Preprint
UCRL-JC-134007

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This article was submitted to
First International Conference on Inertial Fusion Sciences and Applications, Bordeaux, France, September 13-17, 1999

December 17, 1999

U.S. Department of Energy

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TARGET EXPERIMENTAL AREA AND SYSTEMS OF THE US NATIONAL IGNITION FACILITY

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ABSTRACT

One of the major goals of the US National Ignition Facility is the demonstration of laser driven fusion ignition and burn of targets by inertial confinement and provide capability for a wide variety of high energy density physics experiments. The NIF target area houses the optical systems required to focus the 192 beamlets to a target precisely positioned at the center of the 10 meter diameter, 10-cm thick aluminum target chamber. The chamber serves as mounting surface for the 48 final optics assemblies, the target alignment and positioning equipment, and the target diagnostics. The internal surfaces of the chamber are protected by louvered steel beam dumps. The target area also provides the necessary shielding against target emission and environmental protection equipment. Despite its complexity, the design provides the flexibility to accommodate the needs of the various NIF user groups, such as direct and indirect drive irradiation geometries, modular final optics design, capability to handle cryogenic targets, and easily re-configurable diagnostic instruments.

Efficient target area operations are ensured by using line-replaceable designs for systems requiring frequent inspection, maintenance and reconfiguration, such as the final optics, debris shields, phase plates and the diagnostic instruments. A precision diagnostic instrument manipulator (DIMS) allows fast removal and precise repositioning of diagnostic instruments. In addition we will describe several activities to enhance the target chamber availability, such as the target debris mitigation, the use of standard experimental configurations and the development of smart shot operations planning tools.

INTRODUCTION

This paper provides a summary of the NIF Target Experimental Systems. Design requirements for NIF target experimental systems and target chamber is presented. Vacuum requirements are also outlined. Special discussion of the NIF final optics assembly includes detailed design discussions. Target alignment and positioning systems are discussed as well as a summary of target diagnostics. Finally, radiation and shielding protection is described.

NIF TARGET CHAMBER SYSTEM

The NIF Target Chamber must first provide proper target illumination geometry for baseline indirect drive. This consists of 32 beams (eight groups of four beams or ‘quads’) positioned at an angle of 23.5° to a NIF baseline design hohlraum, another 8 quads at 30 °, 16 quads at 44.5°, and 16 quads at 50°. Further, access ports are being provided to accommodate direct drive. These 24 ports, which would be used when half of the beams are re-directed to allow symmetric illumination of a direct drive target, are positioned at 77.5°. The quads at 30° and 44.5° would be used for both direct and indirect drive. The chamber system must support the diagnosis of laser system performance. The chamber wall must provide a stable platform to mount, support, insulate and align targets, and provide support for diagnosis of target experiments.

The chamber must also manage shrapnel, debris, and x-rays produced by targets such that debris shields will experience an economical lifetime. Finally, the chamber system will minimize

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

personnel exposure to radiation from yield experiments, activated components, and tritium or other radioactive materials used in the chamber for experiments. The chamber has been fabricated (see Figure 1) and moved into the under-construction building that will house the laser.

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Figure 1. The NIF target chamber

The chamber vacuum system will evacuate the target chamber to the pressure required for target shots. This is 5 x 10^{-5} Torr within 2 hours for non-cryogenic targets and 5 x 10^{-6} Torr within 4 hours for cryogenic targets. Further specifications have been set for specific condensable gases. The system under operation will be able to accommodate a single diagnostic outgassing rate of 0.1 Torr-liter/sec and a cryo target with leak rate of 2.5x 10^{-4} Torr liter/sec (He/H_2) and still maintain required chamber vacuum. The system is also quite flexible in that it is designed to recover from a ruptured cryogenic yield target (that contains up to 1.5 Ci of tritium). When chamber pressure exceeds 1x10^{-2} Torr under these conditions, the off-normal roughing system routes the chamber gas to the tritium processing system for scrubbing and collection of tritium. The vacuum system is not required to evacuate the 48 final optics assemblies (FOA). Since each FOA has a vacuum isolation valve and a sealed debris shield separating the final optics from the chamber, each FOA will be pumped by a separate pumping system.

Target alignment and positioning is performed using both the 10-meter target positioner and a novel target alignment sensor (see Figure 2). The target alignment is designed to be performed to within 3 μm stability for up to 30 minutes before a shot.

