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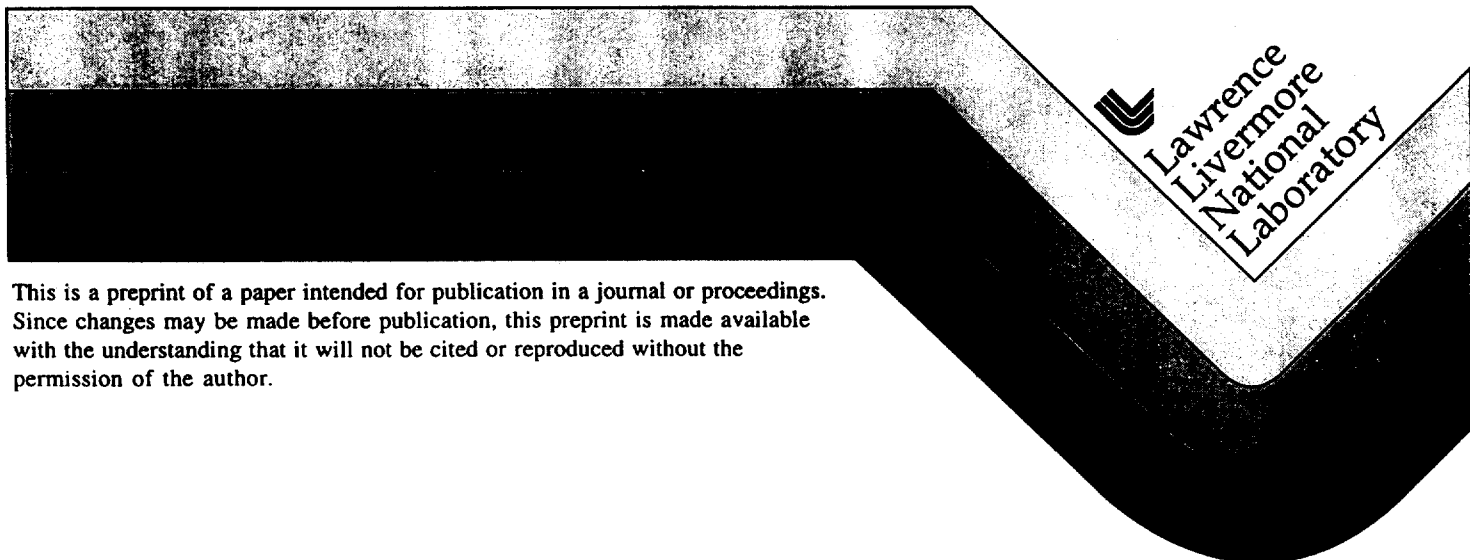
Design of the Target Area for the National Ignition Facility

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ABSTRACT

The preliminary design of the target area for the National Ignition Facility has been completed. The target area is required to meet a challenging set of engineering system design requirements and user needs. The target area must provide the appropriate conditions before, during, and after each shot. The repeated introduction of large amounts of laser energy into the chamber and subsequent target emissions represent new design challenges for ICF facility design. Prior to each shot, the target area must provide the required target illumination, target chamber vacuum, diagnostics, and optically stable structures. During the shot, the impact of the target emissions on the target chamber, diagnostics, and optical elements is minimized and the workers and public are protected from excessive prompt radiation doses. After the shot, residual radioactivation is managed to allow the required accessibility. Diagnostic data is retrieved, operations and maintenance activities are conducted, and the facility is ready for the next shot. The target area subsystems include the target chamber, target positioner, structural systems, target diagnostics, environmental systems, and the final optics assembly. The engineering design of the major elements of the target area requires a unique combination of precision engineering, structural analysis, opto-mechanical design, random vibration suppression, thermal stability, materials engineering, robotics, and optical cleanliness. The facility has been designed to conduct both x-ray driven targets and to be converted at a later date for direct drive experiments. The NIF has been configured to provide a wide range of experimental environments for the anticipated user groups of the facility. The design status of the major elements of the target area is described.

1. INTRODUCTION

The Department of Energy is proposing to construct and activate into operation the National Ignition Facility (NIF) by the year 2002 to embark on a program to achieve ignition and modest gain in the laboratory. The preferred site is the Lawrence Livermore National Laboratory (LLNL). The NIF Project has completed the Title I preliminary design phase.

The NIF will consist of a 1.8-MJ, 0.35-mm laser with 192 independent beamlets. This represents a 50-fold increase in laser energy over the Nova laser at LLNL. The main laser pulse will be ~3 ns and 500 TW of power. Target experiments will be positioned and contained in a 5-m radius, 10-cm-thick aluminum sphere. Diagnostics are primarily positioned around the mid-plane of the sphere for data collection. The NIF Target Area is designed to safely contain up to an annual yield of 1200 MJ distributed among shots ranging from ~100 kJ to 20 MJ, with as many as 350 shots producing significant D-T neutron yield each year. In addition, as many as 850 non-yield shots may also be conducted in the same year, depending on the quantity of induced radioactivity and access requirements to support the desired shot rate. Although indirect drive inertial confinement fusion (ICF) is the baseline, direct drive experiments will also be possible after a conversion time to reconfigure the beam paths.

