Radiation Detection and Measurement

Range of charged particles (e.g., $\alpha$: $\mu$m; $\beta$: mm)
Range of high energy photons (cm)
Two main types of interactions of high energy photons
  - Compton scatter
  - Photoelectric absorption
Types of radiation detectors
  - gas-filled detectors
  - solid state (semiconductor)
  - organic scintillators (liquid plastic)
  - inorganic scintillators (imaging systems)
Modes of operation (pulse mode, current mode)
Counting statistics (mean, variance)
Poisson distribution (mean = variance)
Confidence intervals (standard deviation from mean)
Error propagation (adding in quadrature)
Please turn in your evaluation forms for Drs. Kanal and Stewart.
Nuclear Medicine Imaging Systems:
The Scintillation Camera

Robert Miyaoka, PhD
University of Washington
Department of Radiology
rmiyaoka@u.washington.edu
The Planar Gamma Camera
# List of Nuclear Medicine Radionuclides

<table>
<thead>
<tr>
<th></th>
<th>Energy (keV)</th>
<th>Half-Life (Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc-99m</td>
<td>140.5 keV</td>
<td>6.03 hours</td>
</tr>
<tr>
<td>I-131</td>
<td>364, 637 keV</td>
<td>8.06 days</td>
</tr>
<tr>
<td>I-123</td>
<td>159 keV</td>
<td>13.0 hours</td>
</tr>
<tr>
<td>I-125</td>
<td>35 keV</td>
<td>60.2 days</td>
</tr>
<tr>
<td>In-111</td>
<td>172, 247 keV</td>
<td>2.81 days</td>
</tr>
<tr>
<td>Th-201</td>
<td>~70, 167 keV</td>
<td>3.044 days</td>
</tr>
<tr>
<td>Ga-67</td>
<td>93, 185, 300 keV</td>
<td>3.25 days</td>
</tr>
</tbody>
</table>

From: Physics in Nuclear Medicine (Sorenson and Phelps)
Gamma Camera Instrumentation

- Electronics boards
- Acquisition and processing computer
- PMT
- LG
- Crystal
- Collimator

Robert Miyaoka, PhD., UW Radiology, Summer 2008
The Scintillation Camera: Detector System
Crystal and light guide

- **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

Nal(Tl) (3/8” thick)

Robert Miyaoka, PhD., UW Radiology, Summer 2008
Light response function versus position (spatial resolution)

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

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

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

From: Physics in Nuclear Medicine (Sorenson and Phelps)

Robert Miyaoka, PhD., UW Radiology, Summer 2008
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
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
Parallel Hole Collimator

PMTs

detector - NaI(Tl)

$I_e$

Robert Miyaoka, PhD., UW Radiology, Summer 2008
Collimators - Septal Penetration

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

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

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.

LEG, LEHR, MEGP, High Energy.
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

Pinhole

Converging

Diverging

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

Robert Miyaoka, PhD., UW Radiology, Summer 2008
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

<table>
<thead>
<tr>
<th>Collimator</th>
<th>Spatial resolution&lt;sup&gt;a&lt;/sup&gt;</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 at collimator surface)</td>
</tr>
<tr>
<td>Diverging</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases (m &lt;1 at collimator surface)</td>
</tr>
<tr>
<td>Pinhole</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases (m largest near pinhole)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Spatial resolution corrected for magnification.
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
(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 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

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)

Robert Miyaoka, PhD., UW Radiology, Summer 2008
Spatial Resolution Test

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

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

Robert Miyaoka, PhD., UW Radiology, Summer 2008
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.
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. _____