Radiation Detection and Measurement

Range of charged particles (e.g., α: μm; β: 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)

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

Gamma Camera Instrumentation

Please turn in your evaluation forms for Drs. Kanal and Stewart.
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

**Detection Efficiency**

<table>
<thead>
<tr>
<th>γ-ray energy (keV)</th>
<th>Detection efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.64</td>
</tr>
<tr>
<td>200</td>
<td>2.54</td>
</tr>
<tr>
<td>300</td>
<td>5.98</td>
</tr>
</tbody>
</table>

**Spatial Positioning**

**Energy Resolution**

*Figure 14-5: Photon detection efficiency versus γ-ray energy for NaI(Tl) detectors of different thicknesses. (Reprinted from chapter 13, In Instrumentation in Nuclear Medicine, Vol. 1, New York: Academic Press, 1967, p 336.)*
Scatter

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

Gamma Camera Energy Spectra

Source behind 10 cm water

Source in air

Gamma Camera Energy Spectra

NaI(Tl) Energy Spectra (140 keV)

Counts

Energy

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
Collimators - Septal Penetration

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

$$t \geq \frac{6d}{l}$$

Collimator Efficiency

Collimators typically absorb well over 99.95% of all photons emitted from the patient.

Trade-off between spatial resolution and detection efficiency.

LEGP, LEHR, MEGP, High Energy.

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Gamma Camera - spatial resolution

$$R = \sqrt{R_i^2 + R_c^2}$$

Types of Collimators

Collimator: Resolution and Sensitivity

Figure 14-21. Performance characteristics of a scintillation camera, showing spatial resolution, $R$, 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 Miller RJ. A low-energy low-magnification collimator compared with a pinhole collimator at 20 cm and an energy window of 140 keV. J Nucl Med 21:310-312, 1980.)
TABLE 23.3. THE EFFECT OF INCREASING COLLIMATOR-TO-OBJECT DISTANCE ON COLLIMATOR PERFORMANCE PARAMETERS

<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 = 1/0))</td>
</tr>
<tr>
<td>Diverging</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases ((m = 1/0))</td>
</tr>
<tr>
<td>Proximal</td>
<td>Decreases</td>
<td>Decreases</td>
<td>Increases</td>
<td>Decreases ((m = 1/0))</td>
</tr>
</tbody>
</table>

\(^a\)Spatial resolution corrected for magnification.

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 radioidine 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 radioidine 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

D76. 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

Energy channel vs. event location
Gamma Camera Processing Electronics
(with and without energy correction)

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

Photopeak window

Flood uniformity

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

properly adjusted

improperly adjusted
Spatial Resolution Test

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

Pulse Pile-up

Energy spectra

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

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

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. _____