The neutron, x-ray, debris, shrapnel, and unconverted light environments created by these experiments introduce unique conditions requiring innovative design solutions to allow confinement of ignition and yield. Solutions to these issues include in-chamber laser light absorbers and a first wall facing material designed for x-ray protection. Confidence in overall Target Area system performance will be developed by evaluating the

ability of the various subsystems, once established to meet design requirements, to interact safely, affordably, and with low risk to meet the required shot rate.

2. TARGET AREA PERFORMANCE CRITERIA

The Title I (Preliminary Design) target area component designs were based on the NIF system design requirements (SDRs). The SDRs provide a detailed apportionment of the various positioning, stability criteria, and operating parameters as required by the primary criteria and functional requirements. These include:

- Contain 1200-MJ annual yield
- Conduct 50 shots of 20-MJ yield in one year
- Withstand a 45-MJ maximum credible yield
- Field both cryogenic and non-cryogenic targets
- Operate in both classified and unclassified modes
- Conduct non-yield experiments every four hours
- Achieve a vacuum of $< 10^{-5}$ Torr
- Position and align a target to within 50 μm (SRSS).

Additionally, the target area will not preclude the ability to:

- Add a second target chamber for weapons physics or radiation effects testing
- Conduct direct drive experiments
- Conduct radiation effects testing, which includes allowing laser irradiation of distributed target arrays.

3. TARGET AREA ENGINEERING

The NIF target area engineering team has responsibility for the design of all the subsystems associated with the Target Experimental Systems. The subsystems include the target chamber, target positioner, structural systems, target diagnostics, environmental systems, and the final optics assembly.

These designs must provide mounting structures that provide stability from both vibrational and thermal excursions, the target chamber environment, including the vacuum system, first wall for debris protection, and beam dumps to absorb stray, and unconverted laser light; the target positioner for the precise location and stability of targets including cryogenic targets, multiple diagnostics systems to receive and record a wide variety of experimental information; beam transport and final optics for steering, aligning, frequency conversion and focusing the multiple laser beams onto the target, and finally providing the equipment, space, and methodology for the installation, removal, and maintenance of the optical components, diagnostics and target chamber systems.

3.1 Structural design

The target area building is used to provide the basic shielding, structural support, opto-mechanical stability, and thermal conditioning for the experimental equipment that is being designed to meet the functional requirements.

The target bay facility is bordered by six-foot thick concrete walls of conventional construction. There are six interior concrete floors, each one-foot thick, ribbed, and column supported that provide access to chamber subsystems, and stability for the turning mirrors, target positioner, target diagnostics, and target chamber. Beam entrances from the switchyard to the target bay are enclosed in concrete collimators that extend six feet into the switchyard to suppress neutron leakage into the laser bay. The roof of the target bay is 4.5-feet thick (see Figure 1).

The target chamber sits in a shielding cylinder and is surrounded by horizontal floors for easy access

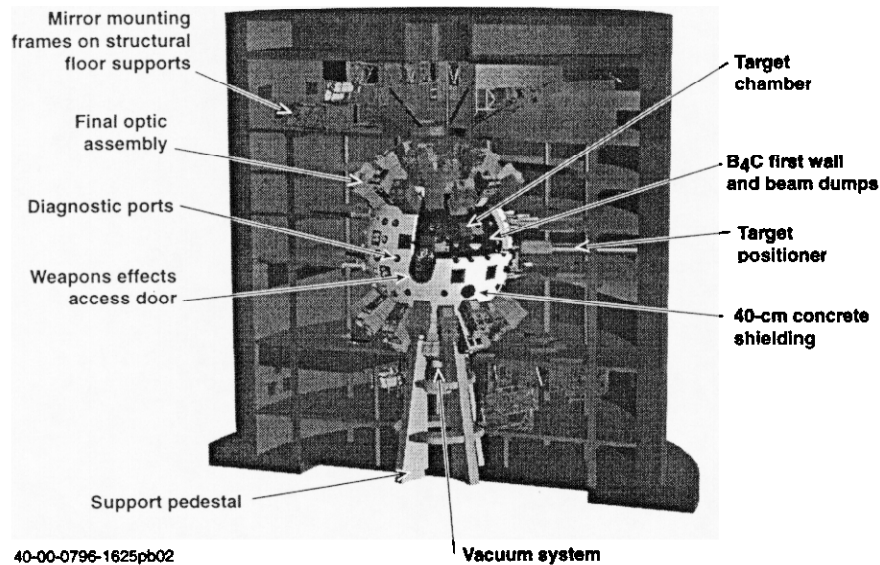


Figure 1. Overall view of the target area facility and the integrated subsystems.

The design of the structural system must provide a stable platform of less than $\pm 7 \mu\text{m}$ translation and $\pm 0.7 \mu\text{rad}$ RMS rotation under both random vibration and differential thermal environments for the turning mirrors, target positioner, and final optics assemblies (FOAs).

