NIF Ignition Campaign Target Performance and Requirements: Status May, 2012

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And pretty much everybody in this room…

May 21, 2012
The National Ignition Campaign is well underway, with many successes in hand and some challenges ahead

- We have successfully fielded all of the experimental platforms planned for NIC, and used the results to adjust the target design and laser pulse

- Generally, the design and requirements remain essentially the same as before the campaign began

- There have been some minor adjustments:
  - Si dopant instead of Ge
  - New hohlraum dimensions
  - For the future, emphasis is on exploring wide range of targets including new ablators, various Si configurations, thicker shells

The target fabrication community deserves to be hugely congratulated for successfully fielding a wide variety of complex targets, meeting all requirements and a demanding schedule
Integrated implosion experiments—and soon ignition experiments—use a graded doped capsule in a Au or U hohlraum driven by up to 1.6 MJ of laser energy.

Updated items since last TFSM:
- 5.75 mm (Was 5.44)
- 195-235 μm thk
- 1130 μm
- 0% Si
- 1-2% Si
- 2-4% Si
- 1-2%
- 0%
- 9 mm
- 0.96 mg/cc
- 3.1 mm LEH
- 0.96 mg/cc

Au or U Hohlraum:

Laser pulse needs to be tuned with precision:

Experiments to date have used less laser power and energy than will be needed for ignition.
We use a variety of targets to tune the capsule shape, adiabat, velocity and mix.

<table>
<thead>
<tr>
<th>Solid high-Z sphere</th>
<th>Liquid D2-filled capsule</th>
<th>Both Gas-filled and THD Cryo-layered Capsules</th>
</tr>
</thead>
</table>

| Reemit | Keyhole | Symmetry Capsule | Backlit Capsule |

Each of these is used to optimize respective features of laser pulse or target geometry, before doing implosion with cryo layer.
Reemission spheres were used to set cone power ratio for first 2 ns to ensure symmetric foot picket drive

**Experimental Geometry**

<table>
<thead>
<tr>
<th>Bi sphere “Reemit” replaces layered capsule</th>
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<tbody>
<tr>
<td>0.7 keV Gated X-ray images</td>
</tr>
</tbody>
</table>

**Observable:**
Limb brightness vs. angle as picket cone fraction changed

[Image of experimental setup with Bismuth-coated re-emission sphere and 0.7 keV gated X-ray images]
“Keyhole” targets are used to set shock strengths and timing, to minimize fuel adiabat

<table>
<thead>
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<th>Experimental Geometry</th>
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<tr>
<td>Liquid D$_2$-filled Cone-in-sphere “Keyhole” replaces layered capsule</td>
</tr>
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</table>

May 2011
VISAR streak

<table>
<thead>
<tr>
<th>Shock velocity (microns/ns)</th>
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<tbody>
<tr>
<td>Time (ns)</td>
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</table>

Measured (black) and simulated (red), shot N120106

**Four shocks are tuned in velocity and time, to compress fuel before peak pressure for acceleration. Simulations adjusted to fit v(t).**

**Observables:**
Fringe shift(t) ~ shock speed(t)
Shock overtake distance ~ $\int v dt$
New dual axis keyhole allows symmetrization of all shocks

< 1% asymmetry in 1st shock velocity and breakout confirms efficacy of earlier reemit picket symmetry tuning

Set 2nd and 3rd shock symmetry (Oct 2011) to ± 3% in velocity, ± 200 ps in merge depths by varying cone fraction and power levels
Symcaps are used to tune symmetry and get first look at implosion performance.

These have been completely successful and implosions are now routinely round.
Backlit Capsule ("ConA") measures velocity and remaining ablator mass, which sets mix susceptibility.

**Experimental Geometry**

<table>
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<tr>
<th>Backlit D-(^3)He-filled capsule or THD Cryo-layered capsule</th>
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</thead>
<tbody>
<tr>
<td>Streaked or gated X-ray radiographs</td>
</tr>
<tr>
<td>Imaging slits or pinholes</td>
</tr>
</tbody>
</table>

**Backlighter Zn or Ge Observables:**
- Radius vs time
- Thickness, density, remaining mass
- Limb \(v_{imp}\) at \(r = 300\) \(\mu m\)
Finally, the integrated performance is measured with a layered implosion.
Implosion experiments utilize THD or DT ice layers that are characterized for surface roughness and isolated defects, e.g. grooves.
Cryo layer analysis now includes a low mag, high contrast diagnostic to observe grooves

| Layer shows 5 larger grooves that result in a K value of 0.74 μm |
| Example of groove characterization |

<table>
<thead>
<tr>
<th>Groove</th>
<th>Depth (µm)</th>
<th>Area (sq µm)</th>
<th>Length (µm)</th>
<th>K (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11</td>
<td>518</td>
<td>310</td>
<td>0.33</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>377</td>
<td>410</td>
<td>0.28</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>283</td>
<td>260</td>
<td>0.17</td>
</tr>
<tr>
<td>D</td>
<td>11</td>
<td>518</td>
<td>851</td>
<td>0.55</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>236</td>
<td>275</td>
<td>0.14</td>
</tr>
</tbody>
</table>

For the 5 grooves, Total K = 0.74 microns.
Integrated implosions have used THD or DT ice layers that routinely meet experiment requirements.

