Title: NIF Neutron Imaging System Update

Author(s): Frank Merrill

Intended for: NIF Diagnostics Workshop, May 5-7, 2010
Abstract

The NIF Neutron Imaging System (NIS) will provide measurements of the direct (14 MeV) and the down-scattered (6-10 MeV) neutrons generated during a capsule implosion at NIF. Two camera systems, both viewing the same scintillator array, will be used to collect these images at a distance of 28 m, where the neutrons will have been separated due to energy dependence on time of flight. The “in-line” camera system is coupled to the scintillator array with a coherent fiber bundle while the second camera system collects the scintillation light through a lens system. The status and preliminary performance characteristics are presented here along with a status update on the hardware and software required to field this system at NIF.
Neutron Imaging

Frank Merrill, LANL
for the NIS team
Neutron Imaging Team

LANL
Steven Batha, Robert Gallegos, Gary Grim, Steve Jaramillo, Drew Martinson, Frank Merrill, George Morgan, Carl Wilde, Mark Wilke, Tom Archuleta, Danielle Esquibel, Valerie Fatherley, Dave Clark, Eric Loomis, John Oertel, Doug Wilson

LLNL
David Fittinghoff, Dan Bower, Pat Roberson

NSTec
Robert Buckles, Steve Lutz, Robert Malone, Morris Kaufman
Outline

• Overview of the neutron imaging system
• Experimental results
• May experimental plans
• Future Improvements
• Analysis algorithms
• Installation plans for NIF
# Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Direct</th>
<th>Down-scattered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure size and shape of the imploded core</td>
<td>13.5-14.5 MeV</td>
<td>6-10 MeV</td>
</tr>
<tr>
<td>Minimum Field of View</td>
<td>100 microns</td>
<td>150 microns</td>
</tr>
<tr>
<td>Resolution FWHM (post-processed)</td>
<td>10 microns</td>
<td>10 microns</td>
</tr>
<tr>
<td>Yield</td>
<td>$5 \times 10^{15}-1 \times 10^{19}$</td>
<td>$5 \times 10^{14}-1 \times 10^{18}$</td>
</tr>
<tr>
<td>Signal-to-Noise ratio (peak)</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Signal-to-Noise ratio (20%)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Line of Sight</td>
<td>28 m</td>
<td>28 m</td>
</tr>
</tbody>
</table>
Systems Layout

Pinholes: 26.5 cm from TCC
Collimators
Alignment system
Scintillator at 28 m from TCC
2 Imaging/camera systems
Triggering and recording electronics
Magnification of 104
Facility safety boundary
  Collimator
  Beam stop
Neutron Imaging Hut

In-line Imaging System
- Scintillator BCF 99-55 160mm square
- 250µm fibers, 5cm thick
- 160 mm to 75 mm fiber taper
- 75 mm MCP
- 75 mm to 37 mm fiber taper
- 37 mm coherent fiber bundle
- CCD camera

Lens-coupled Imaging System
- Scintillator BCF 99-55 160mm square
- 250µm fibers, 5cm thick
- Turning mirror
- Lens
- 75 mm MCP
- 75 to 37 mm 37 mm fiber taper
- CCD camera
In-Line System Resolution: 1.1 mm

With a magnification factor of 104 the uncorrected resolution at the object plane is 11 µm (FWHM).
Lens Fabrication and Bench Testing Completed

Wavelength matched light through an Air Force resolution target shows the lens resolves 16 lp/mm exceeding design requirements.
Lens Coupled System Tests at Omega

Tests completed on April 13:
- Full system resolution
- Scintillator characterization

Measured resolution is 1.1 mm, very similar to the inline system. This results in uncorrected resolution of 11 microns at the object plane.
Features on the scintillator face are observed when the coupling is optimized. This optimization can degrade as a function of time.

New coupling design is being developed.
- Modification tested in May
- New potential design for NIF installation
Scintillator Studies

Tungsten edge at 45 to scintillating fiber array

Relative fiber rotation between layers

Grid pattern is generated by multiplying the image by an optical calibration grid.

