Imaging $\gamma$-ray’s at the NIF

CEA-DOE Diagnostics Workshop

29-30 June 2016, LLE, Univ. of Rochester, Rochester, NY
Summary

- NIF plans to implement imaging of gammas along the (90,315) line-of-sight in FY-17.

- Gammas from $^{12}\text{C}$ (n,n’g) reactions provide quantitative information on the distribution of carbon in layered implosions using CH and HDC ablator materials.

- Scoping activities have taken place and initial indications are that imaging carbon is viable on layered shots with DT yields in the low $10^{15}$’s.

- A concept for implementation is almost complete and implementation will principally involve reconfiguring the NI camera table by adding a gamma scintillator and extra imaging channels.
γ-ray imaging uses neutrons from the source to probe the carbon ablator. This complements the primary and down-scattered neutron data.
\(\gamma\)-ray images should be larger than the down-scattered image.

- **Primary NI**
- **Scattered NI**
- **Gamma Image**

Simulated images

Courtesy: Charlie Cerjan
Symmetric dipole excitation — equal emission in the forward and backward directions.

The full shell assembly will contribute to the image, unlike in downscattered images.
Penumbral apertures are needed at current yields...

- For 26 cm TCC pinholes at least 5 are needed for decent images at $10^{15}$ neutrons. Even worse as pinhole is moved away from TCC.
- Penumbras are needed to improve SNR

\[
\text{Number of Pinholes} \quad \begin{array}{c}
10^0 \\
10^1 \\
10^2 \\
10^3
\end{array}
\]

\[
\text{SNR} \quad \begin{array}{c}
10^0 \\
10^1 \\
10^2 \\
10^3
\end{array}
\]

Penumble Throughput *
Source to Pinhole = 0.26 m
Pinhole to Detector = 28 m

\[
10^{14} \text{ neutrons} \\
10^{16} \text{ neutrons} \\
10^{18} \text{ neutrons}
\]
To ensure DQE, pixelated LYSO was selected* as the converter...

<table>
<thead>
<tr>
<th>Scintillator</th>
<th>Formula</th>
<th>Density (g/cm³)</th>
<th>Light Yield (ph/Mev)</th>
<th>Decays (ns)</th>
<th>Emission Max (nm)</th>
<th>Refractive Index</th>
<th>Atten. @ 4.44MeV (cm³)</th>
<th>%Int of 4.44MeV in 2cm</th>
<th>Light Yield</th>
<th>In 100ns (ph/MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGO</td>
<td>Bi₄Ge₃O₁₂</td>
<td>7.13</td>
<td>8,200</td>
<td>300</td>
<td>480</td>
<td>2.15</td>
<td>0.276</td>
<td>42</td>
<td>2,300</td>
<td></td>
</tr>
<tr>
<td>LSO</td>
<td>Lu₂SiO₅:Ce</td>
<td>7.4</td>
<td>27,000</td>
<td>40</td>
<td>420</td>
<td>1.82</td>
<td>0.278</td>
<td>43</td>
<td>24,900</td>
<td></td>
</tr>
<tr>
<td>YSO</td>
<td>Y₂SiO₅:Ce</td>
<td>4.45</td>
<td>9,200</td>
<td>42</td>
<td>420</td>
<td>1.8</td>
<td>0.144</td>
<td>25</td>
<td>21,500</td>
<td></td>
</tr>
<tr>
<td>LYSO</td>
<td>Lu₁₄Y₀.₂SiO₅:Ce</td>
<td>7.11</td>
<td>32,000</td>
<td>41</td>
<td>420</td>
<td>1.81</td>
<td>0.264</td>
<td>41</td>
<td>29,200</td>
<td></td>
</tr>
</tbody>
</table>

**BGO**
- Slow Decay
- FWHM = 1.1 mm
- Low light Output

**YSO**
- Low Density
- FWHM = 1.7mm
- Low light output

**LYSO**
- Fast
- High light output
- FWHM = 1.2mm
- Lutetium decay negligible

*D. Lemieux, University of Arizona*
A proto-type was fielded* at Omega, collecting images of hot-e bremsstrahlung in CH implosions…

