The National Ignition Facility Neutron Time-of-Flight System and its Initial Performance

1 MJ shot N091204

High quality n recording: 2 shots with different bang time and Ti

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The NIF nTOF system was developed by large international team of scientists and engineers


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The NIF neutron time-of-flight detector (nTOF) system performed to specification during the first yield campaign on the NIF last fall

- The NIF nTOF system was designed to measure neutron yield, ion temperature, bang time and downscattered neutron fraction to infer $\rho R$ of implosion
- OMEGA absolute yield calibration will be transferred to the NIF ($\pm 5\%$ DT and $\pm 10\%$ $D_2$)
- The first detectors of the NIF nTOF system successfully operated on the NIF in August through December 2009 with 100% effectiveness

This talk will focus on full nTOF system design and initial performance on the NIF.
The specifications on the NIF nTOF diagnostic exceed what has been done in the past (NOVA/OMEGA)

- Yield: 7%–10% for D$_2$/DT from $10^9$ (D$_2$) to $10^{19}$ (DT)
- Ion temperature: 3%–5% for THD/DT from $10^{11}$ to $10^{19}$
- n bang time: $\leq 30$ ps for THD/DT from $10^{12}$ to $10^{16}$ (GRH up to ignition)
- $\rho R$ fuel: $\leq 10\%$ for THD/DT from $10^{12}$ to $10^{16}$ (MRS up to ignition)

D$_2$ yield and ion temperature were measured last fall.
The nTOF system consists of eight detectors with 18 channels based on three different techniques:

- Plastic scintillator (BC-422 or BC-422Q) coupled with gated PMT or photodiode.
- Oxygen saturated liquid scintillator with gated PMT.*
- Detectors based on chemical vapor deposition (CVD) diamonds.

*See C. Stoeckl poster, B09
Approximately half of the NIF nTOF suite will be located at 4 diagnostic wells at 4.5 m from TCC
The locations of the ignition and spectroscopic nTOF detectors will be outside the Target Bay shield wall.
The calibration of the NIF nTOF detectors at 4.5 m on OMEGA is complete.
The nTOF4.5-BT consists of 3 CVD diamond detectors of different sizes and sensitivity in a lead shielding.

Even though the impulse response is hundreds of picoseconds, the bang time can be determined to within a few tens of picoseconds.
Tests of CVD diamonds at 4.5 m on OMEGA demonstrated with 10 ps timing accuracy

Additional experiments have shown that the temporal calibration technique used on OMEGA (100-ps x-ray pulses from a gold-coated sphere) will work at the NIF.

The bang time precision is given by \[ \frac{\Delta t}{\sqrt{\text{n's}}} \Rightarrow \sim 30 \text{ ps for THD yields} \]

See R. A. Lerche, talk A02
Design and manufacturing of NIF nTOF20-IgnLo and nTOF20-IgnHi detectors is completed

4× PMT’s mounted around the scintillator comprises nTOF20-IgnLo

BC422 scintillator

4× CVD detectors mounted on the back of the IgnLo housing comprises IgnHi

For yields <10^{16}, the IgnHi detector mount plate is swapped for one that mounts two CVD’s

Filter glass
Three CVD diamonds of the nTOF4.5-BT detector will cover the yield range from $10^{12}$ to $10^{16}$. 

![Graph showing signal integral vs. NIF-equivalent neutron yield with different symbols for CVD 5 x 0.25, CVD 10 x 1, and CVD 16.5 x 1. The expected saturation limit is indicated by a red line.](image-url)
Five nTOF detectors will measure DT yield in the NIF THD/DT campaign with precision better than 4%.

Monte-Carlo simulation of both OMEGA and NIF is needed for absolute yield value.
The nTOF20-IgnLo will measure ion temperature in THD/DT campaign with better than 5% precision

Monte-Carlo simulation of both OMEGA and NIF is needed for absolute $T_i$.
The NIF nTOF system will infer the $\rho R$ by measuring “down-scattered fraction” (DSF)

The conceptual design of DSF measurement

The most challenging task for NIF nTOF is that it has never been done before.
A new liquid scintillator without a long decay component is being tested for nTOF20-Spec ($\rho R$ from the DSF)

$O_2$ saturation quenches the long decay component by a factor of $\sim 100\times$ for the relevant n time-of-flights.