Fiber shifts do not appear to be a significant source of resolution degradation.

FWHM of 1.2 mm
Use the upper and lower knife edge data to measure optical "in place" resolution and the tungsten (W) edge to measure system resolution.
Potential Improvements...

Practical experience with the first generation system is identifying areas for improvement.

- Optical Improvements:
  1. Design and implement improvements to optical coupling (first step in May).
  2. Investigate improved 75 mm MCP resolution (appears to be next element limiting optical resolution).

- Investigate improved scintillator design
  a. Investigate discrepancy between measured and predicted resolution function. This also would enable single fiber identification to reduce fixed pattern noise.
  b. Investigate new scintillator options
     - Improved fiber bundle assembly
     - Liquid scintillator filled capillaries (liquid A)
     - Monolithic scintillators viewed with large depth of field lenses.
  c. ...

Rough estimate based on April data
Data collected at Omega in April to investigate down-scattered neutron image

- Image collected 44 ns after 14 MeV neutron arrival.

- Analysis will continue to identify source of the very weak image (0.7%±0.5% of intensity from 14 MeV neutrons)
Smearing due to pinhole PSF almost completely removed following reconstruction.

Raw source (be257) has 70%, 23%, -6% for p2/p0, p4/p0, and p6/p0.
Initial investigations of scintillator resolution and noise effects on reconstructions

Smeared with 1 mm Gaussian at image plane

With Poisson noise added

Los Alamos
NIFv2 Pinhole Array

- Square cross section apertures in double conic profile through aperture body.
- Cone apex positioned 5 cm from front face of aperture body (26.5 cm from TCC.) (M = 104)
- FOV defined by diameter of circumscribed circle projected to TCC.

\[
\Delta_{ph} = \frac{\lambda \left| \ln\left(\pi^2 - \sqrt{\pi^4 - 64}\right) - \ln 8 \right| \cdot fov \cdot M}{2L}
\]

- The NIFv2 pinhole array is comprised of 2 pinholes sizes, 141 & 200 µm FOV:
- Calculated resolutions =>
  - (Verified using MCNP)
    \[
    \Delta_{ph}^{141} = 5.7 \ \mu m \\
    \Delta_{ph}^{200} = 8.1 \ \mu m
    \]

System resolution is dominated by pinhole position and camera resolution.
NIFv2 is designed to cover ~400 μm of FOV @ TCC.

- **21 small** FOV pinholes
  - 5 x 5 array, missing the 4 corner locations
  - Spaced on a 70μm grid
  - Array centered on central pinhole

- **16 large** FOV pinholes
  - 4 x 4 array
  - Spaced on a 70μm grid
  - Array centered around the center- No central pinhole
Pinholes are machined in layered gold slabs and stacked with high precision.

Machining of NIFv2 Pinhole array is schedule for completion on May 14 in time for installation and tests at Omega on May 25.
NIF Electronics Tests at Omega

- A 9U Rack with NIF IBC will be added to the Omega-NIS configuration for May tests.

