NRL Experiments in Support of
High Gain Target Designs*

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Outline

- Brief overview of NIKE facility
- Two recent experimental campaigns related to high gain pellet design:
  - Spike-Prepulse Experiments
  - High-Z Overcoat Experiments
NIKE Overview
Nike laser group has extensive experimental program in support of ICF Physics

- Observation of hydrodynamics: Rayleigh-Taylor instability, Richtmeyer-Meshkov instability, imprint growth, target acceleration
- Fundamental equation of state of shocked materials
- Benchmarking of atomic physics codes
- Cryogenic foam target development
- Studies of laser-plasma instabilities
- Advanced diagnostic development
Nike KrF Laser Facility

- KrF excimer laser operating at 248 nm with 1-2 THz bandwidth
- Angular multiplexing through large electron pumped amplifiers provides 3 kJ for planar target experiments
- Focal profile of beam on target is smoothed by the Induced Spatial Incoherence (ISI) technique.
- Typical laser pulse has 4 ns long low intensity foot and a higher intensity 4 ns long main pulse
- Up to 44 main beams can be overlapped on the target, focal spot FWHM of 0.75 mm and a flat central region 0.4 mm in diameter.
- Up to 12 beams are used for backlight x-rays, focal spot FWHM of 0.4 mm, 0.2 mm flat top.
Nike laser provides highly uniform target illumination

Essential for well controlled hydrodynamic and shock experiments.

- Profile analysis using center 50% of FWHM
  - tilt: 1.3%
  - curvature: 2.9%
  - rms: 0.7% (diagnostic limited)

- Single beam measurements show no appreciable change in profiles with E-beam amps on or off

  beam overlap shifts much of the rms nonuniformity to < 5 micron wavelengths

Nike is well optimized to study hydrodynamics in planar geometry.

Spike Prepulse Experiments
High gain target utilizing spike prepulse and zooming

Pellet Design

NRL FAST Code 2 D simulations
Total Laser Energy 2.5 MJ

no spike, gain <1
with spike, gain = 160

Spike prepulse creates sloped density profile in front of main shock

- 0.3 ns, 5 TW/cm² spike
- 4 ns, 50 TW/cm² main pulse

A. Velikovich, Phys. of Plasmas, 10 (8), 3270 (2003).
Spike prepulse causes a delayed onset of mode growth

Single mode perturbation: $\lambda = 30 \, \mu m$, $A_0 = 0.25 \, \mu m$

- 3%, 4 ns foot
- 10% spike, 2.0 ns delay

N. Metzler, …
Spike Prepulse Capability of Nike Laser

- Fast pulse Pockels cell driver and optics added to foot beam optical path
- Spike pulse with ~ 300 ps FWHM created on all main beams
- Spike intensity up to 20% of main peak, maximum delay up to ~ 4 ns
Observation of shock propagation from spike prepulse

Laser interferometer provides time history of spike shock propagation through target

Comparison of observed shock propagation and analytic prediction

Shock velocity is proportional to fringe shift

Data verify the desired shock motion has been achieved

Jaechul Oh, Andrew Mostovych, et al.
Initial target data qualitatively confirm predictions for mode growth

40 µm thick CH, sinusoidal ripple $\lambda = 30$ µm, $A = 0.25$ µm

- Mode amplitude growth is observed to be delayed
- Spike results appear insensitive to spike-main delay

Much more data left to analyze from this campaign…….
40 um Flat CH

3% 4 ns foot, 46 TW cm$^{-2}$

10%, 3 ns delay spike, 43 TW cm$^{-2}$
40 um CH: 30 um x 0.25 um ripple

3%, 4 ns foot, 37 TW cm$^{-2}$

10%, 3 ns delay spike, 42 TW cm$^{-2}$
40 um CH: 30 um x 0.25 um ripple

1%, 3 ns foot, 43 TW cm⁻²

10%, 3 ns delay spike, 42 TW cm⁻²
40 um CH: 30 um x 0.5 um ripple

3%, 4 ns foot, 36 TW cm\(^{-2}\)

10%, 3 ns delay spike, 43 TW cm\(^{-2}\)
40 um CH: 30 um x 0.5 um ripple

1%, 3 ns foot, 43 TW cm$^{-2}$

10%, 3 ns delay spike, 43 TW cm$^{-2}$
40 um CH: 20 um x 0.5 um ripple

3%, 4 ns foot, 43 TW cm$^{-2}$

10%, 3 ns delay spike, 43 TW cm$^{-2}$
40 um CH: 20 um x 0.5 um ripple

1%, 3 ns foot, 44 TW cm\(^{-2}\)

10%, 2 ns delay spike, 42 TW cm\(^{-2}\)
High-Z Overcoat Experiments
High gain target designs have been achieved with combination of zooming and high-Z overcoats.

