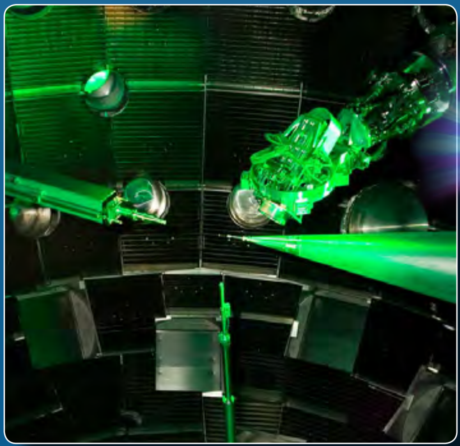
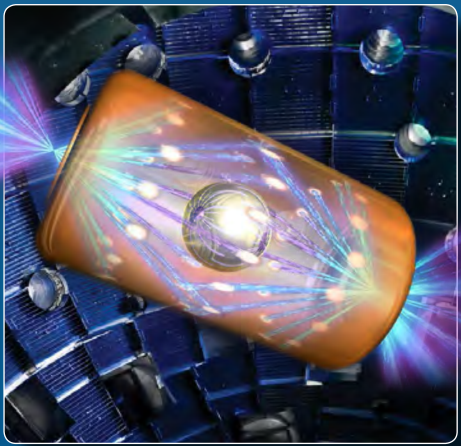
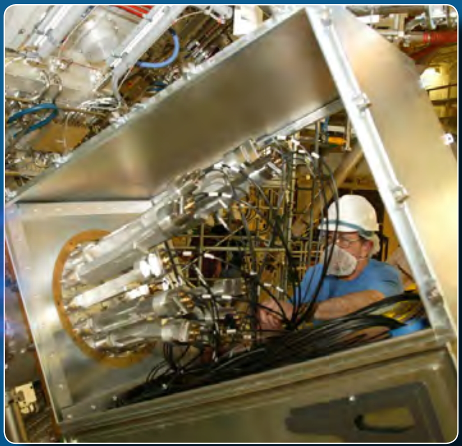
NIF

National Ignition Facility

User Guide







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Auspices Statement
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Contents

1. NIF Overview

1.1. NIF Missions and Users

The National Ignition Facility (NIF) is an operational multi-megajoule laser facility at Lawrence Livermore National Laboratory (LLNL) in Livermore, CA. NIF completed construction and entered into full operations in March 2009. The NIF was constructed by the Department of Energy (DOE) National Nuclear Security Administration (NNSA) to execute high-energy-density science experiments in support of the U.S. Stockpile Stewardship Program (SSP), the DOE's energy and fundamental science missions, and the Department of Defense and other federal offices and agencies. NIF will be operated as a national and international user facility to support this range of missions and associated national laboratory, academic, and private sector user communities.

Users of NIF include researchers from the NNSA and Office of Science national laboratories, other federal agencies, academia, the private sector, and the international scientific community. This user manual is intended to provide sufficient information to allow researchers to become familiar with NIF and develop preliminary plans for NIF experiments. It also provides references to further detail that will allow detailed experiment planning.

Much of this information is also available on the NIF Users portion of the NIF website: **https://lasers.llnl.gov/for_users/**

1.2. NIF History

Figure 1-1: NIF aerial view, showing the two laser bays, switchyard, target chamber area, Operational Support Building, and Optics Assembly Building.

The formal commencement of NIF was the signature of NIF "Key Decision Zero" by the then Secretary of Energy, Admiral James D. Watkins (retired), on January 15, 1993. Site construction on the 192-beam laser system—the size of three football fields and 85 feet tall—began with NIF groundbreaking in May 1997.

In June 1999, the 264,000 pound, 10-meter-diameter target chamber was moved from its assembly pad across the street from the facility and installed into its berth 21 feet below ground level using a 900-ton steel crane from the Nevada National Security Site.

The conventional facility was completed in 2001. This included the concrete foundations and monolithic mat floor slabs for the switchyards and target bay (six feet thick) and the foundations for the laser building; the Optics Assembly Building (OAB) and the laser building's envelope—the structural steel shell, metal skin, and roof; the interior of the laser building with mechanical and electrical utilities as well as architectural finishes and the central plant (which includes boilers, chillers, and cooling towers); and the target area building envelope, mechanical and electrical utilities, and the architectural finishes. During its construction, more than 210,000 cubic yards of soil was excavated, more than 73,000 cubic yards of concrete was poured, 7600 tons of reinforcing steel rebar was used, over 5,000 tons of structural steel was erected, and more than 1.7 million hours of craft labor was expended.

In April 2003, the full 192-beam precision-cleaned and aligned beampath was completed in both laser bays. In May 2003, NIF produced 10.4 kJ of ultraviolet laser light in a single laser beamline into a dedicated precision diagnostic system as part of the NIF Early Light (NEL) campaign, setting a world record for laser performance and meeting its primary criteria for beam energy, beam output, uniformity, beam-to-beam timing, and delivery of shaped pulses required for ignition. The first NIF target physics experiments, involving laser–plasma interaction studies in small gas-filled targets ("gas pipes"), were also executed during the NEL campaign.

October 2004 marked the end of the NEL effort, and build-out of the NIF facility resumed full time. This period of construction consisted largely of installation of modular line-replaceable units (LRUs) in the previously installed facility infrastructure. By the completion of construction in March 2009, over 6000 LRUs had been installed in the NIF, including over 3100 pieces of amplifier glass, 8000 large optics, and 30,000 small optics.

Target experimental campaigns began at the end of 2008 using hundreds of kilojoules of energy. Since that time, NIF has been conducting experiments in support of national security, stockpile stewardship, and basic science, with much of the effort dedicated to demonstrating inertial confinement fusion (ICF) ignition in the laboratory for the first time. The NIF laser has demonstrated that it meets all specifications required for ignition and stockpile stewardship.

In late October and early November 2010, NIF set world records for neutron yield from laser-driven fusion fuel capsules and laser energy delivered to ICF targets. These experiments followed closely on the heels of NIF's first integrated ignition experiment in September 2010, which demonstrated the integration of the complex systems required for an ignition campaign. In that first integrated shot, one megajoule of ultraviolet laser energy was fired into a cryogenically layered capsule filled with a mixture of tritium, hydrogen, and deuterium, tailored to enable the most comprehensive physics results.

Experiments in 2011 and 2012 have continued to explore ignition physics. Several scheduled maintenance periods have allowed NIF to ramp-up in operational capability with higher laser energy and power, new diagnostics, and other new capabilities for high-yield ICF implosion experiments. On July 5, 2012, the laser system delivered more than 500 terawatts of peak power and 1.85 MJ of ultraviolet laser light to its target, validating NIF's most challenging laser performance specifications set during NIF planning in the late 1990s.

1.3. NIF Facilities

As shown in Figure 1-2, the NIF encompasses three interconnected buildings: the OAB, the Laser and Target Area Building (LTAB), and the Operational Support Building (OSB). Inside the OAB, large precision-engineered laser components are assembled under stringent cleanroom conditions into modules called LRUs for installation into the laser system.

The LTAB houses the 192 laser beams in two identical bays. Large mirrors, specially coated for the laser wavelength and mounted on highly stable 10-story-tall structures, direct the laser beams through the switchyards and into the target bay. There they are focused to the exact center of the 10-meter-diameter, concrete-shielded target chamber.

The OSB, located adjacent to the NIF target area, accommodates development, calibration, and maintenance of diagnostics for use on the NIF, as well as a neutron activation counting room, the NIF Hazardous Materials Management Area (HMMA), and areas to stage and test instruments. There is direct access from the OSB to the target area at several different floor levels in the target bay.

