NIF Target Diagnostic Automated Analysis Recent Accomplishments – Turning Raw Data Into Performance Metrics

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The National Ignition Facility is the world’s largest laser-based inertial confinement fusion research platform

NIF is currently in the midst of the National Ignition Campaign where the goal is to achieve a sustained fusion reaction with high energy gain

- 192 laser beams heat gold hohlraum which re-emits the energy as X-rays
- Fuel capsule contains hydrogen isotopes deuterium and tritium inside an ablator shell
- X-rays heat capsule’s ablator surface causing it to explode and creating a shock wave
- Target fuel layers are driven inwards and compressed into a small hot spot of extremely high density

- When temperature and density of the hot spot are high enough, fusion reactions occur
- High energy particles such as neutrons, gamma rays and alpha particles are released
What key information about the target is needed to optimize NIF performance?

**Key performance metrics**

- **Temperature**:  
  - Hot spot temperature  
  - Hohlraum radiation temperature

- **Density** – areal density of hot spot

- **Yield** of fusion reaction – total production of neutrons or gammas

- **Velocity** – measure of capsule radius over time

- **Shape** – symmetry of the implosion

- **Timing**  
  - Shock timing  
  - Bang time – time of peak fusion reaction

- **Preheat** of the ablator
Specialized target diagnostics record optical, nuclear, and x-ray raw data that is used to estimate key performance metrics.
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What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?

Performance Metric: Radiation Temperature History
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Diagnostic analysis usually involves a series of nonlinear & ill-posed inverse problems as well as timing analysis and unique processing.
What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?

Correct for recording device distortions
Examples: non-linear time base of oscilloscope, warping of CCD images
What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?

Combine partial datasets
Examples: stitching scope traces, overlaying images
What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?

Remove system response of specialized diagnostic hardware
Examples: Compensate for subsystem responses using parametric minimization or deconvolution, linear gain compensation, peak finding, noise suppression
What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?

Reconstruct performance metric from detected quantities

Examples: linear or nonlinear optimization for spectrum reconstruction, yield integration, peak fitting for timing, image segmentation and reconstruction
What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?

Timing analysis must be accurate to tens of ps, usually subpixel

Examples: accurate & precision peak finding, data dependent delay calculations, calibration dependent delays, cross timing with laser system
Automated analysis is run after each shot for all of these diagnostics, analysis team’s recent accomplishments are highlighted.
New nTOF analysis solves inverse problems from raw data through burn physics performance metrics, Essex Bond will review his work with a focus on time domain deconvolution.
New Dante spectrum reconstruction uses an evolutionary algorithm to estimate radiation drive, Abbie Warrick will present details of her work at the poster session.

Calculated \( V_{ch1, \text{time1}} = \sum \text{energy bins} \times \frac{\text{Total Flux per eV}}{\text{Gw/eV}} \times E (\text{eV}) \)

Calculated \( V_{ch18, \text{time1}} = \sum \text{energy bins} \times \frac{\text{Total Flux per eV}}{\text{Gw/eV}} \times E (\text{eV}) \)

Work by: A. Warrick
GRH automated analysis now reports gamma bang time and burn width with tens of ps accuracy

GRH Inverse Problems Include:

- Demodulating amplitude modulated signal from Mach-Zehnder hardware
- Stitching multiple channel data
- Deconvolving system responses of PMT and Cherenkov Gas cells using constrained least squares filtering in the frequency domain

\[ H(f)^{-1} = X(f) \cdot \text{Conj}(Y(f)) \frac{1}{(Y(f)^2 + G)} \]

Work by: J. Liebman
SXI analysis now reports camera health statistics and calculates effective hohlraum laser entrance hole size

SXI LEH size analysis includes:
- Recording instrument corrections
- Neutron noise removal
- Robust region selection
- Image segmentation: minimum perimeter thresh
- Best fit ellipse: Hough space
- Match filtering to identify all pinhole centers

Work by:
A. Warrick
J. Liebman
New SPBT Analysis reports X-ray bang time with error bars

Work by: E. Bond
VISAR automated analysis exemplifies streak camera corrections, new fiducial and comb analysis provide cross-timed shock timing image.

Work by: H. Chandrasekaran & A. Warrick
New time resolved FFLEX analysis produces preheat measurement as well as hot electron temperature and power over time.

**Results include:**
Electron preheat energy integrated to the time of the end of the laser drive.

**Work by:** E. Bond
Automated diagnostic analysis is used to estimate key performance metrics and enable NIF optimization.

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• FFLEX: E. Dewald, G. LaCaille
• Dante: K. Widmann, J. Kline, A. Moore, C. Thomas
• SPBT: D. Edgell, A. MacPhee
• SXI: M. Schneider, N. Palmer, A. Teruya
• VISAR: P. Celliers, M. May
Fifty diagnostics on NIF for ignition, HED science, and basic science

Hohlraum diagnostics

Capsule diagnostics

Ignition diagnostics

A focused national effort has developed new diagnostics providing a foundation for many programs
Gamma Reaction History
VISAR
Velocity Interferometry for Any Reflector
NIF is in the midst of the National Ignition Campaign where performance is optimized around four key metrics.

**Adiabat**
- Measure of heat transfer or entropy through the ablator.
- Can cause preheat of the Deuterium Tritium fuel.
- Goal: Low

**Velocity**
- X-ray Backlit Shell Trajectory.
- Measure of capsule radius over time.
- “Convergent Ablator”

**Mix**
- Measure of ablator mix with DT fuel layers.
- Can cause hydrodynamic instability.
- Goal: Low

**Shape**
- Measure of implosion symmetry.
- “Symcap”

**How can we measure these four key metrics as well as experiment performance variables such as radiation temperature, hot spot temperature, bang times, and fusion yields?**
Accurate diagnostic analysis enables NIF optimization around key metrics

- **Adiabat (α)**: VISAR interferometry analysis enables shock timing
- **Ablator**: FFLEX analysis reports energetic hot electrons & preheat
- **DT Ice**: Gated X-Ray Detectors use timing analysis
- **DT Hot spot**: DISC uses corrected images
- **M (Mix)**: Indicators include nTOF analysis’ neutron yield, Tion and DSR and GRH’s gamma yield
- **“HDT/DT”**: SPBT analysis reports bang time
- **Shape (S)**: Shape metrics rely on GXD, Ariane, NIS timing and image analysis
- **“Symmetry Capsule”**: X-ray and neutron core images

Performance variables including nuclear bang time, X-Ray bang time, and radiation temperature are reported from the automated GRH, SPBT, Dante, & SXI diagnostic analyses.
Fifty types of diagnostic systems are planned for the National Ignition Campaign (NIC)
The diagnostic capabilities have grown significantly.