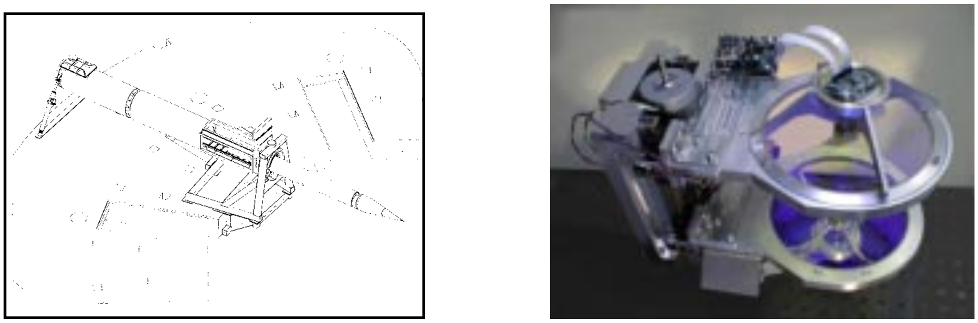

Figure 2. The target positioner is positioned horizontally to the chamber (left). The target alignment sensor is currently being acceptance tested (right).

NIF FINAL OPTICS ASSEMBLY

The NIF final optics final arrangement is highly modular and flexible. (See Figure 3) Clean and efficient insertion of a debris shield was verified with a test on the prototype Final Optics Assembly that was built in 1998 for test and evaluation purposes. A technician is shown changing a debris shield cassette under clean protocol procedures in Figure 4. The modified cassette prototype resolves cleanliness issues identified with an earlier design.

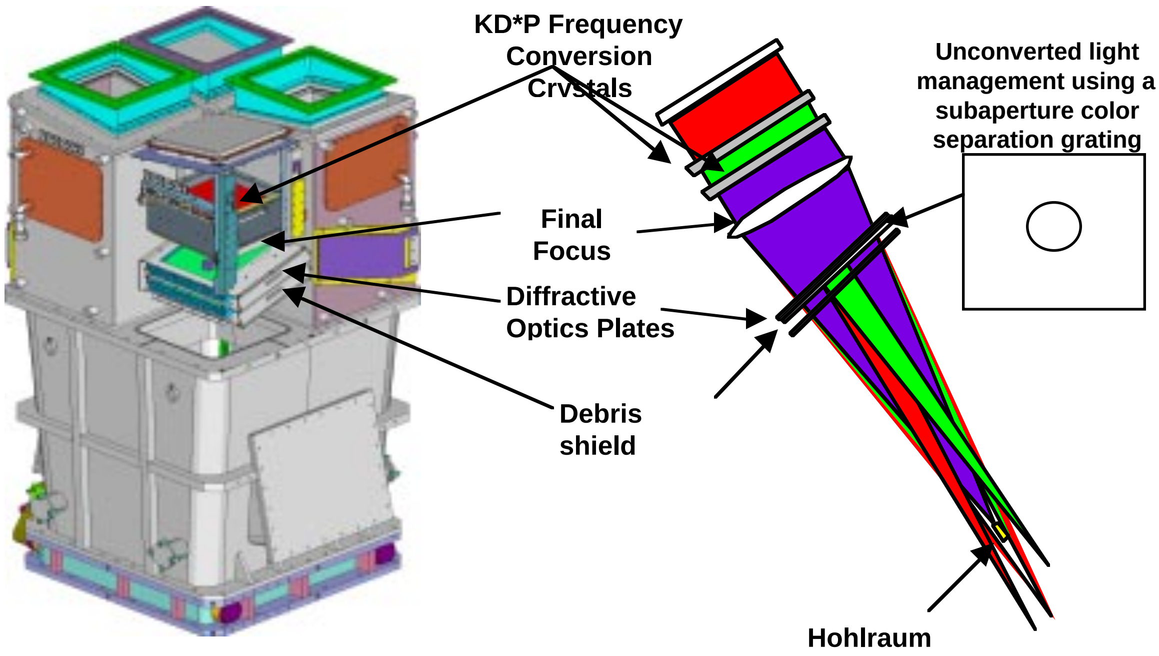

Figure 3. NIF Final Optics Assembly manages unconverted light and directs 3w beams on target.