Layers have some surface grooves

\[ K = \sqrt{\frac{1}{V_{fuel}} \sum_j A_j^2 L_j} \]
There is often a big mode 1 aligned with the fill tube.

Thickness vs angle, three orthogonal views from shot N120321:
Thickest at $\theta \sim 90$, $\varphi \sim 180$, just opposite the fill tube.
Thinnest at fill tube, $\theta \sim 90$, $\varphi \sim 0$. Fill tube and support arms at $\varphi=7$ in this coordinate system.
This is big enough to have a significant effect on performance

For most recent shot:

- Yield is reduced by 30%
- Tion reduced by 9%
- Average DSR is reduced by 2.8% (i.e. from 5.71% to 5.55%)
- $\rho R$ relative to original origin varies +/- 10%. $\rho R$ is high where layer is initially thin, i.e. phi~30, theta ~90
- DSR varies +/- 7%, high on side initially thin (towards 90-30)
- Primary neutron yield varies +/- 2%, is high in direction initially thick
- 17% brightness contour moved towards initially thick fuel by 5 $\mu$m
- 17% contour still within <1$\mu$m of round (very small residual m=2, 3, etc.)
- Brightest part of image is shifted toward initially thick fuel by 8 $\mu$m

Mode 1 in the ice is clearly an issue and is being addressed with another heater
For 1½ year now, THD and DT shots have been marching up in yield and compression

- Pre shock tuning early 2011
- Post 1st pass shock tuning (June 2011)
- 5.75mm hohlraum CHSi capsule (Sept-Dec 2011)
- Low-power pulses, better symmetry and pulse-shaping (2012)

About half the gap between where we are and the ignition regime results from known issues that can be fixed with more laser power and energy (measured velocity). The other half represents challenges that we need to identify and solve.
We have made a lot of progress but challenges remain

• We have successfully fielded all of the experimental platforms planned for NIC, and used the results to adjust the target design and laser pulse

• Principal challenges we are finding:
  ➢ Velocity was 10-15% low with Ge, now ~10% low with Si dopant
  ➢ Compression as measured by down-scattered neutrons is ~5% low
  ➢ Yield is below simulated by 3-10x, probably because of 3D hydro
  ➢ To get ignition at NIF scale, these 10-20% issues must be reduced to be less than about 5%, and mix made reliably lower

What are the implications for target fab of what lies ahead?

  — Minimize seeds for implosion hydro instabilities
  — Need operational speed and flexibility
  — Wide variety of variations on the point design
  — Alternate ablators
Performance is a strong function of hot spot shape and mix

2D simulation of capsule at stagnation time with roughness and ice grooves

- Ice roughness
- Ice grooves
- Ablator roughness (low modes <~30 feed through and grow at hot spot boundary)
- Ablator
- Cold shell of DT
- Distorted hot spot

- Mix between cold and hot DT decreases hot spot volume, mass, and Yield
- We used simulations to set requirements on all surfaces; now moving towards experimental optimization
Special capsules and spectrometer were developed to trace origin of ablator mix in the hot spot

<table>
<thead>
<tr>
<th>layer</th>
<th>dopant (atomic %)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Cu(0.1%)</td>
</tr>
<tr>
<td>2</td>
<td>Si(0.7%) Ge(0.15%)</td>
</tr>
<tr>
<td>3</td>
<td>Si(1.7%) Ge(0.15%)</td>
</tr>
<tr>
<td>4</td>
<td>Si(1%)</td>
</tr>
<tr>
<td>5</td>
<td>none</td>
</tr>
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</table>

- We routinely see Ge emission lines in the core emission, measures how much Ge gets into radiating core after implosion
- Cu layer also made lines, but very faintly
- Si does not emit an x-ray line at useful energy
- This Cu/Ge/Si design told us mostly Ge layer is getting into core, as well as letting more of the high-energy x-rays out
- Imposed perturbations (laser ablated) could make the experiment controlled and quantitative
- Flexibility to design and field experiments like this will be very important in the coming years
The tent seeds a perturbation where it leaves contact with the capsule (was 300nm, now 100nm)

- Contact ring at ~45°. Tent safely away from surface by ~60°. Between that it is a hard-to-model perturbation shape with amplitude PTV about 100nm.
- It is very difficult to simulate this directly because the topology cannot be zoned without a significant zoning perturbation
- Our recent simulations put a tanh step at 45° with various widths

Here the ablator is effectively 100nm thicker

Transition of 20-300 µm lateral extent

Tent has no hydro impact
We do 1D calculations with a parallel tent at various elevations above the surface, and 2D with equivalent step on the CH surface.

