S. Skupsky
University of Rochester
Laboratory for Laser Energetics

45th Annual Meeting of the American Physical Society
Division of Plasma Physics
Albuquerque, NM
27–31 October 2003
Summary

Polar direct drive (PDD) is a promising technique to achieve ignition conditions using direct drive while the NIF is in the x-ray-drive configuration.

- PDD will employ all the techniques used in high-performance direct-drive target designs:
  - adiabat shaping
  - high laser–target coupling

- PDD is a more difficult design problem than “standard” direct drive.

- PDD simulations will be validated by experiments on the OMEGA laser.
The PDD simulations use a scaled-down version of a NIF high-performance direct-drive target design.

High-gain direct-drive target designs combine wetted foam with adiabat shaping for enhanced absorption and stability.

**Equivalent 1-D design**

- **Incident:** 1.1 MJ
- **Absorption:** 95%
- **$\rho r$ (peak):** 1.2
- **Velocity:** $4.1 \times 10^7$
- **Gain:** 54

**Graph:**

- **Intensity (x 10^14 W/cm^2)**
- **Time (ns)**

**Diagram:**

- CH(DT)$_4$
- DT

1.8 mm
The picket launches a decaying shock, placing the ablator on a higher adiabat than the fuel.

Adiabat ($\alpha$) $\sim$ pressure
Ablation velocity $\sim \alpha^{3/5}$

![Graph showing pressure vs. distance from inner edge of shell]
The x-ray-drive beams are pointed to six latitude rings on the target for PDD.

- 23.5°—“polar” ring
- 30.0°
- 44.5° – ring 2
- 50.0°
- 77.5°—“equatorial” ring

Polar Direct Drive

- X-ray-drive port
- PDD pointing
Equatorial irradiation is at incident angles greater than $\sim 40^\circ$ for PDD

Turning point

$$= \cos^2(\theta_{\text{inc}}) n_c$$

Ray distribution function

Incident angle ($^\circ$)

0.00 0.02 0.04 0.06 0.08

0 20 40 60 80

Polar region

Equator
One-dimensional (spherical) simulations are used to estimate the effects of oblique irradiation.

The distribution function $P(\theta_0)$ of incident laser rays at any point on the target surface is calculated from a 3-D beam superposition code.

$n \sin(\theta) = \text{constant}$

$n = \left(1 - \frac{n_e}{n_c}\right)^{1/2}$

- The distribution function $P(\theta_0)$ of incident laser rays at any point on the target surface is calculated from a 3-D beam superposition code.
1-D simulations estimate the increased laser intensity required to compensate for oblique irradiation at the equator.

<table>
<thead>
<tr>
<th></th>
<th>Pole</th>
<th>Equator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident (MJ)</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Absorption%</td>
<td>95%</td>
<td>83%</td>
</tr>
<tr>
<td>V ($\times 10^7$ cm/s)</td>
<td>4.1</td>
<td>3.9</td>
</tr>
<tr>
<td>$\rho R$ (g/cm$^2$)</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Gain</td>
<td>54</td>
<td>10</td>
</tr>
</tbody>
</table>

Time (ns)

Intensity ($\times 10^{14}$)
Differences in density and temperature profiles in the 1-D estimates indicate that full 2-D simulations are required to account for lateral flow.
Uniform target drive requires increased intensity at the equator to compensate for the oblique irradiation.

**Repointing for PDD**

<table>
<thead>
<tr>
<th>Angle</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.5°</td>
<td>(45°)</td>
</tr>
<tr>
<td>30°</td>
<td></td>
</tr>
<tr>
<td>50°</td>
<td>(45°)</td>
</tr>
<tr>
<td>45°</td>
<td></td>
</tr>
<tr>
<td>78°</td>
<td></td>
</tr>
</tbody>
</table>

- PDD issues at the equator
  - reduced absorption
  - reduced hydro-efficiency
  - lateral heat flow
  - nonradial beams
A spot shape for beams in the equatorial ring contributes to uniform irradiation toward the pole while providing enhanced intensity at the equator.

Focal-spot shape for equatorial beam

Vertical lineout
A 3-D ray-trace algorithm is used to simulate PDD

"Equatorial" ring ($\theta = 50^\circ$)

Radius (mm)

$\theta = 0^\circ$

$\theta = 180^\circ$
An automated pulse-shape refinement technique is used in 2-D simulations of PDD to minimize drive nonuniformities.

Current state of the absorption profile is sampled from DRACO; determines surface-illumination pattern

Surface-illumination pattern due to each NIF ring is decomposed and fed into optimizer; forms basis-set

The optimizer can be biased for different $\ell$-modes.

Nonuniformity $\sim 1.2\%$
The variation in intensities at the pole and equator show the compensation required for PDD.
The angular averaged density profile at the end of the acceleration phase is similar to the 1-D profile (8.2 ns)
Density variations at the end of the acceleration phase of the implosion show that further optimization in drive uniformity is required (8.2 ns)
PDD simulations are starting to show the onset of hot-spot formation (9.03 ns)
Angular averaged profiles of the PDD simulation show the characteristics of the 1-D simulation at the onset of hot-spot formation (9.03 ns)
The total fuel $\rho R$ is 1.1 g/cm$^2$ during neutron emission 
($Y = 6 \times 10^{16}, G = 0.1$)
Strategies to improve irradiation uniformity for PDD are being developed

• The automated pulse-shape refinement algorithm will be further optimized to better detect drive uniformity and adjust pulse shapes accordingly.

• Drive uniformity will be “fine tuned” by optimizing beam pointing, focal spot shape and spot size.

• Target “shimming”.

PDD experiments on OMEGA over the coming year will validate the computer modeling of PDD.
Measurements of shock-wave propagation in planar targets will study laser coupling of oblique beams

Shock-wave arrival at the rear surface and velocity for transparent targets are measured with a VISAR* diagnostic on OMEGA.

The position of the target and shock wave are determined by x-ray radiography with either a streak camera or a framing camera for targets opaque to the VISAR probe.

OMEGA symmetry can be maintained for non-normal incidence implosions by repointing all beams.
The NIF polar-direct-drive configuration with 48 quads can be approximated by repointing 40 beams of OMEGA.
Summary/Conclusions

Polar direct drive (PDD) is a promising technique to achieve ignition conditions using direct drive while the NIF is in the x-ray-drive configuration.

- PDD will employ all the techniques used in high-performance direct-drive target designs:
  - adiabat shaping
  - high laser–target coupling

- PDD is a more difficult design problem than “standard” direct drive.

- PDD simulations will be validated by experiments on the OMEGA laser.

PDD might be the best approach for fast-ignitor experiments and for high $\rho R$ diagnostic development.
PDD simulations are starting to show the onset of hot-spot formation (9.03 ns)