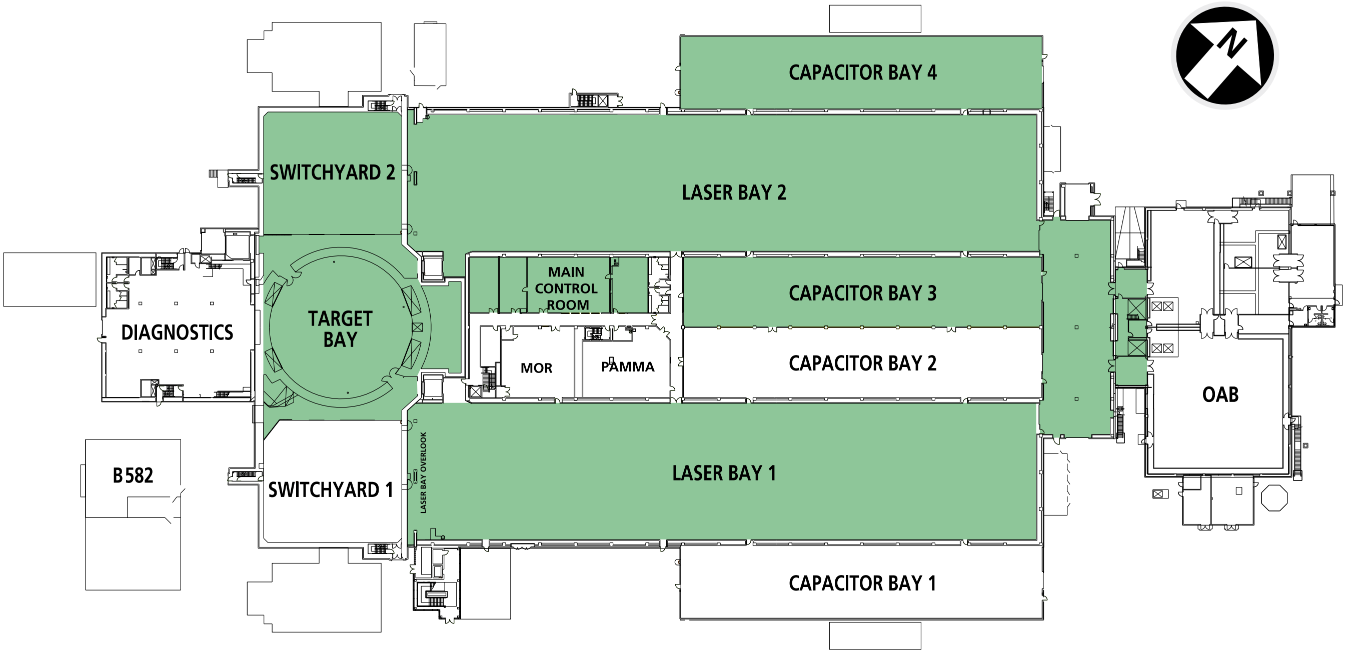

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Figure 1-2: Map of the OSB, OAB, and key regions of the LTAB.

Figure 1-3: Images of NIF. Clockwise from upper left: NIF control room. A preamplifer module installed as an LRU. One of NIF's two identical laser bays. Maintenance on a NIF beamtube in the target bay. NIF laser glass cassettes holding amplifier slabs.

1.4. LLNL Facilities

LLNL has many different onsite facilities available to users, including cleanrooms, classified areas, and facilities devoted to electronic fabrication, conventional and micro-machining, and target fabrication. Further information on LLNL facilities is available from the NIF Visitor Office.

2. Policies and Access

2.1. Accessing NIF

2.1.1. Site Access

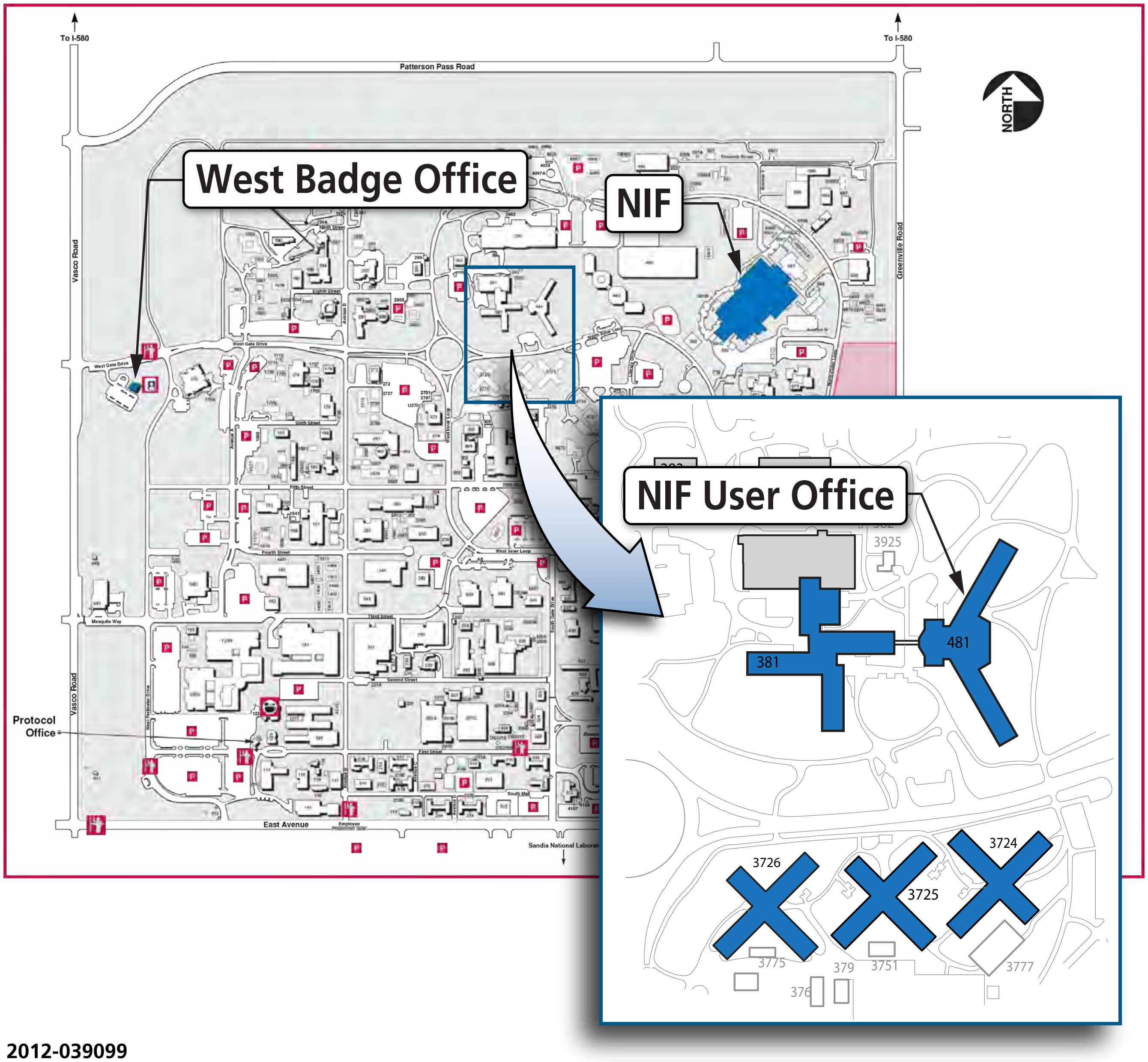

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Figure 2-1: Map of LLNL, indicating the West Badge Office and NIF. The NIF HED campus, housing the NIF User and Visitor offices, is shown enlarged.

LLNL is a national security laboratory with regulated entry. Visitors must make prior arrangements and pick up a badge at the Westgate Badge Office (located off Vasco Road in Livermore) in order to gain admittance to the Laboratory. To obtain a badge, visitors must supply a Social Security number and a valid driver's license or other form of official photo identification. Non-U.S. citizens must present a Permanent Resident Card or valid passport plus visa and all accompanying documentation. All visitors must wear the badge conspicuously, between their neck and waist, at all times while at LLNL.

Privately owned video recording equipment (cameras or camcorders) may be brought into non-classified areas but must be turned off and kept secured in a locked vehicle or a cell phone garage. Privately owned cellular telephones (including those with cameras) may be used within non-classified areas and in the outdoor portion of classified areas, but the camera function of any privately owned cell phone must be kept turned off while on site. More information on LLNL's policies for bringing restricted and controlled items onto the site is available on LLNL's website:

https://www.llnl.gov/about/controlleditems.html

2.1.2. NIF Access

Access to the NIF site and buildings is controlled and limited to authorized personnel. NIF access requires approval from LLNL and the facility manager and may require completion of web-based classes, including site access policies and safety training. Upon completion of these courses and authorization of site access, individuals will be added to the TESA lock access system, and an access control card will be provided. Personnel who have not completed site access training must be escorted on site. Personnel must remain current in required training to maintain access, and additional training is required to perform work at the site. The NIF User Office, located on the first floor of B481, facilitates the site access process for visiting researchers.