- Displacement of shock front from 300nm tent at various elevations

Simulations below assume 300nm step, 100 micron width. With 40 micron step the growth is ~40% more.
Simulation w/ 300nm tanh step, 100µm lateral, at 30° from pole, looks a lot like the N110904 data
In addition to THDs, symcaps have also shown a feature that could be the tent

Simulation of 300nm x 100 micron step on N110821

N100113

N120421 ConA (missing beams produce 3D asymmetry too)

Waist view Pole view
Ripples in the tent around contact ring could explain “bear-claw” image in shot N110615

Polar x-ray emission image from DT shot N110615 (quite oblate in the other view)

The tent is important. Already reduced from 300nm to 100nm; going to 50nm is a valuable next step.

As tent lifts away from capsule surface, was it wrinkled or rippled?
Uranium hohlraums improve the drive, but may affect implosion performance

First U shot had same pulse shape, Au in N120205 and N120126, then U in N120213. Gained 15-20 km/s in implosion velocity, but yield went down.

Is low yield in U shots a result of the higher drive, or something else about the U?

Tried AB comparison 120417 (Au, 345 TW) to 120321 (U, 320 TW), got same performance.

Physics community has not yet reached consensus on Au vs U issue. More tests next month (and more requests for target fab on variety of targets!)
Average oxygen of 1 at% or more affects implosion velocity unacceptably

Requirement is “Average Oxygen < 1 at%”
Each 1 at% reduces velocity by 1.9%, we need implosion velocity within 3% of nominal for ignition
An oxygen ramp near the ablator surface changes the shock timing

- Oxygen profile ramping up to 4% over 50 microns changes shock timing by 50 ps, which is 1x spec for Keyhole shock timing
- Because it changes several shocks, changes adiabat from 1.44 to 1.472, loss of 8.5% in ITF
- If Keyholes set timing with this ramp, and this is reproducible for Keyholes and THD/DTs, it doesn’t matter
We are requesting a bewildering array of capsules

Original campaign goal was “tune the laser pulse for the Rev5 point design” which allowed for focused target fabrication

Now we are optimizing the target design experimentally, which opens up a huge parameter space to try to explore

Target options now include:
1. Two thicknesses, in addition to nominal (+20µm, +40µm)
2. Various dopant configurations (1.5x, 2x, sometimes 3x, uniform Si 1% or 2%, all with or without Ge)
3. Au and U hohlraums

This is stressing to the target fab team and we are very grateful to you for your work to accommodate all the options!
We are working to implement a round of improvements in target features

- Radiation loss through diagnostic hole at the waist is calculated to change the symmetry significantly, and we do suggestions of the asymmetry in implosions. Currently hole is plugged with HDC (to keep it open!). Fix by coating inside of HDC plug with Au

- Also cover starburst with thin Au film

- Fill tube often causes visible perturbation. Have developed 5µm tubes, will begin shooting next month

- Working to develop thinner tents

- Improved surface roughness (near term goal 20% better, long term 2x)

- Complete measurement of foreign surface material with “4pi”
N120126 vs N120205 showed that incidental changes can change yield by 2x

- Two nominally identical shots. Second shot was intended to test effect of bad layer, but we got a good layer and shot it anyway
- Capsule and layer on second shot were very good. Yield was twice as good!

- Red N120205, better performer
- Everything on this bar chart is ideally small, so N120205 was better in every way except ice layer modes 12 and up
- It is tempting to ascribe better performance to major differences (CH modes 2-6) but maybe performance is very sensitive to something else (modes 7-12), or something else entirely (dust?)
Designs with Be and diamond ablators are on the planning horizon

- I don’t have pie diagrams to show, since both designs are very much still in flux
- We have fabricated preliminary designs, and plan to test them this summer, but for both ablators the “real” design will be different from these preliminaries
- Preliminary tests will address the principal questions about the designs:
  1. Is the low velocity we see in GDP similarly low for Be and HDC?
  2. How are the laser-plasma instabilities for these ablators, with appropriate pulse-shapes
  3. Are the hydrodynamic instabilities (and capsule yield) qualitatively different?
  4. Maybe the experimental results will provide guidance on doping and drive
- Final designs are evolving because the preheat part of the x-ray drive spectrum (~2keV) is higher than we expected a couple years ago, and getting the correct dopant is a challenge. Very high Z (e.g. W) is a problem if it mixes into the igniting core; Si or Al, anything between Na and Ar in periodic table, up to 4-5 at%, would be wonderful
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