See C. Stoeckl poster, B09
A new liquid scintillator without a long decay component is being tested for nTOF20-Spec ($\rho R$ from the DSF) (continued)

A comparison of the x-ray response from 10 ps, 1 kJ in gold cone-in-shell targets

This is the first measurement of neutron yield from OMEGA fast ignition targets!

*See C. Stoeckl poster, B09
The design and manufacturing of the three nTOF20-Spec detectors is completed.

- Design can accommodate an expansion chamber
- Mounting holes on back of PMT mount similar to nTOF20-IgnLo
- Two nTOF20-Spec for NIF
- One nTOF20-Spec for OMEGA
- Off the shelf metal bellows
- Fused silica windows
- Photek PMT 240 Gain E6
- Filter glass
- 6-in./4-in.-diam × 2-in.-thick Al or stainless steel cavity filled with Xylene

nTOF20-Spec requires extensive calibration in DT and D₂ implosions.
The first NIF nTOF detectors were successfully installed and operated in August to December 2009

08/29/09 – Hard x-ray flash was recorded by the first nTOF4.5 detector
09/04/09 – First NIF neutrons were produced and recorded
10/05/09 – Second nTOF4.5 detector became operational
11/07/09 – Third, less sensitive nTOF detector installed (nTOF4.5-DTLo)
11/16/09 – Hard x-ray flash gating was implemented

• More than 40 NIF shots were recorded with 100% effectiveness
• Two nominally identical nTOF detectors allow the yield and ion temperature precision to be determined
“Energetics” implosion with doped (7%/10%) D₂ in ⁴He or ³He capsule fills gave high quality data at 4.5 m

- Low D₂ fraction to keep n yields ~10^{10}

<table>
<thead>
<tr>
<th>γ’s and n’s from 1 MJ shot</th>
<th>High quality n recording: 2 shots</th>
</tr>
</thead>
</table>

- nTOF measures: (1) Yield, (2) \( T_{ion} \) width, (3) \( t_{bang} \) time arrival time with allowance for neutron effects and (4) MeV electron from γ flash

Two shots with different bang time and Ti?
The leading edge of the NTOF signal is sensitive to bang time and ion temperature

- Detector response function—n scattering, scintillator, PMT, cable response

Ion temperature measurements to ~100 eV at 2 to 3 keV demonstrated.
PMT gating is necessary to eliminate the strong hard x-ray flash from gas-filled hohlraums on the NIF.

 Gate is necessary in order not to saturate PMT.
The $D_2$ yield and ion temperature were measured with better than 5% precision in the range from $8 \times 10^8$ to $2 \times 10^{10}$.

Since scattering effects are different on OMEGA and the NIF, a careful Monte Carlo simulation of both facilities is required for absolute yield and $T_i$.*

*See R. A. Lerche, talk A02
Comparison with 2-D calculations show a reasonable agreement in $T_i$
The NIF nTOF yields were corroborated by Indium activation and CR39 measurements on the NIF.
Summary/Conclusions

The NIF neutron time-of-flight detector (nTOF) system performed to specification during the first yield campaign on the NIF last fall

- The NIF nTOF system was designed to measure neutron yield, ion temperature, bang time and downscattered neutron fraction to infer $\rho R$ of implosion
- OMEGA absolute yield calibration will be transferred to the NIF ($\pm 5\%$ DT and $\pm 10\%$ $D_2$)
- The first detectors of the NIF nTOF system successfully operated on the NIF in August through December 2009 with 100% effectiveness
The neutron time-of-flight (nTOF) technique has been used to infer yield and ion temperature for decades. The bang time, yield, $T_{\text{ion}}$, and $\rho R$ can be inferred from the nTOF spectrum. The time of flight, $\Delta t$, can be calculated as:

$$\Delta t = 122 \times d \times \sqrt{T_{\text{ion}}}$$

$T_{\text{ion}}$ to 3% accuracy at 4.8 keV implies $\Delta t$ accuracy to 360 ps at 4.5-m-high bandwidth, well characterized response and minimal background.
The only way to infer the $\rho R$ on the NIF in 2010 will be the primary neutrons “downscattered fraction”

