection
The Scintillation Camera: Collimators
Parallel Hole Collimator
(resolution and efficiency)

\[ R_c = \frac{d(l_e + b)}{l_e}, \quad \text{where} \quad l_e = l - 2\mu^{-1} \]

\[ \text{Col}_{\text{eff}} = K^2(d/l_e)^2 \left[ \frac{d^2}{(d+t)^2} \right] \]

From: Physics in Nuclear Medicine (Sorenson and Phelps)
Collimators typically absorb well over 99.95% of all photons emitted from the patient.
Gamma Camera - Collimators

Fig. 16-11. Minimum path length \( w \) for a \( \gamma \) ray passing through the collimator septa from one hole to the next depends on length \( l \) and diameter \( d \) of the collimator holes and on septal thicknesses \( t \).

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

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

From: Physics in Nuclear Medicine (Sorenson and Phelps)
Gamma Camera - spatial resolution

\[ R_s = \sqrt{R_i^2 + R_c^2} \]

From: Physics in Nuclear Medicine (Sorenson and Phelps)
SPECT - pinhole collimator resolution

\[ R_c = \frac{d_e(l + b)}{l} \quad \text{where} \quad d_e = \left( d + 2\mu^{-1}\tan(\alpha/2) \right)^{1/2} \]
Gamma Camera - Collimators

From: Physics in Nuclear Medicine (Sorenson and Phelps)
The Scintillation Camera: Corrections and QA
Gamma Camera Processing Electronics
(energy correction)

Energy channel vs. event location

Counts

energy (keV)

10% ER (between)
10% ER (over)
Gamma Camera Processing Electronics
(with and without energy correction)
Gamma Camera Processing Electronics
(no linearity correction)
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)
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).
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.
The presence of I-131 will interfere with a Tc-99m bone scan but not vice versa. This is because the higher energy 364 keV I-131 photons down-scatter into the Tc-99m window, while the reverse is not physically possible. Therefore, the Tc-99m must be administered and scanned first. Answer C would work, but would not optimize the time.
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.
D75. E

Septal penetration occurs when photons travel the shortest distance through the lead collimator, i.e., jump between adjacent collimator holes. The star-like appearance is caused by the hexagonal arrangement of holes in the collimator. A and B would not cause star-shaped artifacts. C gives star-shaped artifacts in PET and SPECT, but an anterior spot view does not require reconstruction. Dead-time leads to a loss of sensitivity.
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.
D81. E

The wrong collimator would increase septal penetration and increase or decrease camera sensitivity, but could not produce a cold spot in the image.