In order to meet these requirements, several stability design features have been incorporated into the facility since the conceptual design report (CDR) (Figure 2), and include:

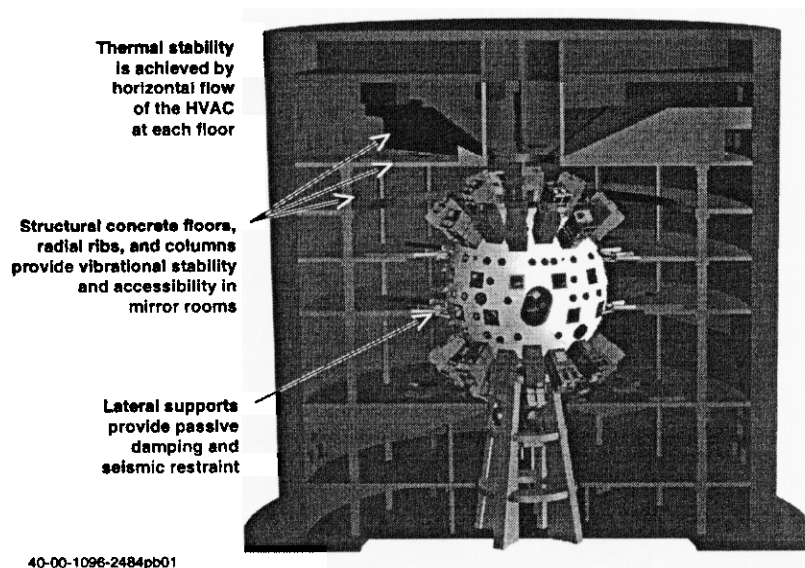


Figure 2. Structural supports provide a vibrationally and thermally stable platform for the target area

- Enhanced stiffness, reduced mass concrete structures
 - Radial, built in ribs
 - Steel/concrete truss structures
 - Interfloor columns
 - Support from switchyard walls
- Passive damping improvements
 - Chamber-to-building attachments (FOA stability)
 - Constrained viscoelastic layers (target positioner)
 - Constrained layer damping of the mirror support structures

The vibration, structural, and thermal performance of the system has been evaluated with global finite element models. These models have included the building, target chamber and pedestal, mirror mounts, target positioner, and chamber-to-building attachments with passive damping techniques to improve stability.

The results of the random vibration analysis of the facility structures shown below and in Figure 3 are based on a random input vibration $1 \times 10^{-10} \text{ g}^2/\text{Hz}$ from 1–200 Hz.

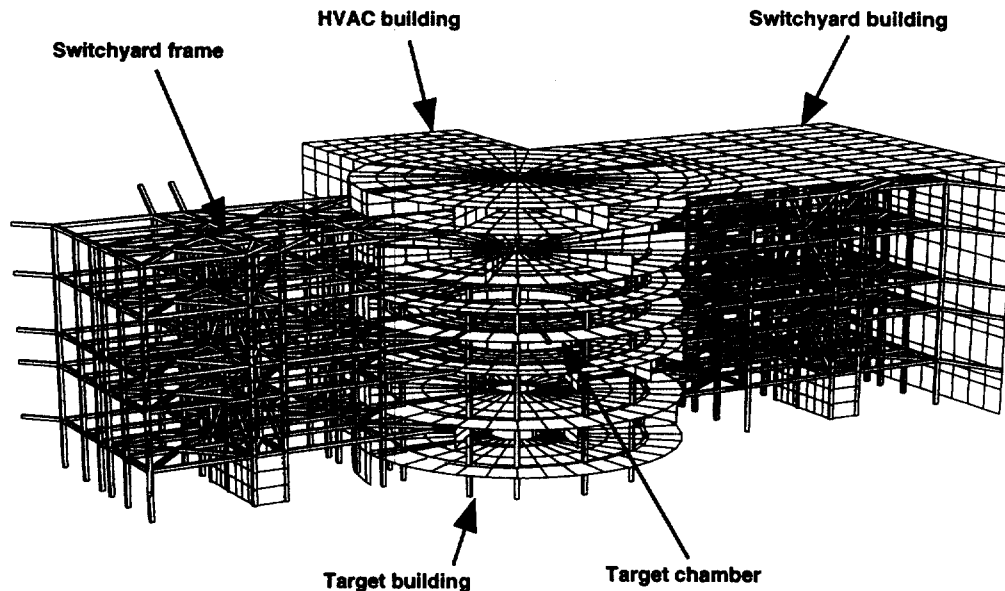


Figure 3. Global finite element model has been used to evaluate random vibration of the building and equipment.

- Eigenfrequencies
 - Floor diaphragming: 6.8 Hz
 - Rocking of building: 7.3 Hz
 - Mirror mounts: ~29 Hz
- Rotational displacement near mirror mounts
 - ~0.75 μrad SRSS
- Stability performance of structures limited by displacement of floors
 - Mirror frames
 - Relatively stiff
 - Passive damping will reduce displacement

3.2 Target chamber

The target chamber, as shown in Figure 4, is a 10-m-diameter sphere, constructed of 10-cm-thick 5083 aluminum. The chamber is located in the center of the target bay and is supported in the vertical direction on a four-tier pedestal and laterally with viscoelastic damping and support structures from the facility floors near the equatorial plan. These connectors serve as stability, seismic and torsional supports.

