Development of Radiochemical Diagnostics at NIF Through Collection of Solid and Gaseous Debris

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Collection of the activated target debris after implosion for radiochemical diagnostics are under development.

Longest range – probes remaining shell.

\[(^{124}\text{Xe} + n \rightarrow ^{123}\text{Xe} + 2n)\]

\[E_{th} = 8.7\ \text{MeV} \quad 1.4\ \text{barn (14.5 MeV)}\]

\[(^{124}\text{Xe} + n \rightarrow ^{125}\text{Xe} + \gamma )\]

low \[E_{th} = 0.01\ \text{barn (1 MeV)} \quad 0.002\ \text{barn (5 MeV)}\]

Intermediate range – probes inner shell.

\[(^{127}\text{I} + d \rightarrow ^{127}\text{Xe} + 2n), \quad ^{79}\text{Br}(d,2n)^{79}\text{Kr}\]

\[E_{th} = 4.2\ \text{MeV} \quad 0.4\ \text{barn (10 MeV)}\]

Shortest range – probes hot spot region.

\[(^{18}\text{O} + \alpha \rightarrow ^{21}\text{Ne} + n)\]

\[E_{th} = 1.8\ \text{MeV} \quad 0.2\ \text{barn (3.5 MeV)}\]

Based on simulations, only \(10^{15}\) target atoms can be loaded into the capsule without interfering with implosion performance.
Collection efficiency must be optimized based on the specific elements loaded into the capsule.

- The type of debris that is generated inside the chamber during an implosion has not yet been identified.
  - For gas collection, the chamber must be evacuated efficiently without jeopardizing the confinement envelop.
  - For solid collection, debris from target chamber center (TCC) must be identified.
    - There may be a directionality of the debris based on the hohlraum design.
    - We must evaluate optimal collector materials and how far away they must be from TCC.
Radiochemical Analysis of Gaseous Samples (RAGS)
Xenon will be used for fuel density ($\rho R$) diagnostics and to test the RAGS system collection efficiency.

**Xenon Reactions**

- \((^{124}\text{Xe} + n \rightarrow ^{123}\text{Xe} + 2n)\)
  - \(E_{th} = 8.7\ \text{MeV}, \ 1.4\ \text{barn (14.5 MeV)}\)

- \((^{124}\text{Xe} + n \rightarrow ^{125}\text{Xe} + \gamma)\)
  - low \(E_{th}\), 0.01 barn (1 MeV)
  - 0.002 barn (5 MeV)

Energy dependence of \((n,x)\) cross sections provides neutron down-scattered fraction.

Calculations performed by C. Cerjan, LLNL.
Background xenon can be avoided through the use of less abundant neutron-deficient isotopes.

Isotope abundances:
- $^{124}\text{Xe}$: 0.1%
- $^{126}\text{Xe}$: 0.1%
- $^{128}\text{Xe}$: 2%
- $^{129}\text{Xe}$: 26%
- $^{130}\text{Xe}$: 4%
- $^{131}\text{Xe}$: 21%
- $^{132}\text{Xe}$: 27%
- $^{134}\text{Xe}$: 10%
- $^{136}\text{Xe}$: 10%
RAGS (Radiochemical Analysis of Gaseous Samples) is used to collect and analyze activated gases.

- Cryo pumps are closed right before the shot and the turbos are opened.
- After a shot, exhaust from the NIF turbo pumps is pushed to a pre-cleaner with He gas.
- Pre-cleaner removes reactive gases, water, and particulates.
- Xe is collected for mass spectrometry and gamma-ray detection.
- Noble gas puff is used to establish collection efficiency.

Future expansion will include subsequent stations for Kr, Ar, Ne.
The collection fraction will depend on the time constant for evacuation of the NIF chamber.

Based on calculated pumping times, gases will be collected for a few minutes.

- Calibrated noble gases will be used to measure actual pumping times.
- This is an upper limit on collection efficiency; losses due to transport and decay will be evaluated in commissioning.

Half time refers to the time required to pump out half of the NIF chamber volume.
Solid Collection for Radiochemical Diagnostics
Our initial focus has been on determining what type of debris is generated inside the target chamber.

Several witness plates were obtained from different areas to determine what type of debris was generated in the chamber.

**Al Shields**: covered Neutron Activation Diagnostic

**Ta Collimators**: part of x-ray diagnostic assembly

**Glass DDS**: covered the final optics assembly

Chamber diameter is ~10 meters
Several aluminum blast shields have been analyzed to characterize chamber debris.

Analyzed Al witness plates (n =11) that were fielded 25 – 50 cm from Target Chamber Center during the Fall 2009 campaign for shot energies ranging from 50 kJ – 1 MJ.