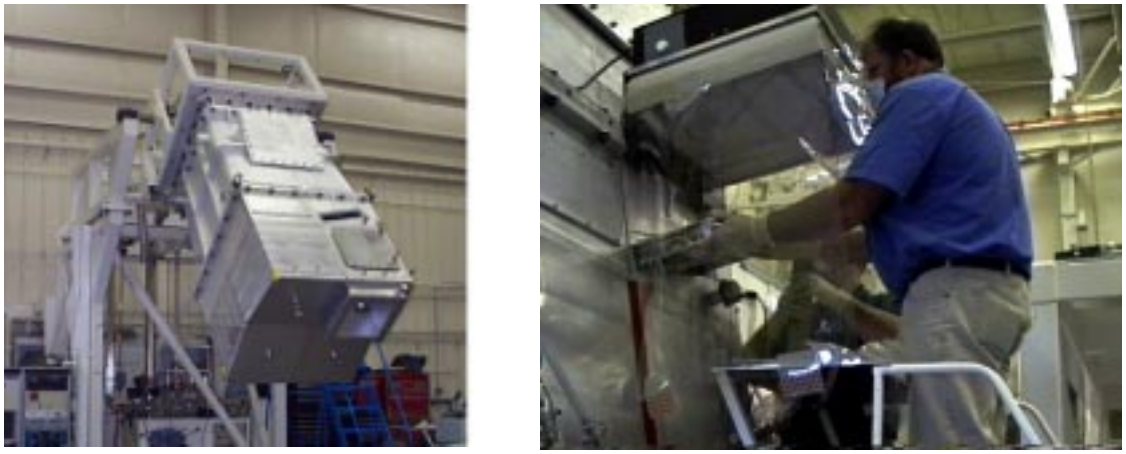

Figure 4. A full-scale Final Optics Assembly was built for testing at LLNL (left). A technician demonstrates the clean and efficient changing of a debris shield.

The unconverted 1ω and 2ω light will be managed, as suggested in Figure 3, using a sub-aperture color separation grating (CSG). B-integral effects for the high power 1-ns square laser pulse precludes using a wedged lens, the earlier candidate for unconverted light management. The diffractive grating deflects the unconverted 1ω and 2ω light from the central aperture of the beam without impacting the 3ω light which continues to be directed to chamber center. The diffracted light is distributed into a number of orders (up to 20) that are in turn directed into a range of angles. The orientation of individual CSGs will be selected to change the distribution of unconverted light to the advantage of the conduct of the experiments. An IDL model has been developed that allows visualization of the resulting patterns of diffracted light in the chamber for various grating orientations. For example, a 0° orientation for all CSGs gives a pattern at chamber center shown in Figure 5 (left). In Figure 5 (right) the same diffracted unconverted light is shown where the CSG orientation has been varied to group or cluster the unconverted light into a smaller volume in the chamber, freeing space for experiments and diagnostic access. The unconverted light is essentially confined to two wedge segments near chamber center. This can be arranged so that up to 20 cm of a ‘vertical slice’ is available for an axial diagnostic line of sight.

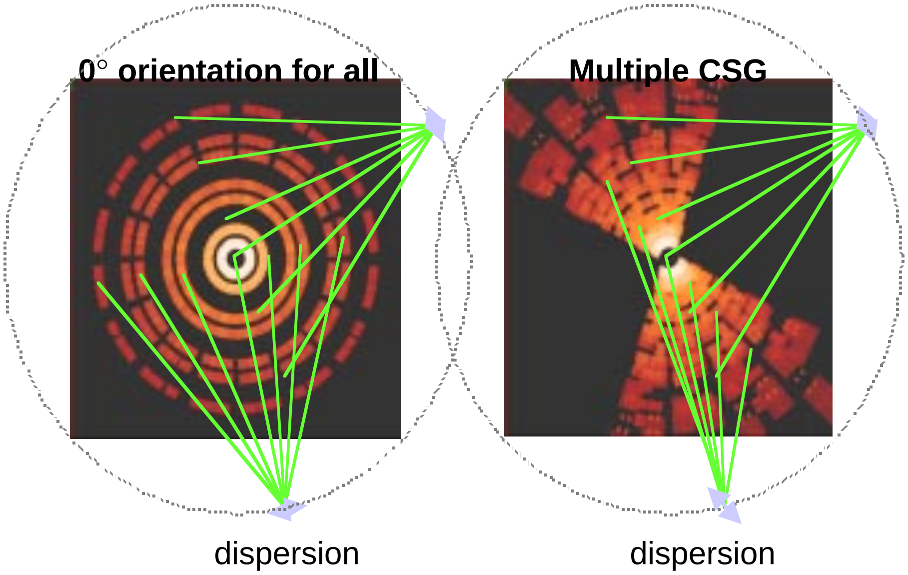

Figure 5. By changing the orientation of the color separation gratings (CSG), the diffracted unconverted light is grouped to leave sufficient to insert diagnostics close-in to the target.