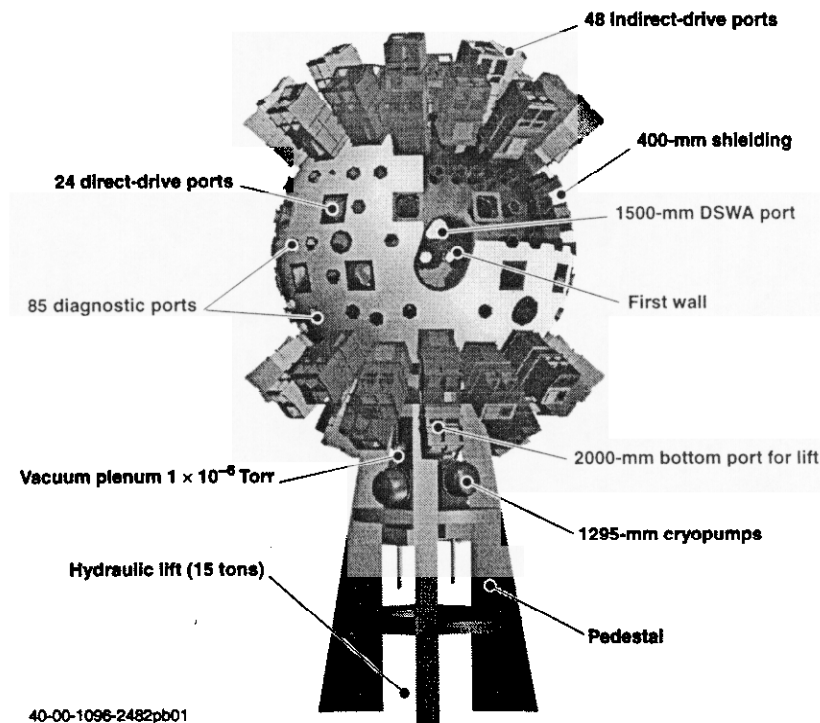


Figure 4. A 10-m-diameter target chamber has been designed that meets the functional requirements for NIF.

The chamber is routinely maintained at a vacuum of 5×10^{-5} Torr by use of an oil-free vacuum system capable of reaching this pressure within two hours. This is provided by four 1.3-m cryopumps. The chamber has ~150 penetrations including: 85 diagnostic ports, 72 laser beam ports (four beamlets per port) for both direct and indirect drive configurations, three ports for the target positioners and target alignment assemblies, and a single large waist port for Radiation Sciences experiments. All these ports have extension tubes between the chamber wall and the flanges to accommodate gamma/neutron shielding. This shielding consists of 40-cm thickness of concrete over the aluminum chamber wall.

This target chamber will most probably be constructed on-site by full penetration welding of multiple sections. Based on manufacturing capability, construction schedule, cost and transportability, the chamber will be either assembled outside the target building and moved or assembled in place on the pedestal during the construction of the target building.

3.2.1 Chamber first wall

The inner wall of the target chamber includes approximately 350 B_4C panels (either hot-pressed or plasma-sprayed on aluminum) each ~ 1-m² panel will be mounted on the chamber wall as shown in Figure 5, to provide first wall protection to x-ray emissions.

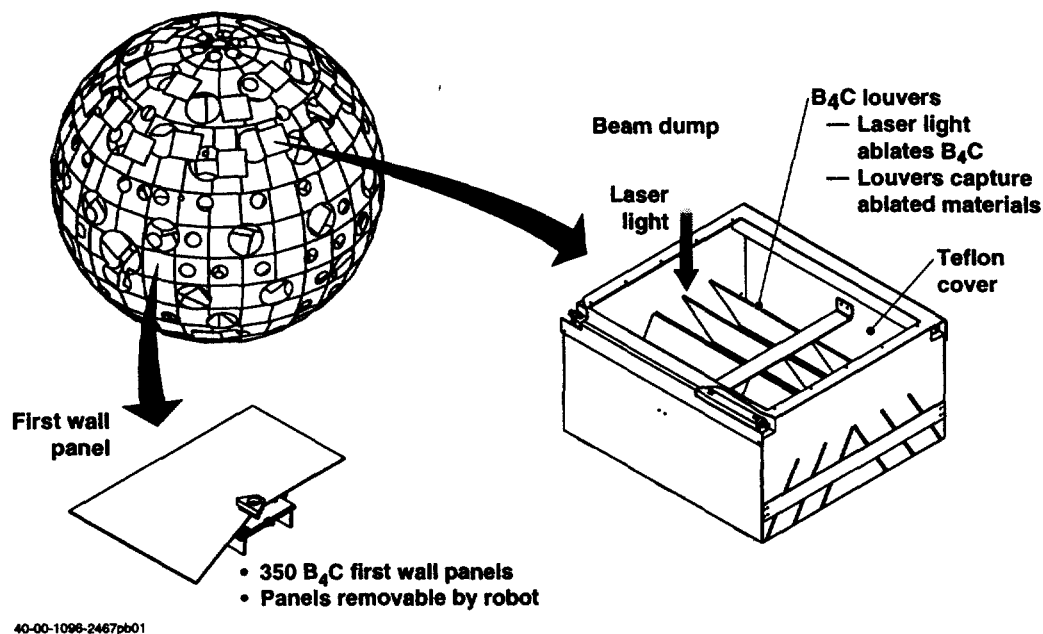


Figure 5. The chamber first wall and laser light beam dumps are incorporated inside to protect the chamber wall.

3.2.2 Unconverted light absorber

In addition to the B_4C first wall panels, there are beam unconverted light dumps attached to the chamber wall. Existing beam dump designs have used Cu-doped phosphate glass, covered with fused silica. Presently, a much lower cost option is being evaluated. These new light absorbers (shown in Figure 5) are constructed from B_4C louvers inserted in a B_4C lined box, which is covered with a Teflon film. As laser light hits the B_4C , the material ablates. The ablated B_4C is captured on the back surface of the adjacent louvers and by the teflon film cover which is stored on rollers and can be replaced remotely as required. Initial tests of this concept have been encouraging and preliminary design, analysis, and costing are continuing.

