OMEGA shot rate allows innovative diagnostics and targets to be developed, opening new areas of science

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Scientific Leader
NIF Diagnostics.
OLAG, April 28, 2010
NIF opens new windows in HED science

As well an important role for OMEGA is to develop techniques / diagnostics for NIF.
Advances in High Energy Density Physics Require:

Drivers

Given a driver innovation in targets and diagnostics drive new science
The HED diagnostic effort on NIF is international

LLNL
- FABS,NBI
- Dante I & II
- Visar
- SXD
- HEXRI
- RadChem1
- hGXI
- ARIANE
- DIXI

NSTec
- Calibration

LBNL
- Calibration
- Rad. Chem.

LLLE
- NToF
- 4\omega fidu system
- MRS, NADS
- SPBT

LLE
- NToF
- 4\omega fidu system
- MRS, NADS
- SPBT

AWE
- FFLEX

LANL
- GXD
- \gamma burn
- Rad. Chem. II
- n imaging

MIT
- MRS
- WRF

CDE
- N imaging

We also work with MFE- High Temperature Plasma Diagnostic Conference, Wildwood NJ, May 16-20
Most of the NIF diagnostics were developed on Nova or OMEGA

- Laser IPT
  - 4 target chamber diagnostics

- Energetics IPT
  - 9 diagnostics
  - Energetics diagnostics, NEL-recommissioned

- Capsule IPT
  - 4 diagnostics
  - Capsule diagnostics, developed on OMEGA, used NEL

- Ignition IPT
  - 19 diagnostics
  - UGT experience, development on OMEGA
Installing 39 NIF Diagnostics up to 2011, most of them developed/tested on OMEGA

<table>
<thead>
<tr>
<th>Diagnostic</th>
<th>Acronym</th>
<th>Purpose and Function</th>
<th>Works</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static x-ray imager</td>
<td>SXI (upper)</td>
<td>Provides time integrated images of low energy (3-7 keV) x-ray emission and is used to survey hohlraum experiments and pointing of laser beams</td>
<td>2009</td>
</tr>
<tr>
<td></td>
<td>SXI (lower)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streaked X-ray Detectors</td>
<td>SXD1</td>
<td>Measures with continuous time resolution x-ray emission from the targets and used to synchronize the arrival time of laser beams on targets</td>
<td>2009</td>
</tr>
<tr>
<td></td>
<td>SXD2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broad-band, time-resolved x-ray spectrometer</td>
<td>DANTE 1</td>
<td>Measures the soft x-ray flux vs time and primarily used to determine the radiation temperature in the hohlraum</td>
<td>2009</td>
</tr>
<tr>
<td></td>
<td>DANTE 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Aperture Backscatter Station</td>
<td>FABS 31B-in</td>
<td>Light backscattering stations that measure the angular, temporal and spectrally resolved light backscattered into the focus lenses. One quad of beams on the inner cone 31B and one quad on the outer cone 36B</td>
<td>2009</td>
</tr>
<tr>
<td></td>
<td>FABS 36B-out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near Backscatter Imager</td>
<td>NBI 31B-in</td>
<td>Light backscattering stations that measure the angular, temporal and spectrally resolved light backscattered near the focus lenses. One quad of beams on the inner cone 31B and one quad on the outer cone 36B</td>
<td>2009</td>
</tr>
<tr>
<td></td>
<td>NBI 36B-out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filter Fluorescer Diagnostic</td>
<td>FFLEX</td>
<td>Measures hard x-rays (10 keV to 400 keV) with time resolution on some channels from which the hot electron fraction can be inferred</td>
<td>2009</td>
</tr>
<tr>
<td>Time-Gated X-ray Detectors</td>
<td>GXD1</td>
<td>Images x-rays with time resolution of 60 micron at 100 MHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GXD2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomson Scattering</td>
<td>TS</td>
<td>4θ Thomson scattering, temperature</td>
<td></td>
</tr>
<tr>
<td>Velocity Interferometer For Any Reflector</td>
<td>VISAR</td>
<td>Measures the shock velocity in the NIC ignition pulse</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VISAR/SOP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VISAR Streaked Optical Pyrometer</td>
<td>VISAR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIM insertable Streak camera</td>
<td>DISC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4θ fiducial</td>
<td>4θ Fidu</td>
<td>4θ fiducial for x-ray streak</td>
<td></td>
</tr>
<tr>
<td>Neutron Recoil Spectrometer</td>
<td>MRS</td>
<td>Measures the absolute neutron spectrum between 6 and 30 MeV from which ion temperature, areal density (νr), and neutron yield can be directly inferred</td>
<td>2010</td>
</tr>
<tr>
<td>Neutron Imaging</td>
<td>NI</td>
<td>Measures static neutron images of primary (14 MeV) and downscattered neutrons from a burning DT capsule to assess hot spot size and fuel asymmetry and from the downscattered fraction, the cold fuel areal density (νr)</td>
<td>2011</td>
</tr>
<tr>
<td>Neutron Activation Detector</td>
<td>NAD</td>
<td>Measures the integrated neutron flux by activation of witness foils</td>
<td>2009</td>
</tr>
<tr>
<td>Advanced Radiographic Capability</td>
<td>ARC1</td>
<td>Advanced radiographic capability using ARC the short pulse laser to produce an x-ray backlighting source to radiographically image imploding capsule</td>
<td>2011</td>
</tr>
<tr>
<td>Radiochemical Diagnostic</td>
<td>RadChem-gas</td>
<td>Uses radiochemical separations and nuclear counting methods to measure neutron activation products produced from tracers embedded in the ablator shell of the target with gas sample collection</td>
<td>2011</td>
</tr>
<tr>
<td>Radiochemical Diagnostic</td>
<td>RadChem-solid</td>
<td>Uses nuclear reactions and nuclear counting methods to measure charged particle activation produced from tracers embedded in the ablator shell of the target with solid sample collection</td>
<td>2011</td>
</tr>
<tr>
<td>Dilation x-ray imager</td>
<td>DIXI</td>
<td>10 psec x-ray imager</td>
<td>2011</td>
</tr>
</tbody>
</table>

