Status and Plans for OMEGA

<table>
<thead>
<tr>
<th>Shot 33687</th>
<th>Shot 33220</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental ($\alpha \sim 4$)</td>
<td>Experimental ($\alpha \sim 40$)</td>
</tr>
<tr>
<td>Yield (1n): $4.6 \times 10^9$</td>
<td>Yield (1n): $1.78 \times 10^{11}$</td>
</tr>
<tr>
<td>TCC offset: 36 $\mu$m</td>
<td>~115%</td>
</tr>
<tr>
<td>23%</td>
<td>40 $\mu$m</td>
</tr>
</tbody>
</table>

R. L. McCrory  
Director  
University of Rochester  
Laboratory for Laser Energetics

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Collaborators


Laboratory for Laser Energetics
University of Rochester

J. Frenje, C. K. Li, R. D. Petrasso, and F. H. Séguin

Plasma Science and Fusion Center
Massachusetts Institute of Technology


Lawrence Livermore National Laboratory
Summary

LLE is making significant progress in direct-drive inertial confinement fusion research

- Adiabat-shaping techniques will allow
  - lower-adiabat (higher-compression) implosions on OMEGA and
  - higher-gain target designs for the NIF.
- Cryogenic target experiments are showing promise.
  - Ice-surface roughnesses are approaching 1 μm rms, ignition specifications.
  - The first wetted-foam target has produced the highest cryogenic D₂ neutron yield.
  - 2-D simulations are in good agreement with experimental observations.
- OMEGA EP (two ps beams, 2.6 kJ each) will extend LLE’s research, including integrated fast-ignition experiments.
The NIF base-line direct-drive ignition target is a thick DT-ice layer enclosed by a thin CH shell

- Target designs are characterized by the isentrope parameter $\alpha$:
  \[ \alpha = \frac{\text{Electron pressure}}{\text{Fermi-degenerate pressure}} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser energy</td>
<td>1.5 MJ</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>$\alpha = 3$</td>
</tr>
<tr>
<td>Gain</td>
<td>45</td>
</tr>
<tr>
<td>Yield</td>
<td>$2.5 \times 10^{19}$</td>
</tr>
<tr>
<td>$\rho R_{\text{peak}}$</td>
<td>1.3 g/cm$^2$</td>
</tr>
<tr>
<td>$&lt;T_i&gt;_n$</td>
<td>30 keV</td>
</tr>
<tr>
<td>Hot-spot CR</td>
<td>28</td>
</tr>
<tr>
<td>Peak IFAR</td>
<td>60</td>
</tr>
</tbody>
</table>
The OMEGA cryogenic implosion campaign is a staged program leading to verification of scaled-ignition performance with DT fuel by the end of FY05.

- The program is driven by three main objectives:
  - Validation of target performance for the lowest effective adiabat
  - Minimization and absolute characterization of DT cryogenic-layer roughness
  - Use of cryogenic DT targets in OMEGA implosion experiments

Most of the experimental work will be accomplished with $D_2$. 
Smother ice layers allow OMEGA cryogenic implosion campaigns to examine ignition-scaled targets at lower adiabats.

NIF: 1.5 MJ
- DT ice: ~3 μm CH, 1.69 mm
- DT gas: 1.35 mm

OMEGA: 30 kJ
- D₂ ice: ~5 μm CH, 0.46 mm
- D₂ gas: 0.36 mm

\[ \alpha = \frac{P_{\text{fuel}}}{P_{\text{Fermi}}} \]

Energy ~ radius³; power ~ radius²; time ~ radius
The OMEGA cryogenic implosion campaign is examining scaled-ignition target designs employing two ablator concepts.
Cryogenic target implosions require significant engineering and development

- Cryogenic implosions have been carried out on OMEGA for ~3 years.
- Significant obstacles have been overcome
  - cryogenic target transport
  - target survival
  - target layer survival
- The final issue has been to minimize target vibration at shot time.

Fielding cryogenic targets is very difficult and requires a lot of time and effort.
Recent $\text{D}_2$-ice layers with IR heating are approaching the NIF 1-$\mu$m rms requirement
Accurate three-dimensional reconstructions for simulations require many sampling traces

(Courtesy of R. Stephens)

- Surface position is mapped onto sphere.
- Data are smoothed.
- Information for low-order modes is provided.
A high-adiabat drive pulse has been used to understand the effect of ice roughness on target performance.
There is good agreement between high-adiabat implosion performance and 2-D hydrocode simulations (DRACO)

Shot 33413

\[ \alpha \sim 25 \]

\[ \text{rms ice roughness (\(\mu\text{m}\))} \]

modes \(\ell = 1\) to 16
Research at GA has produced a variety of dry foams for ICF implosion experiments on OMEGA.