3.2.3 Chamber maintenance

The chamber has a vertical access port at the bottom of the vacuum pump-out tube which is located inside the support pedestal. A 15-ton hydraulic lift extends from below the target bay floor and is used to lift a remotely operated six degree-of-freedom articulated robot (Figure 6). This robot can be used for remote or manual operation with several attachments. The primary use will be for installation and removal of the first wall and beam dump panels.

3.3 Target positioner

The positioner requires: 6- μ m positional accuracy, 6- μ m SRSS stability (vibrational and thermal), three translational degrees of freedom, two rotational degrees of freedom, and the ability to support a 150-kg, 2-m \times 50-cm-diameter target transport cryostat. The positioner has the capability to support both non-cryogenic, as well as cryogenic targets. The boom of the target positioner is made from graphite fiber-reinforced composite, chosen for low activation, low coefficient of thermal expansion (CTE), and high stiffness/mass ratio. (See Figure 7.)

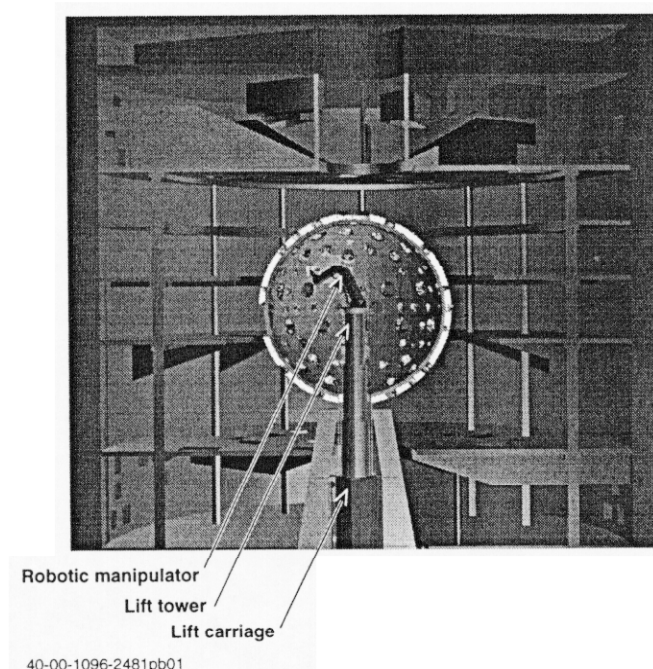


Figure 6. Target chamber maintenance is achieved with a robotic manipulator.

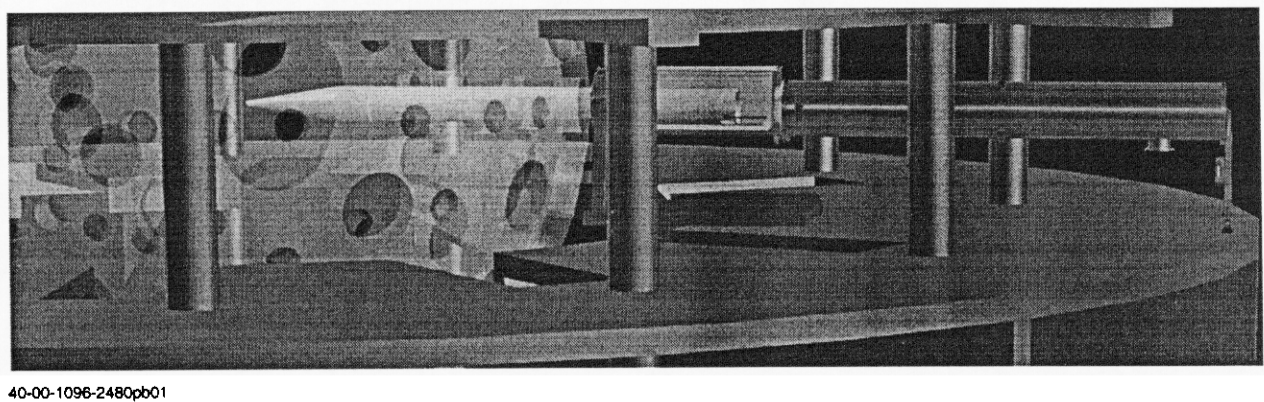


Figure 7. The target positioner incorporates advanced materials and passive damping technologies and is capable of precision location of NIF targets.

The boom is sectioned for ease of installation and maintenance, and commonality of the target positioner and target alignment systems. A borated, hydrogenous, viscoelastic material will fill all or a portion of the boom structure to provide line-of-sight protection from neutrons for the extension and articulation structures and mechanisms. This will permit the use of conventional materials in the mechanism sections, and also provide some passive vibrational damping.

The boom which will also incorporate two-axis remotely-operated articulation just aft of the kinematic target assembly mount, will be extended from an external enclosure, loosely coupled to the target chamber by a bellows. The gimbal support structure carries the weight and pressure loads to the target bay floors. The boom is inserted along longitudinal and guide rails and driven by coarse and fine positioning drive screws.