And there will be more
The technology for backlighting of laser plasmas takes time and shots to develop.

- **1990**: Nova backlighting starts.
- **First absorption spectroscopy on Nova**
- **2000**: OMEGA starts.
- **Z-Beamlet starts**
- **Point projection OMEGA**
- **Z-Beamlet**
- **1st NIF backlighting 11/09**

**Point projection backlighting with thermal x rays is not yet routinely used; hard x-ray backlighting will have new problems.**
Complex multi-target area back-lighter assemblies are routinely fielded on OMEGA.
A wide range of hydrodynamic experiments have been performed on OMEGA for both stockpile stewardship and astrophysics.

Instability at a spherically divergent interface

2D numerical simulation of supernova SN1987A

Coupled instability at multiple interfaces

2D vs. 3D instability

Multi-mode instability

Muller, Fryxell, and Arnett, Astron. Astrophys. 251 (1991)

Radiographic images from recent experiments on Omega studying mixing in supernova explosions
Possible because of technique development with OMEGA shots
The first university experiments at NIF have been conducted (C. Kuranz et al., University of Michigan)

**Backlighter development**
October 27, 2009

Signal (Volts)

<table>
<thead>
<tr>
<th>Time (ns)</th>
<th>Ch 18</th>
<th>Ch 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>10</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>15</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

5.2 keV He-like V

**Drive development**
November 24, 2009

Radiation Temperature (eV)

<table>
<thead>
<tr>
<th>Time (ns)</th>
<th>Trad (eV)</th>
<th>Flux (GW/sr)</th>
<th>Mband flux (GW/sr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>350</td>
<td>18000</td>
<td>2000</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>15000</td>
<td>1500</td>
</tr>
<tr>
<td>4</td>
<td>250</td>
<td>10000</td>
<td>1000</td>
</tr>
<tr>
<td>6</td>
<td>200</td>
<td>5000</td>
<td>500</td>
</tr>
</tbody>
</table>

Conversion efficiency of ~0.4% measured in both channels—agrees with expectation

Highest drive ever measured in gas-filled hohlraum
The serpentine geometry allows a 14-frame sequence of images of an imploding capsule to be recorded over about 700 ps.
On Nova gated x-ray imaging demonstrated control of symmetry by changing beam pointing.
The NIF Gated X-ray Detectors (GXD) are smart versions of detectors developed on OMEGA and Nova.

- CCD Power Supply
- Embedded Computer
- MCP Pulser Electronics
- MCP Module
- CCD Camera

200μs

70 ps duration images

To + 11.9 ns
12.25 ns
12.60 ns
12.95 ns

P0 = 100 μm
P2/P0 = 0.089+/-.008
P4/P0 = 0.037+/-.010
We have successfully commissioned ignition-scale hohlraums at 290eV

Drive needed for ignition

Data from Dec 4th, 2009
1.05 MJ implosion

LPI low enough to meet drive and symmetry req.

