Status of Experiments on National Ignition Facility

Presented to
31st Annual Meeting and Symposium Fusion Energy: Focus on the Future

December 1, 2010

Edward I. Moses
Principal Associate Director
NIF & Photon Science
NIF missions

- Global Security
- Laser Inertial Fusion Energy
- Energy Security
- Forensics and Effects
- Stockpile Science
- Reduced Uncertainties
- New Ideas
- Scientific Leadership
- Applications of Ignition
- High Yield >100 MJ
- Non-Ignition Stockpile Science Experiments
- Ignition
- Planetary Systems
- NIF Missions
NATIONAL IGNITION CAMPAIGN

Institute partners: NNSA, General Atomics, LLE, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Sandia National Laboratories, AWE, CEA.
National Ignition Campaign goals

- Begin ignition experiments starting in FY2010
  - Layered implosion
  - Diagnostic holes

- Develop an ignition platform for HED applications in FY2012

- Transition NIF from project completion to routine facility operations by end of FY2012
NIC Summary

• Following a successful 2009-2010 tuning campaign, we have demonstrated the world’s first MJ hohlraum and associated modeling advances

• Initial hohlraum energetics experiments put us into the hohlraum temperature range for ignition experiments at 280-300 eV

• The laser, diagnostic, target fabrication and other infrastructure capabilities needed for the ignition campaign are now in place

• We have carried out the first THD cryo-layered implosion showing most aspects of system performance

• Ignition experiments in 2011–2012 lay the groundwork for target performance which meets the need for ignition applications and IFE requirements
NIF is now capable of ignition experiments
This talk will focus on NIF, NIC and the path to laser inertial fusion energy.

NIF Project

National Ignition Campaign

Operational

2006–2012

Laser Inertial Fusion Energy

2010 and beyond
— 1 Building, 5 Hectare
— 10 year construction complete
— 30 year operation
NIF concentrates all 192 laser beam energy into a mm³ hohlraum

Matter
Temperature $>10^8$ K
Radiation
Temperature $>3.5 \times 10^6$ K
Densities $>10^3$ g/cm³
Pressures $>10^{11}$ atm
4.1 MJ laser – image of the laser bay with red beams
NIF is the World’s first Mega-Joule Facility — 1.3 MJ
NIF laser has shown excellent ability to obtain the desired pulse shape and energy.
The NIF laser is highly reproducible

This capability enables the National Ignition Campaign tuning efforts
This talk will focus on NIF, NIC and the path to laser inertial fusion energy.
Four steps to ignition

We are taking a systematic approach to learning and improving our engineering design to achieve ignition.
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• Ignition experiments in 2011–2012 lay the groundwork for target performance which meets the need for ignition applications and Inertial Fusion Energy requirements
The fall CY09 experimental campaign demonstrated excellent Coupling, Drive, & Symmetry.

**Coupling:** \( \sim 90\% \) of incident laser stayed inside the hohlraum.

**Drive:** \( \sim 285 \text{ eV} \) which is already quite close to that needed for ignition.

**Symmetry:** To within \( \sim 10\% \) of round, and tunable via \( \Delta \lambda \).

**Peer Review Papers**
- S. Glenzer et al., Science 327, 1228 (2010)
The November 2\textsuperscript{nd} experiment demonstrated ignition point design hohlraum temperatures of 300 eV
During December – August 2010 we added required functionality for yield campaigns.
All the elements are in place, the "first integrated ignition experiments" was conducted on September 29, 2010.
Tritium processing
Major new ICCS Releases
NIF has over 36 diagnostic instruments developed through international collaborations.

**LLNL**
- FABS,NBI
- Dante I & II
- VISAR
- DISC
- RAGS
- hGXI
- ARIANE
- DIXI
- NAD

**NSTec**
- Calibration
- NToF

**LBNL**
- Calibration
- Rad. Chem.

**LLE**
- NToF
- $4\omega$ fidu system
- MRS, NADS
- SPBT
- HEXRS
- PSBT

**LANL**
- GXD
- $\gamma$ burn
- Rad. Chem. II
- n imaging

**SNL**
- SPIDER
- DISC
- NAD (Cu)
- NToF

**Duke**
- Calib.

**AWE**
- FFLEX

**MIT**
- MRS
- WRF
- PSBT

**CEA**
- N imaging

Opportunities with NIF diagnostics attract scientists.
NToF*
The detectors and filters were calibrated in a month of run time at the Brookhaven Synchrotron.
Gamma Reaction History Detector
Three independent diagnostics measured 2.2 ± 0.2 x 10^{14} DT neutrons from an exploding pusher.