The preliminary design has been analyzed for random vibration using a finite element model. The results show that the target positioner has a first fundamental bending mode of approximately 10 Hz and a resulting displacement of the target of 9 μm .

3.4 Diagnostics

The NIF Target Diagnostics are divided into two groups. This division is by purpose of the diagnostic equipment. The first group of diagnostics is to be used to verify the performance of the laser system. These diagnostics are specifically designed to measure the simultaneity of arrival of laser pulses, laser beampositioning accuracy, laser spot size, and the laser pulse smoothness. All of these measurements are to be made on target. The second group of diagnostics will support the ignition and weapons physics experiments. These diagnostics will be designed to measure x-ray emissions from imploded cores, radiation flux out of hohlraums, ion temperatures, duration and time of thermonuclear burn, laser light backscatter from the target, and other parameters of interest.

There are three diagnostics specified to be used in laser performance and verification testing. These are a time-resolved x-ray imager (TRXI), an x-ray streaked slit camera (XSSC), and a static x-ray imager (SXI). The TRXI is a gated imager capable of taking multiple images of the imploding target with enough spatial and temporal resolution to measure spot size, pointing, and smoothness. The primary requirements are for x-ray imaging in the x-ray energy range from 3 to 10 keV with a temporal resolution of 50 to 100 psec. The XSSC records a streaked image of the target with temporal and spatial resolution sufficient to verify beam simultaneity on target and beam smoothness. The required temporal resolution of the XSSC is 10 psec. The SXI is an integrating x-ray imager which will be used to verify pointing accuracy. The design requirements for the SXI are a 1-cm field of view, a spatial resolution of 25 μm , and sensitive to x-rays in the 2 to 3 keV range.

The three diagnostics mentioned above and about sixteen additional diagnostics will be used to support the ignition and weapons physics experiments. These diagnostics are special diagnostics to measure neutron and gamma ray radiation, high energy x-rays and other parameters. They consist of spectrometers, imagers, streak cameras, transient digitizers, and other specialized detectors.

The experimental diagnostics are distributed around the NIF target chamber. Figure 8 shows the target chamber with the full complement of diagnostics and final optics assemblies mounted on the target chamber. Locations for the diagnostics were determined from requirements published by the experimenters responsible for each diagnostic.

To support these diagnostics, a distributed data acquisition system is being designed. The design requirements for this system include local and remote operation of each diagnostic, the capability to accommodate a variety of diagnostic controllers, archiving of all data both diagnostic and laser performance, easily expandable for future growth, and the capability to support both unclassified and classified experiments. The capability to accommodate a variety of diagnostic controllers results from the fact that diagnostics will be designed by different organizations over a long time period. To accommodate the variety of different computer/controllers the network interface, the commands structure, and the data structure are being specified. A group of computers/controllers are being suggested, but a diagnostic controller that complies with the specified interface will be supported.

The target area diagnostic system will also provide other support such as an integrated timing system, control functions, space for setup and maintenance functions, and other utilities.

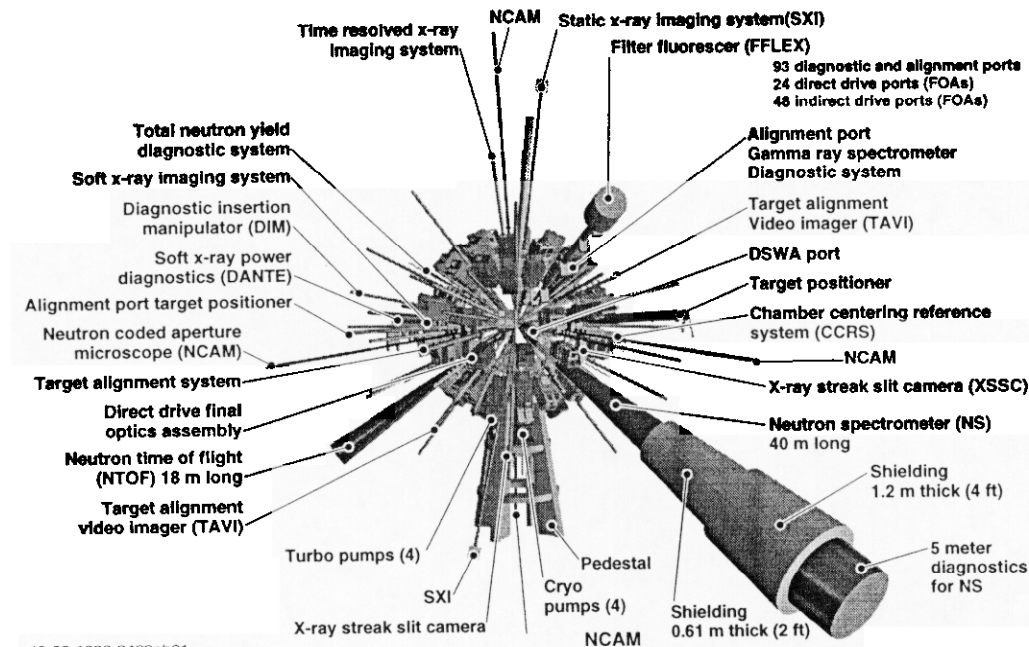


Figure 8. Numerous experimental diagnostics are being planned for the NIF target chamber.