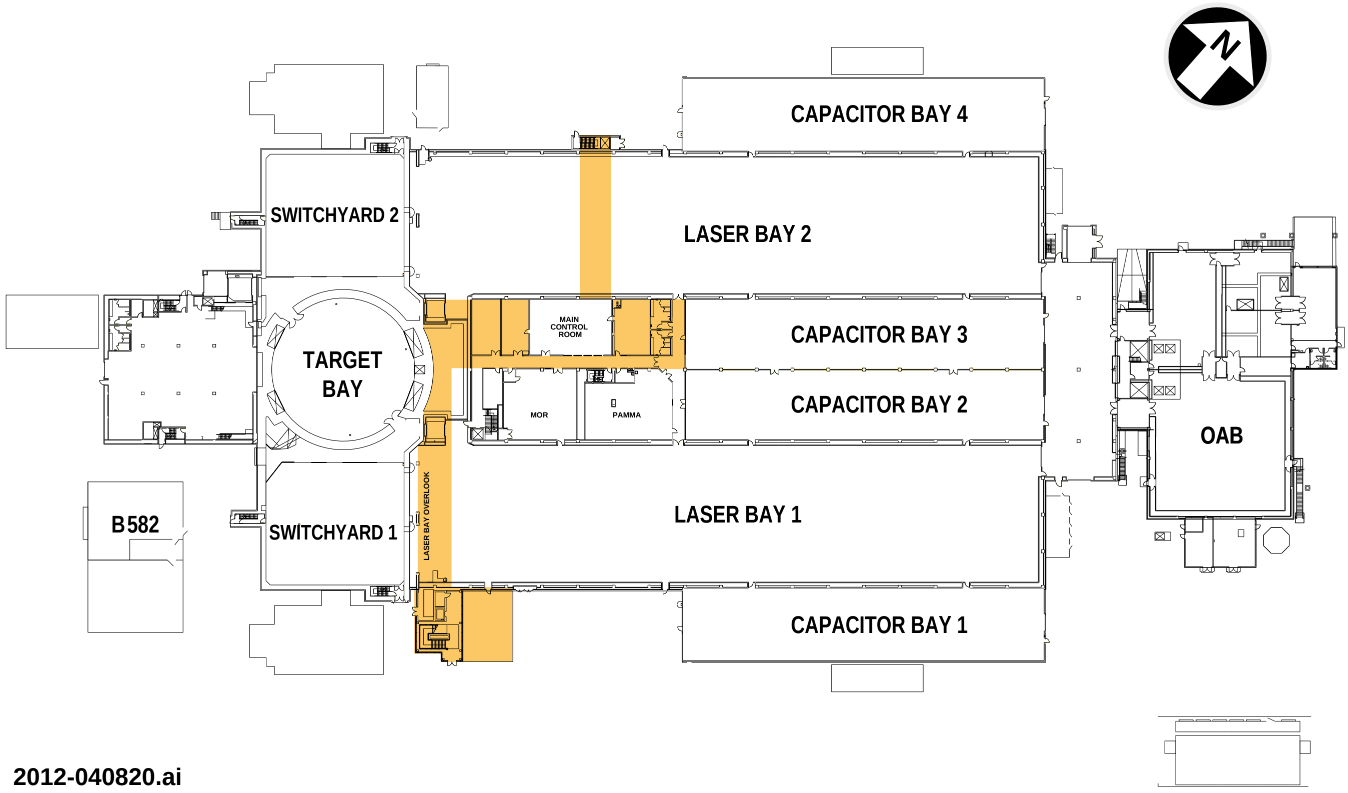


Figure 2-2: General access areas of the LTAB are shown in orange. The areas of the facility shown in white (which includes the control room) require additional access levels and training. They also require personal protective equipment and clean construction protocol practices.

2.1.3. Computer Access

Access to LLNL unclassified computer systems operated by Livermore Computing (LC) can be granted to LLNL collaborators and is governed by DOE and LLNL policies.

These resources include systems on the unclassified, restricted (yellow) network; foreign national unclassified network (blue); and unclassified, unrestricted (green) visitor network. To be granted a computer account enabling access to unclassified resources, offsite collaborators must complete the LC Policies and Procedures form and the Livermore Computing Computer Security Briefing and complete the Create/Update of Open Computing Facility User Account and submit it to the LC Hotline.

Guest wireless is available on business-owned laptops for all visitors and users during business hours while on-site in designated user areas.

2.1.4. Office Space

The NIF User Office will arrange for suitable office space, administrative assistance, and other administrative support for visitors to LLNL. Visiting users will need to abide by all relevant LLNL rules and regulations.

2.1.5. Data Access

NIF users will have access to all raw and analyzed data associated with their experiment, and will be provided access to the NIF data management system as required. Data policies for NIF users are provided in Appendix B.

User access to all NIF data management systems will comply with all applicable LLNL computer access and security procedures. The liaison scientist for each experiment will serve as the interface between the user and the facility for all data management related issues.

2.1.6. Cleanliness Protocol and Personal Protective Equipment

Safety and cleanliness are of paramount importance at NIF site. Workers in operational areas of the NIF site must wear long pants, closed-toe shoes, and shirts with sleeves (no tank tops). Visitors should wear closed-toe shoes suitable for various NIF walking surfaces.

Extreme cleanliness is required at NIF because any bit of debris, oil, or other wayward material could cause the laser light to damage the optics. The cleanroom environment maintained throughout B581 is the same level of cleanliness found in a hospital operating theater, permitting no more than 10,000 particles larger than 0.5 microns per cubic foot of air. There are clean construction protocol levels assigned throughout the facility to designate the degree of cleanliness and the operational behaviors required in that specific work area in order to achieve those cleanliness levels. The minimum requirement everywhere on the site is clean shoes and work clothes. Any tools and equipment must be wiped down prior to being brought into the facility. Additional training and cleanroom garb is required for accessing certain portions of the facility to minimize contamination.

Personal protective equipment (PPE) protocols are an important safety and contamination protection element at the NIF. All PPE must be in good condition and correctly worn. A hard hat is required in the switchyards and target bays. Closed-toe and closed-heel shoes with a non-tapering heel must be worn in the facility at all times. Individuals performing work on site, are required to wear appropriate PPE as identified within the applicable IWS/Work Permit/SPA. This may include a hard hat, safety glasses, steel-toed shoes, and/or other gear.

2.1.7. Control Room Protocol

To ensure personnel and equipment safety, it is imperative that the control room system operators are not disturbed or distracted during shot operations. Experimentalists may have access to the control room to monitor/observe shot activities *only* with explicit, advance approval.

During shot operations, the shot director (SD) and lead operator (LO) have the authority to clear any area of the facility of nonessential personnel. Nonessential personnel are those personnel that the SD/LO determine are not required in the immediate area during shot operations. During the shot cycle, only shot operations staff are allowed in the control room unless approved by the SD/LO. Visitors may remain in the strategy room or other nearby locations until completion of the shot cycle.

The SD/LO may allow the PI or designee(s) (at most 1 or 2 people) in the control room under the following conditions:

- The PI shall be identified during the pre-shot safe plan of action (SPA) meeting and any personnel changes shall be approved by the SD/LO.
- The PI may inspect target alignment, beam positioning or diagnostic setup at appropriate operator stations during the shot cycle with SD/LO approval. However, the LE shall not modify procedures or instruct operators to move or modify devices without prior SD/LO approval.
- Upon completion of setup, the PI shall vacate the control room unless prior arrangements have been made with the SD. During the remainder of the shot cycle, the PI shall obtain SD/LO approval before entering the control room or before modifying procedures or system devices.
- With SD approval, the PI may be stationed in the rear of the control room to witness a system shot. During the shot cycle, the PI may only communicate directly with the SD. During countdown, the PI should refrain from any communication unless personnel or equipment safety is at stake.

The experimental and diagnostic support staff may monitor radio communications during the shot cycle. Loan radios are available from the LO.

2.2. Other Policies

2.2.1. User Agreement

Approved external users will be required to complete a user agreement that defines administrative requirements including safety, liability, training, ownership of property, and intellectual property rights. These rights and obligations vary based upon the proposed experimental campaign. Most users are granted access for publishable research, which falls into the category of non-proprietary use. Such users will be required to sign a non-proprietary user agreement similar to that described in the DOE document *Class Waiver for Non-Proprietary Users*.[1]

In the period before formal DOE approval of a NIF user agreement, as part of accessing the LLNL site, NIF users will sign appropriate Lawrence Livermore National Security (LLNS) agreements regarding personal safety, intellectual property regulations, and the like.

In the instances of proprietary use of the facility, users will be required to sign an agreement similar to that contained in the DOE document *Class Waiver for Proprietary Users*.[2] A separate contractual agreement with LLNS may also be required. Approved international proposals may require execution of a memorandum of agreement in addition to the user agreement to define roles and responsibilities, including safety, training, intellectual property, facility resources, and any relevant regulations governing foreign national visits and collaborations.

2.2.2. Publication and Authorship Practices

Results of NIF experiments are expected to be published in major journals and presented in many scientific forums. Such publications and presentations will follow the American Physical Society Guidelines for Professional Conduct, which states that authorship should be limited to those individuals who made a significant contribution to the research study. Other contributors with more minor contributions should be acknowledged, but not listed as authors. In addition, the sources of financial support for the project should be disclosed and a statement acknowledging the use of NIF should be included in all publications. Proper acknowledgement of the work of others used in a research project must always be given. See the American Physical Society's Guidelines for Professional Conduct (**http://www.aps.org/policy/statements/02_2.cfm**) for additional information.