The NIF will use Tritium:Hydrogen:Deuterium (75:23:2) fuel (THD) for the at-scale parameters tuning of ICF implosions

Much of our recent effort has focused on how to measure the “down-scatter fraction” using nTOF techniques—we are testing a solution now!
The nTOF4.5-D$_2$ was used for neutron bang time measurement, although it was not designed for it.

nTOF bang time is $0.6 \pm 0.3$ ns later than GXD—needs to be resolved.
The nTOF system for the NIF consists of different detectors located at distances from 4.5 m to 22 m

NIF nTOF Detectors Summary Table

<table>
<thead>
<tr>
<th>#</th>
<th>Detector</th>
<th>Site</th>
<th>Scintillator-CVD</th>
<th>PMT</th>
<th>Campaign</th>
<th>Yield range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>nTOF4.5-BT, 3-Chan</td>
<td>DW#1</td>
<td>CVD Set</td>
<td>na</td>
<td>DT, THD</td>
<td>$10^{12}$ to $10^{16}$</td>
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<tr>
<td>2</td>
<td>nTOF4.5-D2</td>
<td>DW#2</td>
<td>BC-422, 40 × 20 mm</td>
<td>PMT140, 1 × 10³</td>
<td>D₂</td>
<td>$10^9$ to $10^{11}$</td>
</tr>
<tr>
<td>3</td>
<td>nTOF4.5-DTLo</td>
<td>DW#3</td>
<td>BC-422Q, 40 × 10 mm</td>
<td>PMT140, 1 × 10³, PMT140, 1 × 10²</td>
<td>D₂, THD</td>
<td>$10^{10}$ to $5 × 10^{12}$, $10^{11}$ to $5 × 10^{13}$</td>
</tr>
<tr>
<td>4</td>
<td>nTOF4.5-DTHi</td>
<td>DW#4</td>
<td>BC-422, 40 × 10 mm</td>
<td>PD040, 1</td>
<td>DT, THD</td>
<td>$5 × 10^{12}$ to $10^{15}$</td>
</tr>
<tr>
<td>5</td>
<td>nTOF20-IgnLo, 4-Chan</td>
<td>Alcove</td>
<td>BC-422, 40 × 20 mm</td>
<td>PMTs + PD</td>
<td>Ignition</td>
<td>$10^{12}$ to $2 × 10^{19}$</td>
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<tr>
<td>6</td>
<td>nTOF20-IgnHi, 4-Chan</td>
<td>Alcove</td>
<td>CVD Set</td>
<td>na</td>
<td>Ignition</td>
<td>$10^{13}$ to $2 × 10^{19}$</td>
</tr>
<tr>
<td>7</td>
<td>nTOF20-Spec, 2-Chan</td>
<td>Alcove</td>
<td>Liquid scintillator</td>
<td>PMT140, 1 × 10³, PMT240, 1 × 10⁶</td>
<td>DT, THD</td>
<td>$10^{12}$ to $10^{16}$</td>
</tr>
<tr>
<td>8</td>
<td>nTOF20-Spec, 2-Chan</td>
<td>Equatorial</td>
<td>Liquid scintillator</td>
<td>PMT140, 1 × 10³, PMT240, 1 × 10⁶</td>
<td>DT, THD</td>
<td>$10^{12}$ to $10^{16}$</td>
</tr>
</tbody>
</table>
The NIF nTOF4.5-D₂, nTOF4.5-DTLo, and nTOF4.5-DTHi detectors were calibrated on OMEGA at 5.2 m from TCC.

**nTOF4.5-D₂**
- Scintillator: BC422, 40-mm diam., 20-mm thick
- PMT: Photek PMT240, gain = $3 \times 10^4$, HV = $-3.9$ kV
- Distance: 5.2 m from TCC
- Cable: 113 ft LMR400 + 11 ft RG142 + 3 m LMR195
- Scope: Tektronix DPO 7104, 1 GHZ, 10 GS/s

All detectors use the same hardware on OMEGA and the NIF.