NIF TARGET DIAGNOSTICS

A Joint Central Diagnostic Team (JCDT) coordinates the selection and design activities for the diagnostics for the National Ignition Facility. The JCDT has proposed the definition of and the set of the core target diagnostics for NIF. This has been accomplished primarily through well-organized and widely attended diagnostics workshops over the past two years. Additionally, certain expert groups have been organized to advise on diagnostics that have required substantial innovation and definition for the environments that will be diagnosed on NIF that are more significantly more challenging than done before on Nova or Omega.

Certain diagnostic categories have been set and defined. Core Target Diagnostics are those solely required to measure the interaction of the laser beams with the targets. These include diagnostics that verify pointing and spot size including two x-ray framing cameras at 90° to each other [DIMS + TRXI], two opposed static x-ray imagers [SXI], a full aperture backscatter system

[FABS + NBI], and an x-ray streak camera [DIMS + SSC]. DIMS is the diagnostic insertion and manipulation system. These laser characterization diagnostics are required to measure the laser beam quality, timing, energy and power. NIF Activation will use simple disk or wedge targets. These diagnostics would support the NIF Activation Phase and are shown in Figure 6.

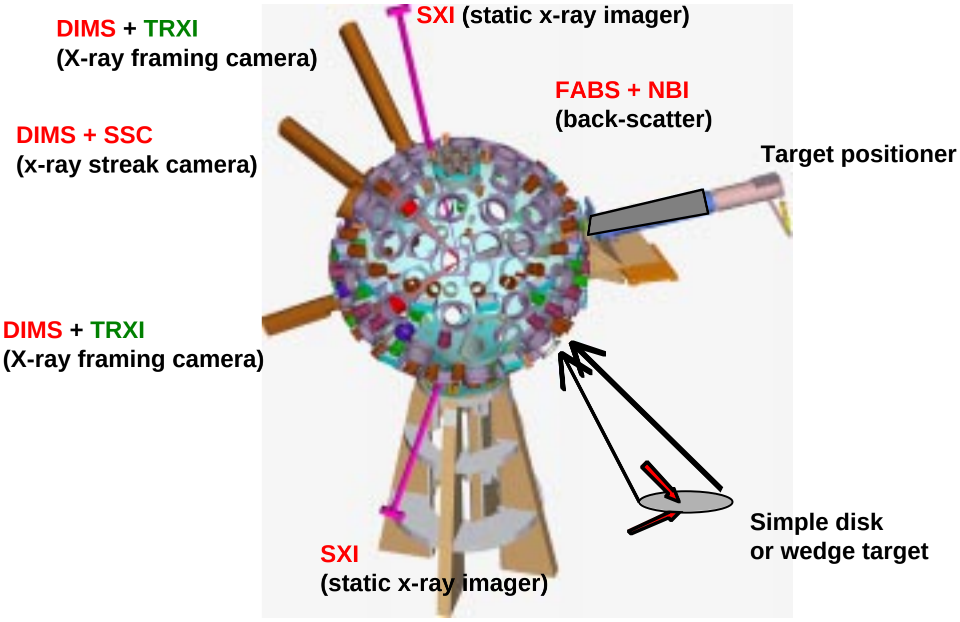

Figure 6. NIF Core Diagnostics necessary for NIF Activation

Most core diagnostics will be in place to support early single cluster experiments. These shots will use horizontal asymmetric hohlraum targets with backlighters and diagnostics including the Henway (x-ray spectrometer), the Dante (x-ray power), the SXRI (soft x-ray imager), the passive shock breakout system (PSBO), the active shock breakout system (ASBO), and the visible shock active readout (VISAR) for shock physics.

NIF Phase 2 will provide symmetric illumination for the first time and therefore supports vertical hohlraum experiments and requires additional diagnostics to the core set. In addition to the set of diagnostics above, the DIMEXART x-ray power diagnostic will be in place and eventually the suite of nuclear diagnostics including the BT (bang-time), three NTOF diagnostics (neutron time-of-flight), the YN (total yield), the TSPEC (spectrometer), the FFLEX (high energy x-ray spectrometer [fast filter fluorescer]), and the NS (Tion) (neutron spectrometer). These are shown in Figure 7. The User experimental plans currently being linked to the startup phases of the National Ignition Facility (NIF) by the ICF/NIF Mission Support Organization.

