The Scintillation Camera: Planar and SPECT

Tom Lewellen, PhD
University of Washington
Department of Radiology
tkldog@u.washington.edu
List of Nuclear Medicine ‘Single Photon’ Radionuclides

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Energy (keV)</th>
<th>Decay Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc99m</td>
<td>140.5</td>
<td>6.03 hours</td>
</tr>
<tr>
<td>I-131</td>
<td>364, 637</td>
<td>8.06 days</td>
</tr>
<tr>
<td>I-123</td>
<td>159</td>
<td>13.0 hours</td>
</tr>
<tr>
<td>I-125</td>
<td>35</td>
<td>60.2 days</td>
</tr>
<tr>
<td>In-111</td>
<td>172, 247</td>
<td>2.81 days</td>
</tr>
<tr>
<td>Th-201</td>
<td>~70, 167</td>
<td>3.044 days</td>
</tr>
<tr>
<td>Ga-67</td>
<td>93, 185, 300</td>
<td>3.25 days</td>
</tr>
</tbody>
</table>

From: Physics in Nuclear Medicine (Sorenson and Phelps)

Tom Lewellen, PhD., UW Radiology, Fall 2007
The Planar Gamma Camera

Siemens e.cam

Tom Lewellen, PhD., UW Radiology, Fall 2007
Gamma Camera Instrumentation

- Electronics boards
- Acquisition and processing computer
- PMT
- LG
- Crystal
- Collimator
The Scintillation Camera: Detector System
Crystal and light guide

- **NaI(Tl)**
  - **Density:** 3.67 g/cm³
  - **Attenuation Coefficient (@140 keV):** 2.64 cm⁻¹
  - **PE fraction:** ~80%
  - **Light output:** 40K/MeV
  - **Decay time:** 230 nsec
  - **Wavelength:** 410 nm

Crystal

Light Guide

3/8” (9.5 mm) thick
Detection Efficiency

Change of solid angle

Light collected

Tom Lewellen, PhD., UW Radiology, Fall 2007
Light response function versus position (spatial resolution)

\[ \hat{x} = \frac{\sum x_i \cdot E_i}{\sum E_i} \]

Intrinsic spatial Resolution: <4 mm FWHM
Spatial Positioning

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

From: The Essential Physics of Medical Imaging (Bushberg, et al)
All scatter counts are within the object (unlike in PET)
Gamma Camera Energy Spectra

Counts

Source behind 10 cm water

Source in air

Energy
Energy Resolution vs. Energy Window

140 keV photons
Gamma Camera Energy Spectra

Nai(Tl) Energy Spectra (140 keV)

Counts

140 keV photons, 9.5 mm crystal

Tom Lewellen, PhD., UW Radiology, Fall 2007
Energy Windows

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).
The Scintillation Camera: Collimators
Parallel Hole Collimator

PMTs

detector - NaI(Tl)

I_e

Tom Lewellen, PhD., UW Radiology, Fall 2007
Collimators - Septal Penetration

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

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

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

Tom Lewellen, PhD., UW Radiology, Fall 2007
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

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

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

- Parallel hole
  - Image in crystal
  - Object

- Pinhole
  - Image in crystal
  - Object
  - magnification

- Converging
  - Image in crystal
  - Object

- Diverging
  - Image in crystal
  - Object

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

Tom Lewellen, PhD., UW Radiology, Fall 2007
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>
<thead>
<tr>
<th>Collimator</th>
<th>Spatial resolution(^a)</th>
<th>Efficiency</th>
<th>Field size</th>
<th>Magnification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel hole</td>
<td>Decreases</td>
<td>Approximately constant</td>
<td>Constant</td>
<td>Constant ((m = 1.0))</td>
</tr>
<tr>
<td>Converging</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases</td>
<td>Increases ((m &gt;1 \text{ at collarator surface}))</td>
</tr>
<tr>
<td>Diverging</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases ((m &lt;1 \text{ at collarator surface}))</td>
</tr>
<tr>
<td>Pinhole</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases ((m \text{ largest near pinhole}))</td>
</tr>
</tbody>
</table>

\(^a\)Spatial resolution corrected for magnification.
The Scintillation Camera: Corrections and QA
Gamma Camera Processing Electronics
(energy correction)

Energy channel vs. event location

Counts vs. energy (keV)
Gamma Camera Processing Electronics
(with and without energy correction)
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)
Spatial Resolution Test

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

From: The Essential Physics of Medical Imaging  (Bushberg, et al)
Pulse Pile-up

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.

Energy spectra

From: Physics in Nuclear Medicine (Sorenson and Phelps) and (Cherry, Sorenson and Phelps)  
Tom Lewellen, PhD., UW Radiology, Fall 2007
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
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)

**Quantitative Results**

---

**Figure 21-24.** Regions of interest (ROIs) (**bottom**) and time-activity curves (TACs) (**top**).
The Scintillation Camera: SPECT Imaging
Gamma Camera Imaging (SPECT)

Siemens e.cam (http://www.medical.siemens.com)

GE MG (http://www.gehealthcare.com)

www.medical.philips.com
Gamma Camera Imaging (SPECT)
Gamma Camera Imaging
(gated cardiac SPECT)

- Images obtained during individual phases of cardiac cycle
- Gating based on EKG
- 8-16 frames per cycle
- Allows assessment of global and regional LV function

www.cardiology.utmb.edu/slides/Gated%20Cardiac%20SPECT.htm

Tom Lewellen, PhD., UW Radiology, Fall 2007
Additional QA/QC Tests for SPECT

Center of Rotation

From: The Essential Physics of Medical Imaging (Bushberg, et al)
Additional QA/QC Tests for SPECT

Detector Uniformity

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

Tom Lewellen, PhD., UW Radiology, Fall 2007
Questions
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.
D67. D

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.
1. A pulse height analyzer window width of 20% detects $^{99m}$Tc gamma rays with energies of:
   a. 140 keV only
   b. Between 135 and 145 keV
   c. Between 120 and 140 keV
   d. Between 126 and 154 keV
   e. Between 118 and 168 keV
D: If the window width is 20%, the PHA lower energy level is 140% - 10% (126 keV), and the upper energy level is 140 keV + 10% (156 keV).
D72. Regarding Anger cameras, all of the following are true except:

A. Resolution increases with the number of photomultiplier tubes per unit area.
B. Resolution increases with increasing collimator thickness.
C. Resolution with a parallel hole collimator increases with decreasing hole diameter.
D. Efficiency increases with decreasing collimator length.
E. High-energy collimators have higher efficiency than low-energy collimators.
D72. E

Efficiency and resolution are inversely proportional to energy. High-energy collimators have more lead and fewer holes than low-energy collimators.
D76. A patient is imaged using a 256 x 256 matrix on a gamma camera with a 40-cm field of view. The width of each image pixel is ______ mm.

A. 3.12  
B. 1.56  
C. 1.01  
D. 0.96  
E. 0.78
D76. B

400 mm/256 = 1.56 mm/pixel.
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.* _____
Raphex Answer

1. Checked daily using a uniform flood source. __b____
2. Checked daily by placing a small amount of a known source of radioisotope in front of the camera. __c____
3. Checked weekly using a bar phantom. __a____