3.5 Beam transport

The current optics design employs a specially developed diffraction grating in the final optics assembly to disperse the unconverted away from the target. A no-wedge focus lens design demands greater horizontal separation during the final portion of transporting the 2×2 beamlet bundles. The layout allows the use of improved unconverted light schemes after the requisite diffraction grating is developed.

The beam transport design for this no-wedge system incorporates the use of interconnecting beam tubes between switchyard turn mirrors and the turning mirrors in the target room. The beam tubes will be mostly 2×2 beam configurations and are designed to accommodate the use of Argon fill gas at an overpressure of ~ 2 cm of water.

The beam tubes enter the target room from the switchyard at two vertical locations, the upper mirror room and the lower mirror room. Within each of the rooms there are 24 beamlines, 12 entering from each switchyard, which are 180° apart. The twelve beams enter each side of the mirror room at three different vertical positions. The space congestion created by the large $1\text{-m} \times 1.6\text{-m}$ beam tubes presents a difficult task for the installation and maintenance of mirror enclosures, diagnostics and operational equipment within this space. Telescoping beam tube sections will be used at the floor level in the mirror rooms to provide accessibility to this equipment.

Since these beam tubes are filled with Argon gas and are connected to optical components at the mirror enclosures and the final optics assemblies, there will be a hermetic seal between the beam tube and the Class 100 clean area required for the optical components. When these optical components are removed for maintenance, in order to meet these criteria, two closure devices have been designed. For the individual beam lines at the FOA and mirror enclosures, a guillotine device similar to the Standard Mechanical Interface (SMIF) systems used in clean room transfer operations in the silicon wafer manufacturing industry has been designed and is currently undergoing prototype evaluation. This guillotine device is inserted between the beam tube flange and the optical assembly. The guillotine has two sealing plates with o-rings, that when separated expose a clean surface to the optical element that is sealed to the external environment. After the beam tube and optical assembly are

separated, and the optical assembly is removed, the exposed surface of the guillotine will become contaminated. Upon reassembly of these beam tubes and optical assembly, the two contaminated surfaces of the guillotine come into contact and are again joined together, and when the guillotine assembly is removed, the space between the optical component and the beam tube remains as a clean environment.

Sections of the larger beam tubes that enclose a 2×2 array of laser beams can be separated by telescoping into adjacent sections. When the tubes are separated, the Argon gas must be contained while controlling contamination that will cause damage to optical components. The preliminary design of a rolling film seal has been completed. This rolling seal uses a reel of kapton film that is passed between rollers on both sides of the beam tube. Before the beam tubes are separated, a solid sheet of film is unreeled to cover the face of each side of the beam tube. An inflatable gasket is activated to hold the film in place and seal against the Argon pressure. The beam tubes are then separated and retracted.

When the process is reversed, the gaskets are deactivated, the reel of film is advanced, with the new section of film having a cut-out large enough to pass the laser beams.

3.6 Final optic assemblies

The FOAs have to meet the following system requirements: $6\text{-}\mu\text{m}$ SRSS lateral stability, $10\text{ }\mu\text{rad}$ angular stability, $\pm 0.1^\circ\text{C}$ thermal control of conversion crystals, $2\text{-}\mu\text{rad}$ resolution of angular adjustment, $\pm 50\text{ mm}$ range of motion for focus, level 50 cleanliness on optics and level 100 for adjacent surfaces, and vacuum levels of 5×10^{-5} Torr. In order to meet these requirements the assembly has been designed in modular fashion where separate components address the key design requirements.

An FOA incorporates 4 beamlines; this results in 48 assemblies populating the target chamber. The FOA, Figure 9, is broken into the following structural elements. A target chamber vacuum isolation valve, which is the direct FOA interface to the target chamber. A 3ω calorimeter chamber, which provides for the mounting of the calorimeter detectors as well as a stable interface for the critical optical elements housed within an integrated optic module (IOM). Temperature stability of this FOA is maintained by use of water cooling through waffled panels surrounding the FOA. Four IOMs are bolted onto the 3ω calorimeter chamber. This IOM consists of a vacuum window, two KDP crystals that convert the frequency of the light, and a focus lens that provides focus to the beam as well as perform other diffractive effects to the beam (i.e. beam smoothing, color separation and 3ω sampling). The vacuum window is at the entrance of the IOM; the thickness of this window (43 mm) has been sized based on finite element analysis to keep the maximum principal tensile stress to less than 500 psi.

The optical package within the IOM is the Final Optic Cell (FOC). This aluminum-based package provides support and locates the conversion crystals accurately to the beamline. Additional provisions are made for the mounting of the final focus lens and a diffractive optic plate. The fabrication tolerances specify that surfaces be flat to $5\text{ }\mu\text{m}$ with angular position accuracy of $10\text{ }\mu\text{rad}$. The FOC has been recently prototyped using diamond turning technology to produce figures with these tolerances, and tests of assembly procedures have been completed that demonstrate the viability of assembling the fragile KDP crystals to the flat and relatively hard surface of the FOC.

Each beamline has the capability of individual adjustment for focus and tip/tilt to the beamline. This adjustment capability is achieved by incorporating three motor-driven leadscrew assemblies per beamline. Through the proper sequencing of these three screws, translation along the beamline as well as tip/tilt to the beamline can be achieved. An important aspect of this design is the use of minimum constraint design or kinematic mounts provided between the FOC and the adjustment system. With this system, application of motion on the cell will not unduly influence or distort the optics within the cell.

