Progress in the development of an “all DT” NIF shock ignition target

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Laser pulse shape for the all-DT design uses a picket + 3 pedestals for fuel compression

- Triangle picket
  - Sets adiabat
  - Smooths laser imprint
  - Sets shock breakout time
- 3 pedestals
  - “foot,” “shock 2,” “shock 3”
  - Compress fuel in-place to high density
- Moderate intensity main compression pulse
  - Implodes target
  - Less intense, slower implosion than conventional “fast compression”
  - Large $\rho R$, but temperature too small to burn
- High intensity shock
  - Launches a strong shock
  - Additional compression
  - Temperature > 10 keV
NIF is a viable platform for demonstrating shock ignition

- Polar direct drive configuration
- 24 compression quads focused at initial radius
- 24 shock quads focused at shock-launch radius
- Sufficient energy
  - \(~0.6\text{MJ for near-term high-gain targets}\)
  - \(\geq 1.3\text{ MJ for high yield designs}\)
- Strong ignitor shocks due to
  - large peak power (400 TW)
  - 250 ps rise time (upgradable to 100ps?)
- Would need a new cryostat
Slow, thick DT ablator design should mitigate Rayleigh-Taylor growth during implosion phase

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>3.16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implosion velocity (km/s)</td>
<td>303</td>
</tr>
<tr>
<td>In flight adiabat</td>
<td>1.56</td>
</tr>
<tr>
<td>Max rhoR</td>
<td>1.95</td>
</tr>
<tr>
<td>Convergence ratio</td>
<td>32</td>
</tr>
<tr>
<td>IFAR (at 2/3 r0)</td>
<td>20</td>
</tr>
<tr>
<td>Yield (MJ)</td>
<td>32</td>
</tr>
<tr>
<td>Gain</td>
<td>52</td>
</tr>
<tr>
<td>Compression energy (kJ)</td>
<td>308</td>
</tr>
<tr>
<td>Shock energy (kJ)</td>
<td>&lt;300</td>
</tr>
<tr>
<td>Total energy (kJ)</td>
<td>&lt;608</td>
</tr>
<tr>
<td>Integrated laser energy efficiency</td>
<td>56%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Segment</th>
<th>Power (TW)</th>
<th>Launch (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picket</td>
<td>8.55</td>
<td>0.</td>
</tr>
<tr>
<td>Foot</td>
<td>0.75</td>
<td>2.85</td>
</tr>
<tr>
<td>Shock 2</td>
<td>3.48</td>
<td>8.08</td>
</tr>
<tr>
<td>Shock 3</td>
<td>16.15</td>
<td>9.85</td>
</tr>
<tr>
<td>Main</td>
<td>115.</td>
<td>10.85</td>
</tr>
<tr>
<td>Shock (all beams)</td>
<td>350.</td>
<td>13.41</td>
</tr>
</tbody>
</table>
Updated target improves on previously circulated all-DT design

<table>
<thead>
<tr>
<th>Changed Quantity</th>
<th>Old Target</th>
<th>Updated Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Flux Limiter</td>
<td>100% at late time</td>
<td>6% sharp cut-off, all times</td>
</tr>
<tr>
<td>DT Gas Density</td>
<td>0.2 g/cc (IFE specs)</td>
<td>0.3 g/cc (NIF quench specs)</td>
</tr>
<tr>
<td>Beam Intensity Profile</td>
<td>Skupsky’s NIF fit</td>
<td>Shurtz’s fit to Craxton’s PD pointings</td>
</tr>
<tr>
<td>Picket shape</td>
<td>Zero rise-time flat-top</td>
<td>Finite rise-time triangle</td>
</tr>
<tr>
<td>Main pulse power</td>
<td>95 TW</td>
<td>115 TW</td>
</tr>
</tbody>
</table>
Polar drive intensity profile results in lower drive efficiency