NIF RADIATION SHIELDING AND PROTECTION

With full laser capability and mature ICF target designs, the NIF target bay may eventually have to contain up to 1200 MJ per year of total yield, perhaps fifty 20-MJ shots or one per week, at some time during its 30-year life. At these levels of neutron irradiation (4.3 x 10^{20} neutrons released), neutron activation is critically important within the NIF Target Bay both from a safety perspective and for numbers of other experiments possible per year. Stay out times limit access after high yield shots and therefore also limit the total number of shots possible in a year. The DOE has committed to maintaining the NIF total worker dose to less than 10 person-rem per year. This means that the sum of all of the workers' radiation doses multiplied by the total number of workers on the NIF site during the year will not exceed 10. Any individual's maximum dose will not be greater than 500 mrem in any one year. This is 1/10 of the 10CFR835 limit as per the LLNL Health and Safety Manual. Prompt doses will be maintained to less than 30 mrem per year in any area that would be occupied for a shot inside or outside the facility (for example walking next to the outside wall of the facility). Extensive three dimensional neutron transport modeling has been performed on the entire target bay, switchyard, and laser bay. Target bay components, in particular, have been analyzed for post-shot induced radiation levels. These analyses support the use of about 1-m of shotcrete around the chamber as neutron and gamma ray shielding. Approximately five to seven days of stay-out time may be needed after shots as large as 20 MJ to meet all of the radiological exposure standards for the NIF. During NIF operations radiation doses will be maintained "as low as reasonably achievable".

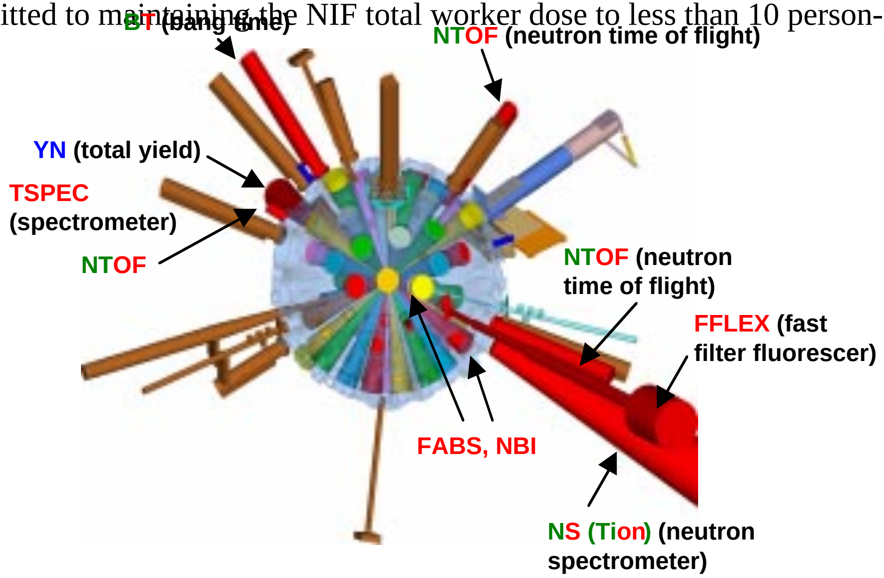

Figure 7. The final stage of NIF diagnostics includes the build-out of nuclear diagnostics.

ENHANCING TARGET CHAMBER AVAILABILITY

Substantial efforts are ongoing to evolve target and diagnostic designs that will create as benign a set of effects (shrapnel, debris and x-rays) as possible on debris shields and diagnostics. With minimum debris shield impacts, more experiments will be able to be conducted per year. Further, the operating budget for NIF will be affordable due to only a modest fraction of resources going to maintain and replace debris shields which will also enable a maximum shot rate. Research is continuing to develop a one-shot disposable debris shield that would suffice for at least the majority of experiments on the NIF. Currently transmission and flatness issues limit the usefulness of several 'throwaway' debris shield candidate materials. NIF experiments will be analyzed well in advance (few months) for their specific effects on the chamber and 'certified' or 'standardized' as to the 'wear' or 'burden' placed on the chamber systems, especially the debris shields. In that way, a code that can fold in the integrated effects of a series of many standardized experiments will be able to optimally schedule shots that provide the most shots during a given time period and still get the most possible use out of the installed set of debris shields. This smart planning tool is under development and will be available when NIF operations commence.