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**Laser Energy:** 1.3MJ  
(with zooming)  
**1D Yield:** 160 MJ  
**Gain:** 124  
**e-folds\(_{max}\):** 7.3  
**e-folds\(_{net}\):** 5.5

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**Debris Summary:**
- Neutrons: 128.83 MJ  
- X-rays: 3.82 MJ  
- Total Ion Kinetic Energy: 22.89 MJ  
- Total Ion Thermal Energy: 0.04 MJ

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A thin high-Z layer substantially reduces non-uniformity from laser imprint (Nike experiment)

Similar results observed using Omega (NRL +LLE planar experiment)
X-rays from high-Z layers create long scale-length plasmas at early time – laser imprint is effectively smoothed

Success with experiments is driving new pellet designs featuring imprint mitigation with early time indirect drive
At higher intensity the laser "bleaches" through the Au layer

CH target with 1000 Angstrom gold overcoat ($I_{\text{laser}} = 20 \text{ TW/cm}^2$)

$T = 1 \text{ ns}$

- absorbed radiation
- laser deposition (> 99% in gold)
- emitted radiation

$\rho (\text{g/cm}^2)$, $p_{\text{Total}}$ (Mbar), $T_e$ (eV)

laser & radiation power density (PW/cm$^2$)

position (µm)
Two basic questions:
• How robust are these results? Can we reproduce them at another laser facility?
• Will these layers actually improve pellet performance?

Omega Laser Facility
- 30 kJ glass laser, 351 nm wavelength
- 60 beams available for spherical implosions
- Advanced pulse-shaping capabilities, pulse lengths are typ. 1-2 ns
- Beam smoothing (~1% level) achieved with SSD and RPP
- Extensive suite of diagnostics available for target experiments

LLE collaborators: J. Knauer, F. Marshall, T. Boehly, V. Smalyuk, D. Meyerhoff, C. Sangster
Mass non-uniformity calculated from X-ray transmission measurements

T~3nsec

30µm CH

30µm CH with 250Å Au

200 µm
Recent implosion experiments at LLE demonstrate improved neutron yield for pellets with an outer coat of Pd.

- **Diagram:**
  - Pd overcoat
  - 1500 Å Al
  - Intermediate layer
  - 3 atmos. D2 fill
  - 20 µm CD shell
  - 860 µm diameter

- **Laser Pulse Shape:**
  - Peak ~ $10^{15}$ TW/cm²

- **Table: Measured Neutron Yields vs. 1D Calculated Yields**

<table>
<thead>
<tr>
<th>Pd Thick Å</th>
<th>Meas. Neutron Yield</th>
<th>1D Calc. Yield</th>
<th>YOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.45E+10</td>
<td>1.12E+12</td>
<td>3.1%</td>
</tr>
<tr>
<td>200</td>
<td>3.93E+10</td>
<td>2.44E+11</td>
<td>16.1%</td>
</tr>
<tr>
<td>400</td>
<td>6.62E+10</td>
<td>1.14E+11</td>
<td>58.1%</td>
</tr>
</tbody>
</table>
NRL has broad experimental program to explore physics relevant to high gain target for ICF:

• Nike KrF laser has unique properties that enable high quality experiments
• Advanced diagnostics are available at the laser facility to create a detailed and precise understanding of target physics

Two designs for high gain targets are being explored:

• Experiments using spike prepulse on the Nike laser have verified our understanding based on simulations and analytical calculations
• High-Z overcoats of Au and Pd have been shown to reduce imprint growth in detailed studies of planar targets and have been shown to increase neutron yield in recent implosion experiments