Users are required to inform the NIF User Office of any publication, thesis, or other documents containing experimental data obtained from NIF. The publication should include the following acknowledgement: "This research incorporates results obtained at the National Ignition Facility (NIF), a national user facility operated by Lawrence Livermore National Laboratory for the U.S. Department of Energy."

2.2.3. Classification Issues

NIF is capable of conducting experiments of which particular aspects are classified. All users considering experiments with classified aspects must contact the NIF User Office prior to submission of any written proposal or other documentation. A procedure exists for executing classified experiments.

2.2.4. Conflict Resolution Procedure

Conflicts will be resolved at the lowest level using existing management structures when possible. Conflicts regarding facility allocations within programs will be referred to appropriate program leadership. The Facility and Laser Integrated Planning (FLIP) Committee will resolve scheduling conflicts, while the NIF Experimental Facilities Committee (EFC) will consider conflicts occurring between user communities, such as disagreements regarding facility allocations and the like. Conflicts not resolvable by existing programs or the NIF governance structure will be referred to the User Office for resolution, which will refer the issue to the NIF Director as needed. If necessary, the NIF Director may assemble an expert panel with appropriate representatives to review the situation and advise on resolution.

2.3. NIF User Office

The User Office is the primary point of contact for the NIF User Group, which includes all researchers performing experiments on the NIF. The User Office provides infrastructure and administrative support for NIF users and the NIF User Group, including badging; operational, security, and safety training; data archiving and retrieval; shot-request form preparation assistance; office and laboratory space; website maintenance; information technology support; and development and maintenance of this manual. The NIF User Office also manages the process and policies for allocations of NIF facility time.

Longer-term visitors are supported by the NIF Visitor Office (see Section 2.4).

2.4. NIF Visitor Office

The NIF Visitor Office supports frequent or long-term visiting experimentalists, researchers, and subcontractors involved with the NIF laser facility and other related programs. This office will assist hosts and their visitors in navigating their LLNL visit. The Visitor Office will assist those visitors whose visits:

- Are over 14 days in a calendar year;
- Require visitors to perform hands-on work; and
- Have been approved by the NIF User Facility and/or program.

Invited speakers, seminar or conference attendees, consultants, and visitors spending less than 14 days at LLNL in a calendar year are not served by the Visitor Office.

For all relevant visits, the office serves as a "one-stop shop" to coordinate all elements of a visit, including aspects such as badging, work authorization, office space, computer and IT requirements, training, etc. The visitor's host will notify the Visitor Office of the scheduled visit and the visitor's requirements for their visit. For all new visits that meet the above criteria, the host or host's administrative assistant will submit a National Ignition Facility and Photon Science (NIF&PS) visitor request form to the Visitor Office Coordinator.

2.5. Required Training

All visitors and users onsite are required to take a standard list of institutional site training requirements. These courses are as follows:

- CS0149-W: Proper Usage of LLNL Unclassified Computers, Networks, and Peripherals
- CL0012-W: Export Control at LLNL
- EP0003-W: New Employee Environmental Orientation
- HS0016-W: Site Access Safety and Security Orientation
- HS0100-W: ES&H Annual Training
- HS4258-W: Beryllium Awareness
- IS0001-W: Integrated Safety Management Orientation
- PA0012-W: Drug Free Workplace Training and Education

Additional training is required to access the special access areas of the facility (e.g., control room, capacitor bay, and VISAR) and to be qualified as a site worker. Additionally, performing work requires training as specified by the integration work sheet (IWS). Training requirements will be identified during the scope meeting with the host and will be sent to the visitor for completion prior to receiving facility access and work authorization.

2.6. Travel and Housing

2.6.1. Housing

Travel to and from LLNL is requested annually by the principal investigator (PI) on each approved experiment. Final travel approval for each experiment is determined in accordance with the annual budget by the NIF User Office Director.

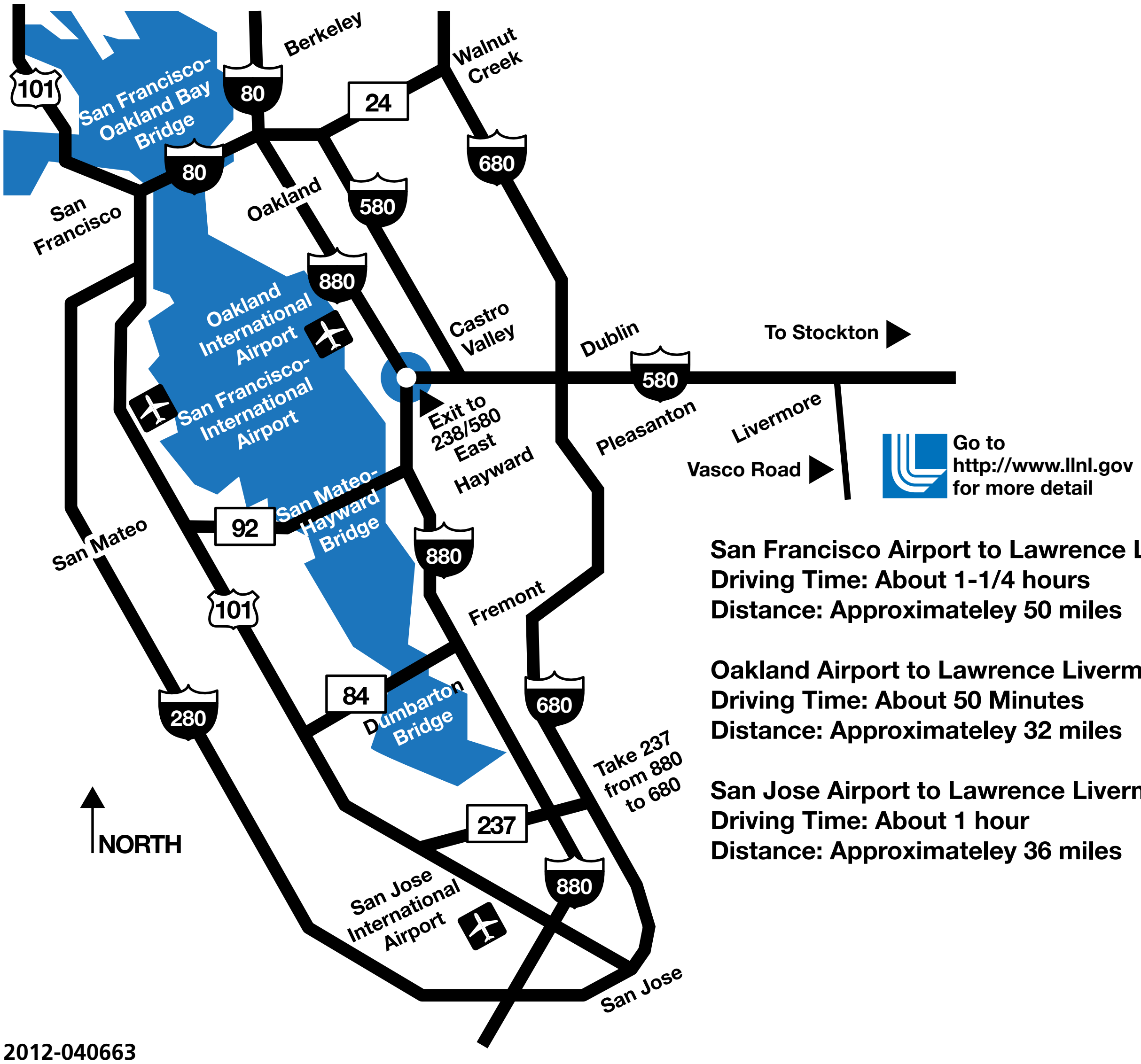
No formal housing is provided for experimentalist but requests for lodging stipends can be built into formal agreements, such as subcontract and/or the Visiting Scientist Program (VSP). Undergraduate students under the Academic Cooperation Program may only receive the daily sustenance allowed by policy during working days.

There are numerous hotels in the area with a variety of amenities and price points. List of local hotels can be found on the following website: **http://www.trivalleycvb.com/visitors/places-to-stay/**.

2.6.2. Airports

Lawrence Livermore National Laboratory is located at 7000 East Avenue in Livermore, California, a community in the Tri-Valley area of northern California, about 45 miles east of San Francisco. In Figure 2-3, directions are given for visitors traveling from the three area airports: Oakland, San Francisco, and San Jose. 511 SF Bay Area (http://www.511.org/) provides instant online access to road, rail, and water transit information for the nine-county San Francisco Bay Area. Note that all visitors to LLNL must first check in at the Westgate Badge Office.

Those being funded for travel by LLNL will need to follow the U.S. carrier rules and DOE government guideline rates.