<table>
<thead>
<tr>
<th>Observable</th>
<th>Simulations</th>
<th>Experiment (weighted mean)</th>
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</thead>
<tbody>
<tr>
<td>Yield (Cu,Zr activation, MRS)</td>
<td>2-3e14</td>
<td>2.2x10^{14} ± 0.2 x 10^{14}</td>
</tr>
<tr>
<td>Ion Temperature</td>
<td>11-12keV</td>
<td>11.7 ± 0.5 keV</td>
</tr>
<tr>
<td>Bang time</td>
<td>1.90 ± 0.2 ns</td>
<td>1.75 ± 0.15 ns</td>
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Advanced Radiographic Capability (ARC)
47 cryogenic targets built with 90% yield since July
On September 29, 2010, NIC conducted the first cryo-layered target experiment on NIF.
In the target chamber
Final x-ray images of the THD ice layer at 17:54 pm with temperature of 18.6K

Goal is 1000x increase in yield from last year
On Sept. 29th at 8:27 p.m. (PDT), NIC conducted the first cryo-layered target experiment on NIF

- All 192-laser beams fired 1 MJ of laser energy into the hohlraum
  - Radiation drive was consistent with earlier shots at this energy (~290 eV)
  - Preliminary yield estimate was ~1 x 10^{13} neutrons based on nToF
- The capsule was filled with a mixture of tritium, hydrogen and deuterium tailored to enable the most comprehensive physics results, not to demonstrate ignition
- All systems operated successfully and 26 target diagnostics acquired data

Preliminary results of the target performance are very encouraging, analysis is continuing
This experiment demonstrated ability of the NIC team to conduct layered implosion experiments

- We have successfully fielded a indirect drive layered implosion experiment with thermonuclear fuel [6% D, 22% H, 72% T]
  - Capsules are driven in hohlraums with 288 eV radiation temperature heated by 1 MJ laser energy from 192 smoothed beams on NIF
  - The capsule was shot with a smooth 65 μm thick nuclear fuel layer at 1.5 degrees below the triple point
  - Successfully fielded 11 nuclear and 8 x-ray diagnostics
    - 14.1 MeV DT yield
    - down scattered neutrons (10-12 MeV)
    - Ion temperature $T_{ion}$
    - Capsule Shape and x-ray emission

- Experiments show compression, yield and fuel rho-r consistent with implosions that are not tuned
  - Compressed to 40 microns (x1.5 more than a symcap)
  - Yield of $8e12$ and 2.8% down scattered neutron fraction

The fielding of the first layered capsule implosions has marked the beginning of the ignition campaign on NIF
Tuning of mix, entropy, shape and velocity is prerequisite for improving THD/DT implosion performance

Reproducibility
Sensitivities
Go-forward laser and target specifications

Check of Tuning accuracy / surrogacy
Physics of layered targets
- Mix
- Ice perturbation growth
- Hot spot formation (no $\alpha$’s)

$\alpha$ heating & burn

Low yield THD layered targets

Tuning parameters

2009-10
Drive

LPI optimization

2010-11

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$\alpha$ heating & burn

2011-12

NIF–1110-20542.ppt
Moses - 31st Annual Meeting and Symposium Fusion Power Associates
We have demonstrated the ability to measure symmetry of 1st shock required to interpret single-point shock timing

Drive asymmetry is inferred from reemission sphere limb brightness vs angle

- Accuracy of ±5% in pole-to-equator drive asymmetry meets requirement
- First shot shows equator is driven with 15% higher flux as expected
And to measure shock velocity history as it compresses fuel which is critical for minimizing adiabat

Shock velocities and overtake times and distances are measured from fringe shifts off reflected reentrant optical velocity interferometer (VISAR)

Liquid D$_2$-filled Cone-in-sphere “Keyhole” replaces layered capsule

Streak record of VISAR

- Accuracies of 2% in velocity and 50 ps in timing meet requirements
- First shots have shown weaker than expected 1$^{st}$ shock, overtaken earlier than expected by 2$^{nd}$ then 3$^{rd}$ shock
We have also demonstrated the ability to measure final 4th shock timing, critical to setting final fuel adiabat.

We measure 4th shock strength from break-out time in Au witness plate

<table>
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<tr>
<th>Liquid D$_2$-filled capsule with Au witness plate at end of cone replaces layered capsule</th>
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<td>Streak record of VISAR</td>
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<tr>
<td>Merged 4th shock breakout</td>
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- Accuracy of 50 ps in shock break-out timing meet requirements
- First shot has shown slightly delayed 4th shock (< 300 ps)
Ignition: Next Steps

• Hohlraum temperature scales to ignition point design
• Laser scatter losses <15%
• Symmetry control demonstrated

• Measure ablator velocity and start mix

Underway

Commission layered target implosions
Ignition on NIF will enable development of Laser Inertial Fusion Energy (LIFE)
Experience with NIF, and evidence from the ignition campaign, are being used to define a path for LIFE

Similar:
- Physical size
- Laser energy
- Target performance
- Concept of operations (LRUs, ... )
An integrated, self-consistent plant design for LIFE has been developed

- NIF-like fusion performance
- Line Replaceable Units for all the high threat systems
- Market based diode laser technology
- Advanced thermo-electric cycle
New laser technology allows dramatic improvements in size and efficiency.
Delivery Plan

- NIF completion 2009
- NIF ignition 2011/2012
- LIFE demonstration 2020’s
- LIFE commercial 2030’s
Fusion energy - soon enough to make a difference!