- Need 2D laser intensity (radius, angle of incidence) to reasonably approximate PD laser absorption
- Refraction and shrinking targets amplify difference in efficiency
- Main pulse power increased to take advantage of larger efficiency at beginning of main pulse

\[ I(r) = I_0 \exp\left(-3\left(\frac{r}{1010}\right)^4\right) \]

\[ I(r) = I_0 \exp\left(-\left(\frac{r}{0.0885}\right)^2.66\right) \]
Laser pulse tuning

- Time picket and 3 compression pedestal shocks to coalesce at gas/ice interface at same time

  - Maximize $pR$ (main launch time, main power) for fixed compression energy
    - LPI thresholds limit main power
    - Falling laser efficiency

- Scan yield (shock launch time, shock power) for fixed shock energy

- Shock power based on:
  - Yield
  - Ignition window
  - Optics damage threshold

- Actual laser energy used less than design assumptions
  - Shock pulse starts before compression energy exhausted
  - Shock remains on after burn initiates
  - 607kJ / 700 kJ for current design
Higher intensity main pulses have larger ignition windows and comparable yield.

No Rayleigh-Taylor in 1D

\( \sim 400 \text{ kJ compression energy} \)

300 kJ shock energy
• Interface between the hot spot and decelerating fuel is RT unstable

• Projecting peak velocity to $r=0$ is a useful metric for tracking RT growth

• Timing of igniter shock determines when on fall line burn initiates

• Optimal 2D/3D/reality shock timing may occur early within ignition window
Physical processes modeled by the HYDRA code for ICF simulations

- Laser light
  - 3D ray tracing
  - Spherical DD raytrace

- Magnetic fields
  - 3D MHD Resistive
  - General circuit model

- Burn products
  - TN reactions
  - Multi-group diffusion CP
  - Free streaming neutron transport
  - Monte Carlo transport of neutrons, gammas, charged particles

- Ion beams
  - 3D ray tracing
  - Monte Carlo

- Radiation
  - Single group diffusion
  - Multi-group diffusion
  - 1D/2D multigroup $S_N$ IMC

- Electrons
  - Thermal conduction
  - Multigroup non-local
  - Relativistic PIC (link)

- Ions
  - Thermal conduction

- Atomic physics
  - Analytic EOS
  - Tabulated EOS
  - Inline QEOS
  - Tabulated LTE opacity
  - TABOP
  - Inline LTE & non-LTE
  - XSN
  - DCA NLTE

- Hydrodynamics
  - Lagrange + ALE
  - Automatic mesh motion
  - Block structured mesh
  - Reduced & enhanced Connectivity
  - Shape generation lib.
  - Isotropic strength
  - Atomic mix model

Slide courtesy of Marty Marinak
Early time resolution of the critical surface is hard

- Folklore: outer surface of ablator should have \(\sim 0.1 \, \mu m\) wide zones
- “Thick” zones seem to poorly resolve critical absorption for picket
- Energy deposits deeper than critical surface, leading to faster shocks
- Shifts shock tuning, but small effect on target performance
- Suggestions/experience from the audience?

![Graphs showing time resolution](image)
Work left to be done

- Finish transition to HYDRA

- Fill out 1D gain curve of hydrodynamically equivalent all-DT targets
  - Scale target quantities by factor “s”

\[
\frac{m}{m_0} = s^3 \quad \frac{E_{\text{laser}}}{E_{\text{laser},0}} = s^3 \quad \frac{P}{P_0} = s^2 \quad Y \sim s^3 \rho R(s)
\]

  at ~constant IFAR, ν, CR, α

- Expect \( G = \frac{Y}{E_{\text{laser}}} \sim c \cdot s^b \) (but need coefficients!)

- 2D stability (single mode→ multimode)

- Optimum beam pointings, focusings and time-dependent powers (laser PD uniformity) for
  entire implosion

- Iteration between 3D beam pointing constraints and 1D target build/pulse shape