San Francisco Airport to Lawrence Livermore
Driving Time: About 1-1/4 hours
Distance: Approximateley 50 miles

Oakland Airport to Lawrence Livermore
Driving Time: About 50 Minutes
Distance: Approximateley 32 miles

San Jose Airport to Lawrence Livermore
Driving Time: About 1 hour
Distance: Approximateley 36 miles

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Figure 2-3: Map of the San Francisco Bay Area and transportation routes to LLNL.

3. Proposals and Experiments

3.1. NIF Governance Overview

The process for allocation of NIF facility time is summarized in the *NIF Governance Plan*.[3] NIF facility time is allocated in four major program areas:

- SSP: ICF
- SSP: High-energy-density stockpile science (HEDSS)
- Fundamental science
- National security applications (national security other than SSP)

The process for allocation of NIF facility time is summarized in Figure 3-1. The NIF EFC generates a recommended multi-mission facility use plan based on NNSA guidance and input from user program and facility leadership in each of the four areas above. Following NNSA and NIF Director approval of the facility use plan, the NIF FLIP Committee generates an experimental schedule. Changes to the schedule are managed via regular meetings of the EFC and FLIP committees. The schedule is accessible to researchers via a password-protected website. Information on accessing the schedule is available from the NIF User Office.

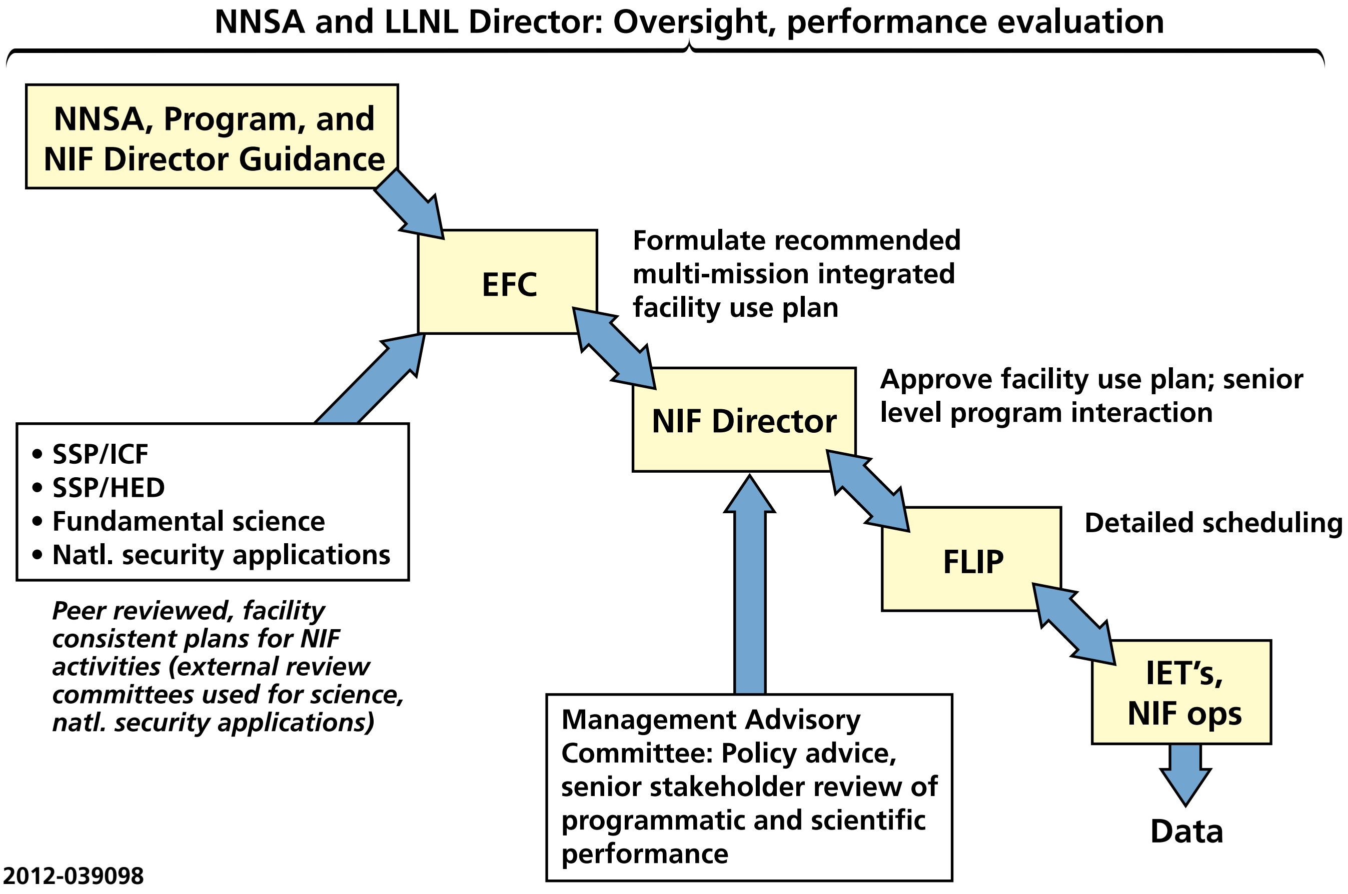

Figure 3-1: NIF facility time allocation process.

3.2. Submission of Proposed Experiments

Researchers proposing NIF SSP experiments should submit their proposal for consideration via management of the NNSA ICF and High-Yield Campaign, Science Campaign, or other appropriate NNSA program. Researchers proposing NIF experiments in the national security applications area should contact the NIF National Security Applications Manager, appropriate federal program management, or the NIF User Office. NIF does not solicit NIF experiments in these areas.

The NIF User Office will periodically issue a solicitation for fundamental science experiments at NIF and arrange for review of these proposed experiments by the Science on NIF Technical Review Committee (TRC) using criteria provided with the solicitation. All information regarding the solicitation will be posted on the NIF website (**https://lasers.llnl.gov/for_users/**). National and international researchers from the academic, national laboratory, and private sectors may apply for facility experimental time. Applicants are encouraged to leverage existing NIF experimental capabilities and platforms whenever possible. This will provide an efficient means to build the NIF user community and advance fundamental high-energy-density (HED) science consistent with available resources.

The NIF User Office will assist in the formulation of proposals, including estimation of required resources.

Proposals will be screened initially by the NIF User Office to ensure they are unclassified and adhere to U.S. export control and nonproliferation policies; nuclear weapon policy; security guidelines; and NIF, LLNL, and NNSA requirements.

In addition to basic background information to be provided via a web-based form (**https://lasers.llnl.gov/forms/user_proposal.php**), proposals should include the following:

- **Scientific discussion**—Description of the purpose for the proposed experiment, the key scientific questions addressed, the proposed experimental method, the desired experimental platform, and the expected results.
- **Experimental feasibility**—Description of how the experiment is uniquely suited to NIF and the feasibility of NIF for conducting the proposed work.
- **Scientific team**—Descriptions of the researchers to be involved in the proposed concept development.
- **Required capabilities and resources**—A short estimate of the capabilities and resources required within and external to NIF to execute the experiment.

All proposed experiments will also be required to submit a written scientific justification as well as a standard “NIF Facility Proposal Form” (see Appendix E) describing specifics of the proposed experiment. All proposed experiments will be pre-reviewed for facility suitability by NIF staff before transmission to the Science on NIF TRC. The NIF Director will select the final set of approved experiments based on the TRC and facility feasibility reviews. The PI will receive from the Director of the NIF User Office a written notification of the result of the proposal evaluation that will include a final committee review report. The EFC and FLIP will incorporate elected experiments into the integrated NIF schedule.

Further information on experimental scheduling and execution is contained in Section 10. Table 3-1 summarizes NIF shots conducted from July 2008 through July 2012.

Table 3-1. NIF shot history, July 2008 through July 2012.

Type	Specific Purpose	Cryo-genic targets	Cryo-genic layered targets	Warm targets	Total
Target shots—program data (278 = 28%)	National Ignition Campaign	138	34	21	193
	High-Energy-Density Stockpile Stewardship			64	64
	National Security Applications			12	12
	Fundamental Science			9	9
Target shots—capabilities (148 = 15%)	Target Diagnostics Commissioning/ Calibration			108	108
	Laser Commissioning/ Calibration			40	40
Laser shots only (557 = 57%)	Optics Performance/ Conditioning			128	128
	Laser Performance			212	212
	Laser Calibration			217	217
Total		138	34	811	983

4. Safety

4.1. Safety Overview

In the NIF and Photon Science Directorate, safety is a value that pervades all that we do. LLNL and DOE principles of the Integrated Safety Management System (ISMS), Occupational Health and Safety Management System (ISO 18001), and Environmental Management System (ISO 14001) are integrated into work to ensure the protection of worker health and safety, and the environment.

At NIF, safety is inherent in how we think about work. It is our belief that all accidents are preventable, and that working safely depends on personal accountability at every level, beginning with the highest level of management and ending with the worker performing the work. Beyond the functions of ISMS, safety is a value and foremost in all work conducted within the NIF Directorate, and every worker has the ability, authority, and responsibility to stop work if they feel it is unsafe.

