EE 5345
Biomedical Instrumentation
Lecture 14: slides 277-296

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slides can be viewed at:
http://www.seas.smu.edu/~cd/ee5345.html
Types of Radioactive Decay (cont.)

- **Electron Capture (EC):** inner K-shell electron captured by nucleus,

\[ \text{proton} + e^- \rightarrow \text{neutron} \]

- Z decreased by 1
- A stays same
- generates \( \gamma \) rays, characteristic x rays
Types of Radioactive Decay (cont.)

- **Isometric Transition (IT):** element goes from metastable state to ground state

\[ ^{99m}Tc \rightarrow ^{99}Tc \]

- \(A, Z\) stay same
# Common Radioisotopes in Nuclear Medicine

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{123}$I (Iodine 123)</td>
<td>13.2 hours</td>
<td>EC</td>
</tr>
<tr>
<td>$^{125}$I (Iodine 125)</td>
<td>60.14 days</td>
<td>EC</td>
</tr>
<tr>
<td>$^{131}$I (Iodine 131)</td>
<td>8.04 days</td>
<td>EC</td>
</tr>
<tr>
<td>$^{99m}$Tc (Technetium 99m)</td>
<td>6.02 hours</td>
<td>IT</td>
</tr>
<tr>
<td>$^{133}$X (Xenon 133)</td>
<td>5.245 days</td>
<td>$\beta^-$</td>
</tr>
<tr>
<td>$^{51}$Cr (Chromium 51)</td>
<td>27.704 days</td>
<td>EC</td>
</tr>
<tr>
<td>$^{111}$In (Indium 111)</td>
<td>2.83 days</td>
<td>EC</td>
</tr>
</tbody>
</table>

source: Bronzino, *Biomedical Engineering and Instrumentation*, PWS
## Common Procedures in Nuclear Medicine

<table>
<thead>
<tr>
<th>Test</th>
<th>Isotope</th>
</tr>
</thead>
<tbody>
<tr>
<td>plasma/blood volume estimation</td>
<td>$^{125}$I, $^{131}$I</td>
</tr>
<tr>
<td>red blood cell life and mass estimation</td>
<td>$^{51}$Cr</td>
</tr>
<tr>
<td>thyroid function</td>
<td>$^{123}$I, $^{131}$I</td>
</tr>
<tr>
<td>cardiac blood pool imaging</td>
<td>$^{99m}$Tc</td>
</tr>
<tr>
<td>brain, liver, kidney, spleen, gallbladder imaging</td>
<td>$^{99m}$Tc</td>
</tr>
<tr>
<td>lung perfusion scan</td>
<td>$^{99m}$Tc</td>
</tr>
<tr>
<td>lung ventilation scan</td>
<td>$^{133}$Xe</td>
</tr>
<tr>
<td>thyroid therapy</td>
<td>$^{131}$I</td>
</tr>
<tr>
<td>bone imaging</td>
<td>$^{99m}$Tc</td>
</tr>
</tbody>
</table>

source: Bronzino, *Biomedical Engineering and Instrumentation*, PWS
Geiger Counter

particle ionizes gas, get current, I
not sensitive enough for biomedical use

anode cathode

air, He, or Ar-filled tube

R

V

+ -

i
Photomultiplier Tube

secondary emission at dynodes produces up to 1 µA ar $R_L$

-1000 V
Scintillation Counter

- $\gamma$-ray
- Pb collimator
- NaI(Tl) (thallium activated sodium iodide) crystal
- light photon
- PM tube
- Pb shield
- amplifier
- pulse height analyzer
- recorder
Pulse Height Analyzer

looks at $\gamma$-ray spectrum

measure of radiation level is based on # counts within a specific energy window.
Anger (γ) Camera

- Patient
- γ-rays
- Parallel hole Pb collimator
- Na (Tl) crystal
- Pb shield
- PM tubes
- PHA/position computer
- CRT monitor
Anger Camera Principle

\[ \hat{x} = \frac{x_1 n_1 + x_2 n_2}{n_1 + n_2} \]
Each $\gamma$-ray event produces a spot on the monitor at location $(\hat{x}, \hat{y})$ provided $\sum n_i$ exceeds a given threshold.

$$\hat{x} = \frac{\sum x_i n_i}{\sum n_i}$$

$$\hat{y} = \frac{\sum y_i n_i}{\sum n_i}$$

$(x_i, y_i)$: center location of $i^{th}$ PMT
Pinhole Imaging System

\[ I(x_d, y_d) = KS \left( \frac{x_d}{M}, \frac{y_d}{M} \right) \]

for infinitesimally small pinhole:

\[ K = 0 \quad M = -\frac{d}{z} \]

planar (flat) source
Aperture Imaging System

pinhole replaced by aperture \( a(x, y) \)

planar (flat) source

\[ s(x, y) \]

\[ I(x_d, y_d) \]

\[ d \]

\[ x \]

\[ y \]

\[ z \]
Aperture Imaging System

System impulse response

Point photon source, $\delta(x,y,z)$

$h(x,y,x_d, y_d)$
Aperture Imager Impulse Response

\[ h(x, y, x_d, y_d) = \frac{\cos^3 \theta}{4\pi(z + d)^2} a\left(\frac{x_d - Mx}{m}, \frac{y_d - My}{m}\right) \]

\[ m = \frac{z + d}{z} = 1 - M \]

Intensity drops off as \( \cos^3 \theta \), ignoring this term gives a 2-D convolution integral:

\[ I(x_d, y_d) = \frac{1}{4\pi(z + d)^2} \int \int S(x, y) a\left(\frac{x_d - Mx}{m}, \frac{y_d - My}{m}\right) dxdy \]
Aperture Imager Response

- $I(x_d, y_d)$ is a blurred version of $S(x, y)$
- blurring function:
  $$a\left(\frac{x_d}{m}, \frac{y_d}{m}\right)$$
- as aperture approaches an infinitesimally small pinhole, $\delta(x,y)$, we get a pinhole imager.
- image still undergoes magnification of $M$. 
Problems with Pinhole Collimators

- image magnification depends on distance between collimator and source (labeled organ or tumor).
- don’t know if it’s a nearby small tumor or a distant large tumor, i.e. get no range (z) information.
- pinhole collimators are typically used for organs positioned close to the surface like the thyroid gland.
Parallel Hole Collimator

regular grid of holes \((a(x,y))\) separated by distance \(w\)

\[
\begin{align*}
D & \quad a(x,y) \\
\text{Pb} & \quad w \\
& \quad d \\
& \quad L
\end{align*}
\]
Point Source Response of Thickness-L Collimator Hole

\[
ad\left(\frac{x_d - M_1x}{m_1}, \frac{y_d - M_1y}{m_1}\right)
\]

Detector plane

\[
a\left(\frac{x_d - M_2x}{m_2}, \frac{y_d - M_2y}{m_2}\right)
\]

Point photon source \((x, y, z)\)
Point Source Response of Thickness-L Collimator Hole (cont.)

- Detector image is intersection of front and back-aperture projections:

\[
\left( \frac{x_d - M_1 x}{m_1}, \frac{y_d - M_1 y}{m_1} \right) \cap \left( \frac{x_d - M_2 x}{m_2}, \frac{y_d - M_2 y}{m_2} \right)
\]

\[
m_1 = \frac{z + L + d}{z + L}
\]

\[
m_2 = \frac{z + L + d}{z}
\]

\[
M_1 = -\frac{d}{z + L}
\]

\[
M_2 = -\frac{d + L}{z}
\]