Tunable Symmetry

We are ready to commission the capsule
NIF gated x-ray imagers allow drive symmetry to be tuned by measuring the shape of the imploded targets.

Core shape:
Gated x-ray imager

Oblate
\(P_2 = -0.6, P_4 = 0.4\)

Less oblate
\(P_2 = -0.36, P_4 = 0.14\) to

~Round
\(P_2 = -0.04, P_4 = 0.13\)

Success of GXD due to OMEGA development
First NIF backlit in-flight capsule experiment was performed on Scale 4.6 mm, 660 kJ hohlraum drive

- 4.6 mm Hohlraum + Backlighter
  - 134 μm-thick CH(Ge) capsule
  - Cu foil for x-ray backlighter
  - Diamond-tamped slot for x-ray access

- Compilation of 1D-resolved 70 ps gated 8 keV radiographs
  - Shell limb
  - Fiducial
Simulations that match measured peak drive calculate 12% mass fraction vs 4% measured

Data versus post simulations that match measured peak drive to <7%

Shell CoM Radius vs. Time

Mass Remaining vs. Time

First backlit shell reached ignition design 380 μm/ns
The Wedge Range Filter (WRF) were used on NIF fall 2009 after major OMEGA/MIT development.

In NIF 2009 campaign, MIT students used their accelerator 16 hr/day for calibration.
Inferred $\rho r$ from energy downshift of the escaping $D^3He$ protons is also less than predicted.

\[ D + ^3He \rightarrow ^4He + p \ (14.7 \text{ MeV}) \]

<table>
<thead>
<tr>
<th>Yield (1e8/MeV)</th>
<th>Measured</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total $\langle \rho r \rangle \sim \Delta E$</td>
<td>$110 \pm 5 \text{ mg/cm}^2$</td>
<td>$260 \text{ mg/cm}^2$</td>
</tr>
<tr>
<td>Shock $\langle \rho r \rangle$</td>
<td>$41 \pm 5 \text{ mg/cm}^2$</td>
<td>$65 \text{ mg/cm}^2$</td>
</tr>
</tbody>
</table>

$\Delta E = 3.5 \text{ MeV}$ for Compression
$\Delta E = 1.3 \text{ MeV}$ for Shock
$\Delta E = 9 \text{ MeV}$
$\Delta E = 2.2 \text{ MeV}$

Similar trend for proton spectrum increases confidence in radiography result.
Next step is confirming sensitivity to initial capsule thickness as we did at OMEGA.
The NIF magnetic recoil was developed on OMEGA by MIT and LLE.
Summary

• Advances in HED requires innovative targets

• New diagnostics require a significant number of development shots

• OMEGA is playing a major role in development of NIF diagnostics
Diagnostics can be categorized by the attributes of the implosion they measure.

**Hot Spot**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{HS}$</td>
<td>4.5 keV</td>
<td>NTOF, hGXI</td>
</tr>
<tr>
<td>$\rho R_{HS}$</td>
<td>0.2 g/cm²</td>
<td>hGXI, ARC</td>
</tr>
<tr>
<td>$&lt;R_{HS}&gt;$</td>
<td>25µm</td>
<td>hGXI, NI</td>
</tr>
<tr>
<td>$Y_n$</td>
<td>$10^{14}$</td>
<td>NTOF, NAD, MRS</td>
</tr>
<tr>
<td>$t_{burn,bang}$</td>
<td>100 ps, ~20 ns</td>
<td>hGXI, SPBT, GRH, NToF4.BT</td>
</tr>
<tr>
<td>$\Delta R_{mix}/\Delta R_{shell}$</td>
<td>&lt; 0.25</td>
<td>hGXI, HEXRS</td>
</tr>
</tbody>
</table>

**Cold Fuel**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;\rho R&gt;$</td>
<td>&gt; 1.7 g/cm²</td>
<td>NTOF, MRS, RADCHEM, ARC, NI, GRH</td>
</tr>
<tr>
<td>$\Delta \rho R(\theta)$</td>
<td>&lt; 0.4 g/cm²</td>
<td>ARC, NI</td>
</tr>
<tr>
<td>$\Delta R_{mix}/\Delta R_{shell}$</td>
<td>&lt; 0.25</td>
<td>hGXI, RADCHEM</td>
</tr>
</tbody>
</table>
Gated x-ray imaging measures mix, presumably seeded by surface perturbations.

Good implosion

Bad implosion

Ugly implosion & ugly simulation

Ignition tuning will use n hardened gated imager to monitor mix.
Probing techniques on large ICF facilities take time and shots to develop.