The hazards associated with NIF and its operation have been identified and evaluated since the earliest stages of design. Safety features have been incorporated into the designs to mitigate these hazards. The bounds of NIF operations are described in the National Environmental Policy Act (NEPA) documentation: *Final Site-wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement*[4] *and the Supplement Analysis of the 2005 Final Site-wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory.*[5] This NEPA documentation ensures that a thorough evaluation of the impacts of NIF operations has been completed, and that the risks to the public and the environment are understood and communicated. These evaluations have resulted in high level limitations on NIF operations, namely the annual yield (1200 MJ/yr), the annual airborne tritium release (80 Ci/yr), the maximum individual shot yield (45 MJ), and material inventories (e.g., tritium inventory limited to 8000 Ci).

The limits specified in the NEPA documentation are flowed into the *NIF Safety Basis Document*[6] (SBD). The SBD provides a more detailed identification and assessment of hazards, resulting in additional controls to ensure that risks to colocated workers and the public are low. In addition to flowing down yield and inventory limits, the safety basis document has identified a set of credited safety systems (e.g., radiation shielding) and other credited administrative controls that govern NIF operations. Inventory limits and yield control are implemented through the *Facility Safety Plan*[7]; Operational Safety Plan (OSP) 581.11, *NIF Laser System Installation, Commissioning, and Operation*[8]; *NIF CIS Radiological Inventory Management System*[9]; and other procedures. Credited safety systems are described in more detail in Section 4.3. Configuration Management of these systems is critical to ensure continued functionality at the level assumed in the SBD.

The safety aspects of specific NIF operations are described in OSP 581.11[8] and in additional IWSs that authorize those operations. These documents provide a specific, detailed evaluation of hazards associated with working in the NIF. These hazards include lasers, electrical hazards, oxygen deficiency, vacuum, standard industrial hazards, and radiological hazards. Controls for these hazards are delineated in the OSP/IWSs and are flowed to specific work team documentation via a work permit.

More details on the hazards associated with NIF operations and the controls in place to mitigate them are provided in the remainder of this section.

4.2. Hazards

A range of hazards exists in the NIF. NIF's primary method for controlling these hazards is through engineered controls. When engineering solution is not feasible, or identified hazards cannot be engineered completely out of normal operations/maintenance work, safe work practices, and other forms of administrative controls provide additional protection along with the use of personal protective equipment (PPE). This subsection provides a brief discussion of the primary hazards at the NIF. This is followed by a discussion on controls in section 4.2.

4.2.1. Laser Hazards

The NIF is the most energetic laser in the world and presents a significant laser hazard. During normal laser operations, the NIF is considered to be a Class 1 laser system because all of the laser beams are fully contained and are not accessible. In addition to the main laser, there are numerous high-powered (Class 3B and 4) diagnostic and alignment lasers in use that can potentially send laser light throughout the facility. All laser safety controls in place at the NIF are approved by a single body called the Laser Safety Working Group (LSWG). The LSWG is a committee that includes physicists and engineers with backgrounds in lasers, optics, and safety; the Laser Safety Officer is also a member. The LSWG's purpose is to evaluate modified and new lasers or systems added to the NIF by reviewing and determining what controls are to be implemented. This in-depth review is completed through a documented hazards analysis. The completed analysis is captured in a document called a Laser Safety Gram. Controls identified in the LSG are flowed into the OSP for the facility.

4.2.2. Electrical Hazards

Electrical hazards are prevalent in the facility. Only qualified personnel are allowed to modify, test, or repair electrical equipment or systems. Workers are always required to de-energize, lockout, and prove electrical components are positively de-energized before beginning work. High-voltage hazards exist during main laser shot operations. The main amplifier, power amplifier, and power conditioning system present a high-voltage hazard. Another electrical hazard is the high-voltage, pulsed-power supplies for the large-aperture plasma electrode Pockels cells, part of the main laser system.

4.2.3. Confined Space

Confined Space is defined as an enclosed area that is large enough for a person to enter and perform assigned work, has limited or restricted means of entry or exit, and is not designated for continuous human occupancy. The beampath, target chamber, and target chamber service system (TCSS) pit are examples of confined spaces. A review of the confined space entry/access requirements, monitoring equipment, and confined space responsibilities reduces the risks involved with access to these types of spaces.

4.2.4. Oxygen Deficiency

NIF uses large quantities of argon gas and liquid nitrogen. Some portions of the NIF beampath are filled with argon (with non-life-supporting levels of oxygen) to minimize beam distortion. The liquid nitrogen is used in the target chamber cryopumps. The potential hazard from both of these materials is oxygen deficiency/asphyxiation. Both argon and nitrogen are simple asphyxiants (displace oxygen) but they are not themselves toxic. In very large quantities or within confined spaces with insufficient fresh air flow, hazardous conditions can exist.

4.2.5. Stored Energy

Various operations (e.g., full system shots) require that portions of the beampath be placed under vacuum. This can represent substantial stored energy (e.g., the evacuated target chamber represents about 50 MJ of stored energy; evacuated spatial filter vessels represent tens of millijoules of stored energy). Brittle optics serve as the vacuum barrier on these vessels. Failure of this barrier could result in personnel injury and significant equipment damage.

4.2.6. Standard Industrial Hazards

Standard industrial hazards such as moving equipment, trips and falls, and dropping equipment also exist at the NIF. Mechanical movement of equipment (vacuum isolation valves, positioners, cranes, hoists, etc.) can result in crushing or pinching, or dropping of loads. Movement of heavy equipment or large items must be planned and coordinated. All crane and hoist movements are performed by trained individuals.

Trip and fall hazards exist throughout the facility. Working at elevated locations such as platforms or structures more than 6 feet high required tie-off when exposed to falls below. This includes working at certain locations in the target chamber and while on the TCSS. Employees are trained and understand how to select and use fall protection equipment such as lanyards and full body harnesses.

Equipment and materials can fall when personnel are working at heights; this presents a hazard to workers below. Hand tools are the most likely item to be dropped from high places. All tools that are exposed to a fall from one level to another are required to be tethered to prevent injury to personnel or damage to equipment. Also, materials and tools are raised and lowered by a rope or other mechanical means.

4.2.7. Radiological Hazards

NIF uses tritium, a radioactive material, as part of the deuterium–tritium (DT) target fuel used in ignition experiments. During these experiments, tritium reacts with deuterium to produce helium and a very energetic neutron. These energetic neutrons further interact with materials in the target materials and materials in and around the target chamber. Some of the interactions lead to activation of these materials and result in radioactive species that then give off ionizing radiation (primarily beta particles and gamma rays) as they decay. This may include very small quantities of fission products produced from depleted uranium which is sometimes used in ignition-type targets.

In addition to the prompt (instantaneous) neutron radiation field produced by the DT fusion reaction, a longer-lived, but much lower level, radiation field is generated by the neutron activation products. The NIF radiological goal is, consistent with DOE rules, to limit the annual dose to personnel and individuals in the occupied areas to levels as low as reasonably achievable (ALARA) and well below the maximum yearly dose limits allowed by DOE. Over time, as part of the experimental program, NIF may use other radioactive or hazardous materials during routine operations. Thus it is imperative that NIF put in place the necessary safety systems to manage these hazards and protect workers, the public, and the environment.

Only a small fraction of the tritium used in NIF ignition targets is consumed in the reactions. The majority of the remaining tritium is captured by the Tritium Processing System (TPS). Post-shot, a small fraction of the target tritium remains on target chamber surfaces and entrant components, such as target and diagnostic positioning systems. The surfaces of these components are identified as “contaminated” and appropriate measures for contamination control are employed when contact with these surfaces is necessary.

Neutrons generated by fusion reactions create prompt radiation that is effectively managed through shielding of the target bay and switchyards. These neutrons also interact with and induce radioactivity in materials (activate) throughout the target bay, which results in decay radiation. At higher yields, radiation from the decay of activated materials is significant and is managed primarily through stay-out times during which radioactivity decays and radiation levels decline. Neutrons that interact with the small amount of uranium in ignition target hohlraums cause the uranium to undergo a limited number of fission reactions, which leads to the production of fission products, which are also radioactive. Fission products such as tritium may be found on target chamber components.

The vast majority of NIF’s removable radioactivity (contamination) is tightly contained in the target chamber and in connected support systems. Surface contamination in the target chamber and entrant components presents a radiological hazard that must be managed because contaminated components are routinely handled during activities such as removal of diagnostic media, target replacement, and diagnostic replacement. Contamination controls at NIF are achieved primarily through the use of installed engineering controls, isolation of impacted areas, PPE, and appropriate worker practices.