The maintenance of cleanliness is important for the optics; therefore the selection of materials, such as the use of vacuum compatible greases (low vapor pressure), as well as design layout choices (direction of gravity with respect to optical surface and moving elements), is to be carefully considered.

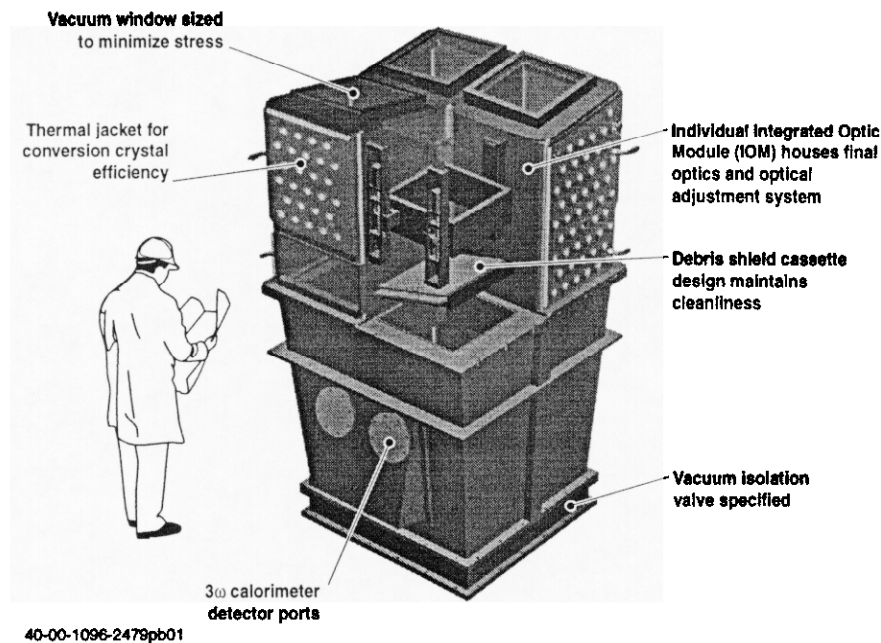


Figure 9. A modular design has evolved that achieves greater system flexibility.

NIF system operation and maintenance were taken into account during the design of the FOA. The concept of individual IOMs as separate line replaceable units (LRU) was the result of these considerations. This IOM unit is smaller in size (1 m long by 0.6 m wide by 0.6 m deep) and weight (200 kg), is easier to handle in the congested target area, reduces the number of spares required, particularly the valuable optic element of the conversion crystals and focus lens, and reduces overhaul time in the optical assembly area. With this design, only the optical elements within a particular beamline will be taken off-line for refurbishment.

The FOA also contains the debris shields that will require replacement as often as once per week. The current design will meet this requirement by placing a debris shield within a cassette or frame on which insertable guillotine or covers can be placed across the beamline prior to removal. This double guillotine separates after insertion with one cover staying on the cassette thus maintaining cleanliness of the debris shield and the other cover staying with the IOM thus maintaining cleanliness within the IOM and its housed FOC. A key part of the design is the use of a local gas supply system which will provide a slight positive pressure within the IOM and not allow contaminated or "dirty" air to enter the IOM.

3.7 System installation, maintenance, and environmental protection

Many of the target area components are large and cumbersome in size and/or weight (several hundred to several thousand pounds). Initial installation or routine maintenance of these components requires unique handling systems to access these components in confined spaces without removing large amounts of adjacent equipment. Due to the heavy target experiment schedule planned during operations, the time allocation for maintenance periods needs to be kept short.

The target area system design has focused on keeping line replaceable units (LRUs) to single beamlines where possible. Mirror enclosures, IOMs, and debris shields are the most common LRUs and have mostly been designed for single beams.

The mirror enclosures and IOMs will be removed with the six degree-of-freedom robot previously described as the robotic manipulator inside the target chamber. This robot will be installed on a transporter and moved about on the target bay floor to access the various components.

The Environmental Protection Systems (EPS) consist of a decontamination area located in the diagnostic building basement. The decontamination area houses the debris shield decontamination system, the first wall cleaning station, and a general purpose CO₂ cleaning room.

4. CONCLUSIONS

The Title I preliminary design for the NIF target area has been completed in October 1996. Many system and design improvements have been initiated since the NIF Conceptual Design Report (CDR), among these are the modularization of the FOA, the incorporation of a gas-filled beam transport system, a detailed methodology for the installation/removal and maintenance of optical components, target chamber first wall panels and beam dumps, improved structural and thermal stability and accessibility within the target bay by incorporating multiple floor levels braced with radial ribs and floor-to-floor columns, and the use of carbon fiber-composites and passive damping materials to produce a highly stable target positioner.

During Title II detailed design, there remain many structural and thermal analyses to be performed in order to provide guidance for improving the stability. During this design phase, the results from fabrication and testing of prototype systems such as the FOA and guillotines will be incorporated.

5. ACKNOWLEDGMENTS

Many people have played a significant role in the Title I design and analysis for the NIF target area; they include the past members of the CDR Team, the Nova Operations Team and the members of the Science and Technology Group who are constructing and testing component prototypes and performing various detailed analyses. We would like to thank all of these people collectively for their valuable contributions. The authors of this paper would like to express our particular appreciation to the engineers, designers, and scientists of the NIF target area group.

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