A Neutron Temporal Diagnostic for High-Performance DT Cryo Implosions on OMEGA

C. Stoeckl
University of Rochester
Laboratory for Laser Energetics

NIF Diagnostic Workshop
Los Alamos National Laboratory
6–8 October 2015
A new neutron temporal diagnostic (NTD) has been built for high-yield DT cryo implosions on OMEGA

- The neutron background and the large scintillator standoff (20 cm) required to clear the cryo shroud severely limits the quality of the data on the previous NTD system on high-performance DT cryo implosions.
- The cyroNTD diagnostic was installed in port P11 close to the equator of the target chamber, allowing the scintillator to be inserted to 9 cm.
- The ROSS streak camera for the cyroNTD is located in the OMEGA EP plenum for >100× improvement in the neutron shielding.
- A ~16-m-long relay system was designed to transport the light from the scintillator to the photocathode with <20-ps group velocity dispersion.
- With the standard 3-ns sweep window, the system has a measured impulse response of 40±10 ps, which allows a 70-ps neutron pulse to be measured with 10% accuracy.
- Preliminary measurements with the 1.5-ns sweep window show an impulse response of 25±10 ps, which allows a 50-ps neutron pulse to be measured with 10% accuracy.
The P11-NTD delivers the instrument performance required to support the current and future LLE cryogenic campaign.

### Performance metrics

<table>
<thead>
<tr>
<th>Performance metric</th>
<th>Performance status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum burnwidth</td>
<td>50 ps</td>
</tr>
<tr>
<td>Bang-time measurement accuracy</td>
<td>±50 ps</td>
</tr>
<tr>
<td>Detectable DD neutron-yield range</td>
<td>$5 \times 10^9$ to $1 \times 10^{13}$</td>
</tr>
<tr>
<td>Detectable DT neutron-yield range</td>
<td>$5 \times 10^{10}$ to $1 \times 10^{15}$</td>
</tr>
</tbody>
</table>
The P11-NTD provides superior data quality on high-yield implosions compared to previous NTD diagnostics.

<table>
<thead>
<tr>
<th></th>
<th>LLNL H5-NTD</th>
<th>LLE H5-NTD</th>
<th>LLE P11-NTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryo shot 69515</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DT yield:</td>
<td>2.95 × 10^{13}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryo shot 76358</td>
<td></td>
<td>2.61 × 10^{13}</td>
<td></td>
</tr>
<tr>
<td>DT yield:</td>
<td></td>
<td></td>
<td>2.61 × 10^{13}</td>
</tr>
</tbody>
</table>
The P11-NTD leverages the power of the ROSS streak-camera platform to provide a well-characterized camera response.

Sweep-time base calibration

- Grid point array
- On-shot 2-GHz comb
- Dwell time plot

Camera bandwidth characterization

- Static line spread function
- Cathode image focus time axis

<table>
<thead>
<tr>
<th>Sweep speed (ns)</th>
<th>Temporal resolution (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>3 (nominal)</td>
<td>15</td>
</tr>
<tr>
<td>1.5</td>
<td>7</td>
</tr>
</tbody>
</table>

Time base corrected with 1% accuracy

15-ps on-shot camera resolution
The impulse response of P11-NTD was measured using short laser pulses (10 ps) from OMEGA EP on an Au foil.

- The high-intensity (>\(10^{17}\) W/cm\(^2\)) laser pulse generates hard x rays with energies >200 keV.
- These x rays penetrate through the heviment shielded nose cone and generate light similar to the high-energy neutrons.
- The temporal width of the x-ray pulse is of the order of the width of the laser pulse.
With the standard 3-ns sweep window, P11-NTD has a measured impulse response of $40 \pm 10$ ps.

- Using an intrinsic width of the x-ray signal, $25 \pm 10$ ps, the measured width of $\sim 50$ ps deconvolves to an impulse response of $40 \pm 10$ ps.

- The absolute timing of P11-NTD is calibrated against NTD with an accuracy of $\sim 50$ ps.

*FWHM: full width at half maximum*
Preliminary measurements with a 1.5-ns sweep window show a shorter impulse response of $25\pm10$ ps

- Using an intrinsic width of the x-ray signal, $25\pm10$ ps, the measured width of $35\pm5$ ps deconvolves to an impulse response of $25\pm10$ ps
The new neutron temporal diagnostic provides an accurate measurement of the neutron production rate.

The NTD measurements show an earlier peak and burn truncation for the current cryo implosions.
It is conceptually quite simple to transfer the P11-NTD design for implementation on the NIF

- The $\sim 10^4 \times$ larger yields on the NIF will require significantly more shielding
  - An additional 1 m of concrete or equivalent compared to P11-NTD is probably necessary

- An $\sim 20$-m-long optical relay system could transport the light outside the 2-m-thick bio-shield

- With a typical neutron production width of $\sim 150$ ps for sub-ignition experiments on the NIF, the time-resolution requirements would be relaxed compared to OMEGA

- The impulse response of a NIF-NTD could be calibrated in-situ using the NIF/ARC short-pulse capability

- A project has been established in Prof. Petrasso’s group at MIT to evaluate designs for a NTD on the NIF (Brandon Lahmann, Ph.D. student)

- A NTD-like setup is being installed on LLE’s short-pulse Multi-Terawatt (MTW) Laser System, which can be used to qualify new scintillator materials and calibration strategies
The OMEGA Target Bay section includes the scintillator-transport mechanism, zoom-optics assembly, and image-relay hardware.
The scintillator is placed inside a telescoping mechanism re-entrant into the target chamber
The final image relay section includes focusing optics, a remote-controlled filter wheel, and the ROSS streak camera.