NIF systems that are exposed to target chamber contaminants are well-isolated as part of an engineered “confinement envelope.” Prior to access, components are isolated from the target chamber by large gate valves and then ventilated. Contamination zones are small work areas established to manage surface contamination where the confinement envelope is breached, e.g., to remove a diagnostic component. Buffer zones are established around the contamination zones. Although no contamination is expected in buffer zones, there is increased monitoring and worker diligence as compared to non-radiological areas. Special permits and radiological worker qualifications are necessary to enter and work in contamination zones and buffer zones.

Figure 4-1: Contamination zone for managing a contaminated surface.

4.3. Administrative Controls and Work Control

Administrative controls may be specified in safety documentation. The NIF work control process, described below, ensures that these controls are flowed into work documents.

Every activity at NIF goes through a detailed review and approval process, from the operation of the main NIF laser all the way down to the smallest of tasks. The work-authorizing document, the IWS, is where this occurs. Work tasks are evaluated, the associated hazards are analyzed, and specific controls for each task are identified. When a more detailed evaluation is required, a safety plan may also be needed. An OSP is an augmentation of the job hazards analysis/ IWS, and is a more detailed ES&H review of certain hazards associated with a specific activity. An OSP provides a more complete evaluation of hazards and their controls. It also describes likely accident scenarios and the possible consequences if there were no mitigating safety limits or controls in place. Mitigations may include engineering controls (e.g., interlocks, alarms, and shielding), administrative controls (e.g., procedures and signs), and PPE (e.g., gloves, safety shoes, and respirators).

OSP 581.11[8] applies to everyone working in or having unescorted access to the NIF, including LLNL employees, contractors, and visiting scientists and engineers. This OSP describes the hazards and control options that can be applied for a wide variety of tasks related to laser, radiological, shot operations, and supporting activities.

For each activity conducted in the NIF, a specific work permit is also required. The work permit considers a subset of activities described in the IWS or OSP and delineates specific controls for that limited scope of work. Within the NIF, there may be workers performing operations or maintenance on various systems at any one time. Many of these systems interact, overlap, or are somehow interrelated. Consequently, the work permit also specifies a time window within which a work permit is valid. This is a means of work coordination within the facility.

Before work is performed, a safe plan of action (SPA) meeting is held to safely plan and analyze the work activity. The SPA is a task-driven document that ensures that every activity receives proper pre-job safety. The SPA is completed daily for each job and acts as the daily work authorization. The intent of the SPA process is to allow the individual or work team to plan their specific tasks in a safe and effective manner. It also requires that workers consider their work environment (i.e., other work going on around them) as part of planning that day's specific activities.

One of the primary administrative controls employed at NIF is lockout/tagout (LOTO). The NIF LOTO program protects personnel from injury while performing servicing or maintenance activities. In situations where unexpected energization (startup) of equipment or the release of stored energy could occur and possibly result in injury, the requirements of the NIF LOTO program are applied to ensure that equipment is stopped, all potentially hazardous energy sources are isolated, and equipment is locked out and tagged out by each affected worker before those workers begin service or maintenance. LOTO may be applied to all hazardous energy sources at NIF, which includes but is not limited to laser sources, electrical, mechanical, pneumatic, and other hazardous stored energy sources. LOTO authorized individuals are required to perform LOTO in accordance with NIF-specific LOTO procedures. All NIF personnel are required to comply with the restrictions and limitations imposed upon them during the use of lockout.

4.4. Safety Systems

NIF's primary method for controlling hazards is through engineered controls. The NIF has identified a set of safety systems that are required to perform specific functions related to maintaining the safety basis, ensuring worker safety, or providing environmental protection. These systems are collectively called configured systems. They are subject to enhanced configuration management, which ensures that the as-built condition, associated documentation, and requirements are always consistent. These systems and their functions are summarized below.

4.4.1.Radiation Shielding

The radiation shielding system is designed to protect facility workers, colocated workers and the public from the radiation hazards generated during NIF operations. A detailed neutronics model of the NIF has been used to accurately estimate the radiation environment during NIF shots.[10] Elements of the shielding system include the target chamber and its gunite shielding, the target bay and switchyard walls, doors and floors. The typical thickness of a concrete target bay wall is 6′, while the switchyard wall is 3′–3″. Shield doors range in thickness from 1′ to 6′. The radiation analysis model also includes all penetrations in the switchyard walls that may allow for radiation streaming from the switchyards to occupied areas or to the outside of the facility. This provides an estimate of the radiation levels throughout the facility during shots. The predictions are being validated through a dose monitoring plan.

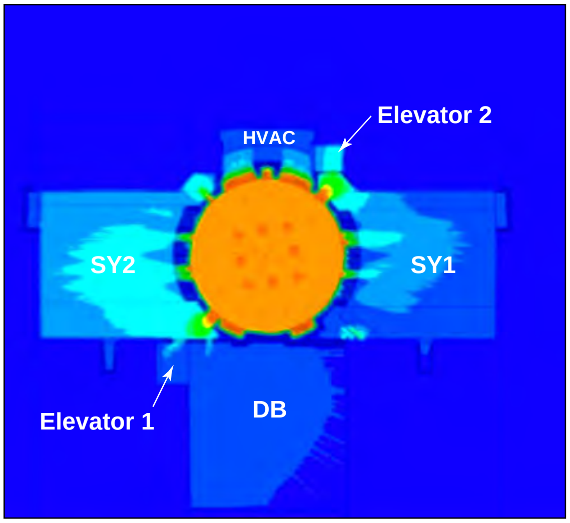

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Figure 4-2 (left): High-resolution models of the NIF facility are used to perform both prompt and post-shot calculations for estimating radiation levels in the facility. Figure 4-3 (right): Completion of shield doors and other shielding elements helped enable NIF to ramp up shot neutron yields. Shown above is one of the 44 shield doors installed throughout the NIF.

4.4.2. Safety Interlock

The NIF safety interlock system (SIS) works in conjunction with administratively controlled procedures to protect personnel from exposure to high voltage, laser light, radiation, asphyxiation, and other hazards, and where feasible, minimize equipment damage in the event of a failure in a monitored component in the NIF. The SIS does this by providing permissive signals for the operation of process power supplies, alignment lasers, and other devices. It monitors the status of safety-related elements in each area of the facility, including shutters, doors (including shield doors), crash buttons, and oxygen levels. The safety interlock system does not control any process devices, but provides a permissive signal for each device interlocked by the system. If the interlock chain for a device is not satisfied, the permissive signal will not be enabled, operation of the device will not be permitted, and it will stay in its fail-safe state or off position. If the interlock chain for a device is satisfied, the permissive signal will be enabled, and operation of the device will be allowed.

Figure 4-4: SIS entry panel and access control system (ACS) badge reader used to control facility access. ACS is used by operations staff to tell who is where in the facility.

4.4.3. Argon, Liquid Nitrogen, and Oxygen Monitoring

Elements of the argon system and the liquid nitrogen (LN) system are safety features. The argon system consists of a utility pad that stores liquid argon and conditions it for use within B581, and a distribution system that distributes it for use within the various NIF beampath enclosures. The critical safety-related functions of the argon system primarily center on confinement of argon, both on the pad and within B581.

The LN system is a storage and delivery system for cryogenic liquid nitrogen, which is supplied to the cryogenic pumps of the target area vacuum (TAV) system. The LN system consists of a storage tank, piping, valves, and other components necessary to safely deliver liquid nitrogen to the cryogenic pumps of the TAV system. The LN system also includes vent piping to deliver the exhausted gaseous nitrogen from the cryogenic pumps to the stack. There are two critical safety functions for the LN system: confinement of nitrogen within the storage tank and distribution piping (i.e., supply and exhaust), and prevention of damage to system components from overpressurization. Confinement of nitrogen is necessary to protect from the potential asphyxiation hazard from an oxygen-deficient condition. The oxygen deficiency hazard is addressed by the monitoring and alarm system. This system monitors and alerts personnel when the oxygen level has dropped below 19.5%.

4.4.4. Fire Protection

The NIF fire protection system is designed to contain and suppress a fire and to protect building occupants and equipment. The system provides fire detection and suppression, fire barriers to prevent the spread of fire and smoke, and alerts to personnel. The NIF is characterized by a level of fire protection sufficient to fulfill the requirements for the best-protected class of industrial risks, which qualifies it as an improved risk facility.

The fire barrier between the OAB and the LTAB is the one critical safety function of the fire protection system that is credited in the *NIF Safety Basis.*[6] This fire barrier, consisting of a 4-hour-rated fire wall and two 3-hour-rated fire rollup doors, essentially separates the OAB and LTAB into two distinct buildings for the purposes of fire hazard analyses. This barrier allows for a separate safety basis for each building area.