*D. Lemieux, Univ. of Arizona
Concept for upgrading the (90,315) camera table to allow $\gamma$-ray imaging...
At this point we are costing out the project and developing requirements

- Image Resolution — 10 µm
- FOV at Source—?
- Minimum Gate Width—10 ns
- Gate Rise Time—1 ns
- Gate Fall Time—1 ns
- # Frames—2?
Possible issues that still need to be addressed

- $\gamma$ production in the Au of the Hohlraum or NIS pinhole array
  - Some MCNP modeling may be useful.

- Possible need for new pinhole array
  - Either for reconstruction, field of view, etc.
Images of gammas were first collected in 2015 using sub-scale Symcaps and the NIF NI system.

13-17 MeV neutron image

Image gated ±38 ns around $\gamma$ flight time

Image strength challenged reconstruction, but demonstrated viability…
Possible sources of the radiation include

1. $^{12}\text{C}(n,n')^{12}\text{C}^* - 4.4 \text{ MeV}$. – Primary signal

2. $\text{T+D} \rightarrow ^5\text{He}^* - 16.7 \text{ MeV} – 100 \times$ weaker

3. $(n,n'_\gamma) – 1 - 2 \text{ MeV}?$ – Background scattering sources
   1. Within penumbral images:
      1. TMP, Blast shield, aperture walls
   2. Outside penumbral images:
      1. NIS blast shield, snout etc...

4. Hot-electron bremsstrahlung in TMP and CH shell $< 1$ MeV
   1. Likely very weak.

*All, but source 1 seems unlikely to contribute much signal in the penumbral regions.*
First gamma image from a layered CH implosion N160602...

Camera 1: 6-12 MeV

Camera 2: $\gamma$-image

Au-lined DU hohl (sc672), T-1 (175 um) CH capsule
0.6 mg/cc 4He hohlraum fill
3-shock high-foot drive, 1.54 MJ, 425 TW

$Y$ (13-15) : 1.65e+15
$T_{\text{ion}}$: 3.45 keV
dsr: 3.9%
Position: (52, -163)
Size @17%: (278,217)
P0 = 129
P2/P0 = -16%

EMML, stop @ $\Delta \chi^2/\chi^2 < 10^{-4}$
Abel inversion:

\[ f(\rho, \phi, z) = S_{left}(\rho, z) \frac{1 - \sin \phi}{2} + S_{right}(\rho, z) \frac{1 + \sin \phi}{2} \]
N160602: 3D rendering of reconstructed gamma source
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The scattering is more strongly directed forward and backward.

Fig. 4. Differential cross section for production of 4.43-MeV gamma rays by 14.1-MeV neutrons.

Images will receive contributions from the entire shell!

Interpreting the images will depend on our understanding of the \((n,n'\gamma)\) scattering.

- **Reaction**

\[ ^{12}\text{C}(n,n')^{12}\text{C}^* \rightarrow ^{12}\text{C} + \gamma(4.43 \text{ MeV}) \]

- **Angular Distribution Fit Function (}\theta\text{ wrt neutron direction)}\)**

\[ \sigma(\theta) = (13.3 \pm 0.6) + (40.0 \pm 4.7)\cos^2 \theta - (34.1 \pm 5.1)\cos^4 \theta \text{ in mb/sr} \]

- **Integrated Cross-section**

\[ \sigma_{n,n'\gamma}(4.43 \text{ MeV}) = 249\pm28 \text{ mb} \]

We are looking at upgrading the existing NIS to allow $\gamma$-ray imaging without sacrificing images.

$\text{n: 13-15 MeV} \quad \text{n: 6-12 MeV}$
Can the different image regions inform the spectrum?

C2 Scattered

C2 Image - 341 μm pixel

C2 Background

Signal Histogram

C2 Penumbral

Image Plane Position (mm)

Number/bin

penumbra
background scattered

ADU