Monte Carlo simulation of the Compton Camera for Nuclear Medical Imaging

CHIBUEZE UCHE PhD
Nuclear Medicine Imaging System – Gamma camera
Gamma camera head

- Bulky
- Low detection efficiency – typical 0.01% (1 in 10000 photons detected)
- Trade-off between detection efficiency and resolution
- Allows mostly low energy radiotracers e.g. $^{99}$Tc $\approx$ 140 keV
Compton camera

Source

$\gamma$

Collimators

Detector
(Absorber)

Gamma camera

Compton camera

Source

$\theta$

$\gamma$

Scatterer

e-$

$\gamma'$

Absorber
Compton scattering (what you were taught)

\[ E_A = \frac{E_0}{1 + E_0 \left(1 - \cos \theta \right) / mc^2} \]
Compton scattering (what really happens)

incident photon

Electron NOT at rest

scattered photon

'electron momentum' \( p_z \)

\[
p_z = -mc \frac{E_0 - E_A - E_0 E_A (1 - \cos \theta) / mc^2}{\sqrt{E_0^2 + E_A^2 - 2E_0 E_A \cos \theta}}
\]
Doppler Broadening

So incident photon can be scattered over a range of angles, NOT a specific angle.
How Doppler broadening affects the electron energy spectrum at $\theta = 90^\circ$
Image degradation (FWHM) due to Doppler broadening for the selected materials

<table>
<thead>
<tr>
<th></th>
<th>Silicon (Si)</th>
<th>Germanium (Ge)</th>
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<tbody>
<tr>
<td>Point Source</td>
<td>0.58 mm</td>
<td>140 keV</td>
</tr>
<tr>
<td></td>
<td>7.3 mm</td>
<td>12.3 mm</td>
</tr>
<tr>
<td></td>
<td>2.4 mm</td>
<td>511 keV</td>
</tr>
<tr>
<td></td>
<td>4.3 mm</td>
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</tbody>
</table>
Theoretical efficiencies with respect to Compton scattering for selected materials

- Si
- NaI(Tl)
- CZT
- Ge

Compton scattering probability

Compton to total attenuation ratio vs. Gamma ray energy (MeV)
Efficiency evaluation of the two detectors across experimental thickness at 140.5 keV

![Graph showing detection efficiency for Ge and Si for coincident single and multiple interactions.](image-url)
Preliminary findings

Si may be a better scatter detector (scatterer) than Ge

- Less Doppler broadening – improve image resolution
- More Compton scattering – more detection efficient.
Pre-clinical evaluations

To test the viability of Compton camera for breast and brain imaging

Targeted imaging scenarios

✓ Breast imaging (tumors near chest wall)
✓ Brain imaging (multitracer technique)

Approach – **GEANT4 simulation software**

✓ it offers the flexibility of understanding steps of the imaging process and identifies changes that have impact on imaging systems.
Diagram illustrating the imaging of two spherical 5mm diameter breast tumours in craniocaudal view with a dual-head Compton camera.
Challenging imaging scenarios for breast lesions (5 mm) located close to the chest wall for $^{18}$F (511 keV)

TRU = tumour-to-tissue radiation uptake
SNR = signal-to-noise ratio
Diagram illustrating the imaging of two spherical brain tumours of 5mm diameter filled with $^{113m}$In and $^{18}$F radiotracers
The reconstructed images of the brain lesions (5 mm) filled with $^{18}$F (left) and $^{113m}$In (right) radiotracers.

(a) Lesions placed at their initial position (10 cm from the camera).
(b) The $^{113m}$In radiotracer was moved backwards by 1 cm and (c) 2 cm.
(d) The $^{18}$F radiotracer was moved backwards by 1 cm and (e) 2 cm.
Conclusion

The Compton camera shows promise for breast and brain imaging in that spherical tumours of 5mm diameter were modelled as being clearly visualised.