### Equatorial DIM Mounts
- ~6 cm
- 46 kJ, $10^9$ neutrons
- 689 kJ, $10^9$ neutrons

### Polar DIM Mount
- 4.5 cm
- 836 kJ, $10^9$ neutrons
- 567 kJ, $10^{10}$ neutrons

Exploding Pusher, No hohlraum
Cryogenic D-D capsules with a Au hohlraum
The surface of each shield was examined by secondary electron microscopy (SEM).

Evidence of Al (MP~660C) surface melt

Debris Splats and Particles (Craters) Arrived After the Al Solidified

Impact craters (~10 µm diameter) show particle velocities of ~km/s

Image field of view = 300 µm
Gold debris from target center was identified.

- Unique elemental signature – usually incorporated with Si and Cu
- These sub-micron Au features contribute little in terms of mass collection but may be of interest in terms of chemical/geometric fractionation.
SEM and Energy Dispersive Spectroscopy (EDS) indicate differences in Au content based on size.

- The majority of the features contain little to no Au and are smaller than 10 μm.
Analysis of materials both close to TCC and at the chamber wall allow for optimized collection distance.

- This Ta collimator (75 µm thick) was fielded on the end of the GXD, 80 mm from TCC.
- Melt region on front side is mainly stainless steel \( \text{MP}_{\text{SS}} \approx 1500^\circ \text{C} \) from the holding ring; there is also evidence of Ta melt \( \text{MP}_{\text{Ta}} = 2980^\circ \text{C} \).

Particle impact craters and molten splats were found on the DDS (7 meters from TCC), but at much lower concentrations.
Gold has been identified on all three shield types.

**Solid Angle Estimate**

- Gold hohlraum mass 118.48 mg
- Assuming homogeneous distribution and complete mixing, we would expect 121 μg Au to be deposited on the Al shield
- Preliminary estimates determined that < 1μg Au was collected (ε_{collection} < 3%).
- This is being verified using neutron activation analysis and mass spectrometry.

**Percent of 4π Covered**

- Ta Disk: 0.1 - 0.2%
- Al Shields: 0.1-0.4%
- DDS: 0.02%

This method is not sensitive to atomic deposition (sub-micron features).
Loss of collected debris must be evaluated.

- Al shields were not available for characterization pre-shot.
- There is no pre- and post-shot surface data comparison

<table>
<thead>
<tr>
<th>Laser Energy (kJ)</th>
<th>Distance to TCC (cm)</th>
<th>Al Thickness (mm)</th>
<th>Average Melt Depth (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>568</td>
<td>50</td>
<td>1.20</td>
<td>n/a</td>
</tr>
<tr>
<td>837</td>
<td>50</td>
<td>1.18</td>
<td>14 ± 5</td>
</tr>
<tr>
<td>689</td>
<td>25</td>
<td>1.18</td>
<td>29 ± 10</td>
</tr>
<tr>
<td>729</td>
<td>25</td>
<td>1.18</td>
<td>43 ± 12</td>
</tr>
<tr>
<td>831</td>
<td>25</td>
<td>1.21</td>
<td>32 ± 14</td>
</tr>
<tr>
<td>836</td>
<td>25</td>
<td>1.22</td>
<td>15 ± 7</td>
</tr>
</tbody>
</table>

The Al surfaces were melted and then re-condensed or ablated.
Solid collection efforts continue with new materials tests scheduled for the next Ignition Campaign.

The Passive Particle Detector (PPD) is mounted on the end of the Diagnostic Insertion Module (DIM).

- Analyzed various witness plates to determine potential collection efficiencies and minimum collector distance.
- Pairs of approved metal foils will be fielded during NIF shots where a hohlraum is present (Spring 2011)
  - These tests will not interfere with other diagnostics
  - Foils will be characterized prior to and after NIF shot
- Direct collection has been observed, but a larger area (increased solid angle) collector should optimally be designed and implemented as a DIM mount
  - Collection geometries are under development.
NIF Solid Collection Collaborators

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We would also like to thank the Los Alamos National Laboratory (LANL) Solid Collection team for their joint efforts and look forward to collaborating with them this year.
Several parallel efforts are underway to optimize collector material and deployment

- Materials optimization studies – what will make the best collector?
  - **Metals for direct collection (equator)**
  - Thin salt films for aerosol assisted debris collection (pole)
  - Samples exposed to various fluences at TITAN, TRIDENT, and ZEBRA (analysis ongoing)
- Analysis of aluminum blast shields – what are the temperature and fluence profiles?
  - Debris characterization, geometric evaluation, minimum distance
- Analysis of disposable debris shields (DDS) – where is the debris going?
  - Preferential location (use of gravity), maximum distance determination, debris characterization
- Collaborations with Colorado School of Mines and Los Alamos National Laboratory