- This will help us to:
  - Ring out NIS equipment with NIF controls and DAQ computers prior to NIF installation, reducing NIF on-site debug time
  - Become familiar with NIF controls and DAQ operations
Neutron Imaging High Level Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hardware</td>
<td>90 days?</td>
<td>Apr 28</td>
<td>Sep 1</td>
</tr>
<tr>
<td>2</td>
<td>Imaging system</td>
<td>75 days?</td>
<td>May 19</td>
<td>Sep 1</td>
</tr>
<tr>
<td>3</td>
<td>May Omega Test</td>
<td>8 days?</td>
<td>May 19</td>
<td>May 26</td>
</tr>
<tr>
<td>4</td>
<td>Start WAP Process</td>
<td>0 days</td>
<td>Jun 14</td>
<td>Jun 14</td>
</tr>
<tr>
<td>5</td>
<td>Delivery to NIF</td>
<td>0 days</td>
<td>Sep 1</td>
<td>Sep 1</td>
</tr>
<tr>
<td>6</td>
<td>Data Acquisition</td>
<td>75 days?</td>
<td>May 19</td>
<td>Sep 1</td>
</tr>
<tr>
<td>7</td>
<td>May Omega Test</td>
<td>8 days?</td>
<td>May 19</td>
<td>May 28</td>
</tr>
<tr>
<td>8</td>
<td>Start WAP Process</td>
<td>0 days</td>
<td>Jun 14</td>
<td>Jun 14</td>
</tr>
<tr>
<td>9</td>
<td>Hardware at NIF</td>
<td>0 days</td>
<td>Sep 1</td>
<td>Sep 1</td>
</tr>
<tr>
<td>10</td>
<td>LOS</td>
<td>72 days?</td>
<td>Apr 28</td>
<td>Aug 6</td>
</tr>
<tr>
<td>11</td>
<td>Pin hole complete</td>
<td>8 days?</td>
<td>May 19</td>
<td>May 26</td>
</tr>
<tr>
<td>12</td>
<td>May Omega Test</td>
<td>8 days?</td>
<td>May 19</td>
<td>May 28</td>
</tr>
<tr>
<td>13</td>
<td>Beam dump design</td>
<td>23 days?</td>
<td>Apr 28</td>
<td>May 28</td>
</tr>
<tr>
<td>14</td>
<td>Beam pipe design</td>
<td>45 days</td>
<td>Apr 28</td>
<td>Jun 25</td>
</tr>
<tr>
<td>15</td>
<td>collimator design</td>
<td>23 days?</td>
<td>Apr 28</td>
<td>May 26</td>
</tr>
<tr>
<td>16</td>
<td>Start WAP Process</td>
<td>0 days</td>
<td>Jun 14</td>
<td>Jun 14</td>
</tr>
<tr>
<td>17</td>
<td>beam pipe at NIF</td>
<td>0 days</td>
<td>Aug 6</td>
<td>Aug 6</td>
</tr>
<tr>
<td>18</td>
<td>Collimators at NIF</td>
<td>0 days</td>
<td>Aug 6</td>
<td>Aug 6</td>
</tr>
<tr>
<td>19</td>
<td>Beam dump at NIF</td>
<td>0 days</td>
<td>Jul 23</td>
<td>Jul 23</td>
</tr>
<tr>
<td>20</td>
<td>WAP Process</td>
<td>28 days</td>
<td>May 5</td>
<td>Jun 14</td>
</tr>
<tr>
<td>21</td>
<td>Rev 1 of WAP Checklist</td>
<td>0 days</td>
<td>May 5</td>
<td>May 5</td>
</tr>
<tr>
<td>22</td>
<td>WAP Plan</td>
<td>0 days</td>
<td>Jun 1</td>
<td>Jun 1</td>
</tr>
<tr>
<td>23</td>
<td>Start WAP Process</td>
<td>0 days</td>
<td>Jun 14</td>
<td>Jun 14</td>
</tr>
<tr>
<td>24</td>
<td>NI Hut BO</td>
<td>0 days</td>
<td>Sep 15</td>
<td>Sep 15</td>
</tr>
</tbody>
</table>

NIF Installation and WAP phasing schedules are in planning
Neutron Imaging System Status

• Imaging system
  – Preliminary analysis of April results (and previous data) show the imaging system works as designed.
  – Areas for improvement have been identified and we are developing and prioritizing a plan for the rest of 2010 and 2011.

• Goals for the Omega experiments scheduled in May:
  – Install and take data with the new pinhole
  – Test timing and data collection electronics in “NIF” configuration.
  – Collect neutron images with a system “as close as reasonably achievable” to the NIF configuration (not alignment system).

• Alignment system tests are planned at Omega for experiments scheduled in September.
  – Bench top demonstrations will take place this summer

• Focus at LANL will shift to software and installation at NIF
  – Forward model, analysis tools, quick look analysis tool and DAQ specifications.
  – Designing and fabricating the final pieces for installation at NIF
  – Preparing the plans and documentation required for installation and operation
  – Nearly complete in defining the WAP approval checklist.
  – Need to ensure close coordination with NIF scheduling and resources.