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

**Gamma Camera Instrumentation**

**Crystal and light guide**

- **NaI(Tl)**
  - Density 3.67 g/cm³
  - Attenuation Coefficient μ (@140 keV) 2.64 cm⁻¹
  - 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)

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

*Intrinsic spatial Resolution:*
< 4 mm FWHM
< PMT size!

**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

- Source behind 10 cm water
- Source in air

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:

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

\[ R_s = R_i^2 + R_c^2 \]

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

Types of Collimators

[Diagram showing different types of collimators: Parallel hole, Pinhole, Converging, Diverging]
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)

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**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.

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

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)
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)

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

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

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

99mTc-MDP bone scintigraphy demonstrating multi-focal increased uptake due to skeletal metastases from a renal carcinoma – note right nephrectomy

Example Clinical Images

99mTc-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

whole body

$^{99m}$Tc

$^{201}$Tl