An increasing fraction of experiments at LLE will use wetted-dry-foam shells.
The first OMEGA cryogenic wetted-foam-target implosion produced a surprisingly high cryogenic neutron yield.

**Experiment:**

- $Y_{1n} = 1.74 \times 10^{11}$
  $(114\%)$
- $Y_{2n} = 3.5 \times 10^8$
  $(30\%)$
- $T_{\text{ion}} = 5.2$ keV

**LILAC**

- $Y_{1n} = 1.5 \times 10^{11}$
- $Y_{2n} = 1.2 \times 10^9$
- $T_{\text{ion}} = 2.7$ keV
2-D DRACO demonstrates good agreement in predicting target performance for shot 33600 ($\alpha \sim 4$)

<table>
<thead>
<tr>
<th></th>
<th>Expt</th>
<th>1-D</th>
<th>2-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{1n}$</td>
<td>$4.30 \times 10^9$</td>
<td>$2.68 \times 10^{10}$</td>
<td>$5.85 \times 10^9$</td>
</tr>
<tr>
<td>$Y_{2n}$</td>
<td>$4.43 \times 10^7$</td>
<td>$1.40 \times 10^9$</td>
<td>$5.97 \times 10^7$</td>
</tr>
<tr>
<td>$\langle \rho R \rangle$</td>
<td>52</td>
<td>63</td>
<td>55</td>
</tr>
<tr>
<td>$T_{ion}$</td>
<td>2.7</td>
<td>1.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>
A stability analysis* of the $\alpha = 4$ design defines the ignition-scaling performance window for cryogenic implosions

- The NIF gain* and OMEGA yield can be related by
  \[ \bar{\sigma}^2 = 0.06 \sigma_{\ell<10}^2 + \sigma_{\ell\geq10}^2, \]
  where the $\sigma_{\ell}$'s are the rms amplitudes at the end of the acceleration phase.

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Scaling gain with \( \bar{\sigma} \) allows the formation of a global nonuniformity budget for the direct-drive point design.
Adiabat shaping reduces ablative Rayleigh–Taylor growth\textsuperscript{1}

For DT foils: \(\gamma_{RT} = 0.94\sqrt{kg} - 2.6 \text{ kV}_a\), where \(V_a \sim \alpha^{3/5}\).

\[
\alpha = \frac{P_{\text{fuel}}}{P_{\text{Fermi}}}
\]

- \(t = 0\)
- \(t = t_p\)

Picket creates a strong shock.

- \(t = t_{RW}\)
- \(t > t_{RW}\)

Rarefaction wave (RW) is launched at \(t = t_p\).

RW meets the shock.

Shock strength decreases in time.

\textsuperscript{1} V. N. Goncharov \textit{et al.}, Phys. Plasmas 10, 1906 (2003).
Picket results have led to examining lower-adiabat, NIF and OMEGA-scaled ignition designs

**Imprint simulations**

**ORCHID:** $\ell = 2-200$, DPP + PS, 1-THz SSD

Significant effort will be devoted to picket implosions in FY04.
Direct-drive target stability is dramatically improved when adiabat shaping is applied

The benefit of pickets has been confirmed in NRL and LLNL simulations.
Polar-direct-drive simulations for the NIF are starting to show the onset of hot-spot formation.
The OMEGA EP beams will be located next to the existing OMEGA facility

<table>
<thead>
<tr>
<th>Short-pulse performance</th>
<th>Short-pulse beam 1</th>
<th>Short-pulse beam 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short pulse (IR)</td>
<td>1 to 100 ps</td>
<td>35 to 100 ps</td>
</tr>
<tr>
<td>IR energy on-target (kJ)</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Intensity (W/cm²)</td>
<td>$6 \times 10^{20}$</td>
<td>$\sim 4 \times 10^{18}$</td>
</tr>
</tbody>
</table>
OMEGA EP will be an important new tool in LLE’s experimental arsenal

- Significant progress has been made toward “hot-spot” ignition.

- Development of radiographic diagnostic capability for HEDP and the NIF

- Validation of “fast ignition” with scaled cryogenic capsules

- Ultrahigh-intensity research capabilities
OMEGA EP will perform integrated cryogenic fast ignition experiments

- HEPW designs underway at LLE, LLNL, and SNL.
An OMEGA direct-drive cryogenic target is designed to give a density > 300 g/cm³

Nearly identical to capsules being imploded now.
The areal density achieved with an OMEGA cryogenic target is close to ignition conditions.

A 1-MeV electron has a range of about 0.4 g/cm$^2$. 
The fast-ignitor beam creates a burst of neutrons that can be used for diagnostic development.
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