4.4.5. Ventilation

The ventilation system in the target area is designed to provide air flows and pressures with the intent of maintaining a sufficiently large differential pressure to ensure that, in the unlikely event of a radioactive release in the target bay, the hazardous material would not spread to uncontrolled areas of the facility. Exhaust air and contaminants would not leave the target bay except by means of the target bay exhaust riser, thus being measured by the stack monitor. A similar requirement for the same reason is imposed on the HMMA in the lower level of the OSB (maintenance area for contaminated items and location of the Tritium Processing System). These negative pressures also provide some worker protection function since, in the event of a release, the flow of contaminants to other areas would be minimized if not stopped completely.

The system operates in "confinement mode" on yield shots with expected yield of greater than or equal to 10^{16} neutrons. Confinement mode is the simultaneous achievement of requirements of target bay space pressure (–0.02 WC relative to surrounding areas and the environment) and target bay riser flow rate (<1% of TB vol/min). Limiting the flow rate from the riser will allow for the partial decay of airborne isotopes (e.g., ^{13}N, ^{16}N, ^{41}Ar created in the target bay air from shot neutrons). The half-lives of these isotopes are relatively short, requiring that the target bay exhaust riser flow rate be limited for only a relatively brief time (for two hours or less).

4.4.6. Confinement Envelope

During the course of NIF operations, targets and target diagnostics will generate a number of hazardous and radioactive contaminants in the target chamber and associated systems. The confinement envelope configured system consists of components belonging to numerous subsystems within the facility that combine to provide the first line of protection against the uncontrolled release of these contaminants into the occupied areas of the NIF. The confinement envelope is not a single standalone system, but takes credit for the vacuum or pressure boundary function of components in a large number of subsystems that are connected to the target chamber and have the potential for migration of target chamber contaminants. These components, by virtue of their boundary function, act to "confine" hazardous and radioactive contaminants and prevent release to the adjacent occupied spaces of the NIF.

4.4.7. Contamination Control

The vast majority of NIF's removable radioactivity (primarily surface contamination or gaseous radioactive species such a tritium) is tightly contained in the target chamber and in connected support systems. Post-shot, a small fraction of the target tritium remains on target chamber surfaces and entrant components, such as target and diagnostic positioning systems. The surfaces of these components are identified as "contaminated" and appropriate measures for contamination control are employed when contact with these surfaces is necessary (e.g., removal of diagnostic media; target replacement; diagnostic replacement). Contamination controls at NIF are achieved primarily through the use of installed engineering controls, isolation of impacted areas, PPE, and appropriate worker practices (see Figure 4-5).

Contamination control system piping includes vacuum pump exhaust piping that is routed to the tritium processing system, or to the stack. Contamination control piping is also used to confine target bay air used to flush diagnostic and positioner vessels to reduce residual tritium levels. The contamination control system also includes enclosures—room-within-a-room enclosures that provide additional confinement of contamination—as well as fume hoods for handling and storing contaminated material and a number of specialized containers, including cabinets for purging optics of residual tritium, transport carts for moving diagnostics from the target chamber to refurbishment areas in the diagnostic building, and containers for transporting tritium gas and tritium-containing targets to and within NIF.

The confinement envelope and the contamination control systems share a common function to provide confinement of contamination until contamination levels are reduced to negligible levels. In general, the confinement envelope is operated at vacuum; the contamination control systems are generally operated at atmospheric pressure.

Figure 4-5: Two facility workers in PPE are exchanging a potentially contaminated optic from the final optics assembly attached to the NIF target chamber.

4.4.8. Radiation Monitoring

Permanently installed radiological monitoring systems are used to measure airborne radioactivity and general area radiation levels. These systems collectively make up the radiation monitoring system. Radiation monitoring is accomplished by both direct reading instruments, and by sample collection devices that are periodically removed for laboratory analysis. The monitoring and alarm system interfaces with the radiation monitoring system to provide alarms when allowable thresholds are exceeded.

4.4.9. Fracture and Electrical Hazards

Significant electrical hazards are present in the power conditioning system supporting the main amplifier system, and the power conditioning unit supporting the pre-amplifier module. These systems contain features that protect workers from their electrical hazards. In addition, the power conditioning system presents a shrapnel hazard during certain electrical failures. The module containing the power conditioning electrical components has been specially designed to vent overpressure and trap any shrapnel generated during such off-normal electrical events. Further, the capacitor bay walls have been reinforced to provide additional protection from any escaping shrapnel.

The beampath vacuum integrity system consists of various components related to vacuum-loaded fracture critical optics whose failure could injure personnel working nearby in the facility. The system controls the hazard of large optics that are also a vacuum barrier. These optics may shatter due to flaws that grow from exposure to high-intensity light. An inspection system and pressure mitigating features compose the system

4.4.10. Laser Safety

The hazard from NIF lasers is controlled by the laser safety system. In addition to the NIF main laser, there are a variety of other lower power lasers used, such as for alignment and for diagnostics. The laser safety system consists of a variety of barriers that protect personnel from exposure to any of these lasers. These barriers include specific beam blocks, shutters, laser curtains, enclosures, as well as room walls and doors (e.g., laser bays).

Each of these systems has been evaluated in detail to understand the specific critical components required to ensure the functionality. Further, necessary maintenance or surveillance activities that support meeting the required function have also been specifically identified and monitored. This, combined with configuration management, ensures that safety function of these important systems is preserved.

4.5. Safety Organization

The goal of our safety program is to provide a safe and healthy work environment for our employees and visitors. At NIF, we have a full-time team of highly skilled environment, safety, and health (ES&H) professionals (health physicists, environmental analyst, safety engineers, industrial hygienist, health and safety [H&S] technicians, and administrators), led by an ES&H manager. This team’s role is to develop, monitor, and ensure safety and regulatory compliance of NIF operations. The importance of safety is embraced at all levels of NIF and ranks above all other aspects of our operations, including schedule and production.

Our ES&H team provides guidance and assistance to ensure a safe working environment, including:

- Identifying and analyzing health, environmental, and safety exposures.
- Evaluating and providing guidance on ES&H requirements, safety plans, environmental issues, permitting, and work authorization documents.
- Monitoring workplace compliance with ES&H-related regulations.
- Training, in conjunction with the Safety Education and Training Section, in occupational health, safety, and environmental areas.
- Responding to off-normal situations (e.g., chemical spills, fires).
- Investigating work-related injuries and illnesses.

NIF also has over 600 qualified radiological workers. These workers are supported by team of radiological control technicians, who are specialists in radiological safety. The radiological control technicians are led by the NIF radiation safety officer, who is responsible for implementation of the NIF Radiation Safety Program. The radiological workers and radiological safety professionals ensure that radioactivity at NIF is well-controlled and doses from radiation are maintained as low as reasonably achievable.

5. Laser System

This section includes specific information about laser performance and pulse shaping for experiments. For more information on laser performance, see The National Ignition Facility 2007 Laser Performance Status[11] and Generating powerful ultraviolet beams with the world's largest laser.[12] User requests to change pulse shape, energy, power, or pulse length are evaluated by NIF Systems Engineering to determine whether the laser system can operate safely and effectively with the requested parameter in place. Requirements are reviewed by the BLIP expert group as communicated through the CMT. Performance calculation using the Laser Performance Operations Model (LPOM)/Virtual Beam Line (VBL) and expert group review may result in modifications to experiment setup to meet requirements and also may motivate definition of pre-experiment calibration activities or performance tests.

5.1. NIF Laser Architecture

The NIF 192-beam neodymium glass laser is capable of delivering up to ~4 MJ of 1.053 µm (often referred to in laser frequency space as "1ω") light that is subsequently frequency converted to 0.351 µm ("3ω") light and focused on a target at (or near) target chamber center (TCC). Figure 5-1 provides the history of energy and power delivered to the target during the three-year time period from July 2009 to July 2012. As seen in the figure, the performance of NIF makes it by far the highest-energy and highest-power laser available in the world today, routinely delivering between 1.2 and 1.8 MJ and between 300 and 500 TW.

NIF was designed to be flexible and responsive to a wide range of user requests for specific values of energy and power, beam smoothing, pulse shape, pulse duration, and spot size on target. Following an introductory description of the NIF architecture, the subsections below will review the ranges of interest and the limits for these and other parameters of significance to users.

Figure 5-2 is a repeat of Figure 1-1, with superimposed identifications of major elements of the 192-beam architecture. The high-energy 1ω components of the system are arrayed in Laser Bay 1 and Laser Bay 2 in close-packed horizontal configurations to save space and to reduce the cost of both the laser components and the building that houses them. In "switchyards" on either side of the target chamber, large mirrors redirect the 1ω beams from their horizontal orientation to one that is near-radial, pointed directly at the target. Just before the beams intercept the "surface" of the spherical target chamber, they are frequency converted and focused by the final optic assembly (FOA). Each of the FOAs works with a quad of four beams; thus there are 48 quads of light that enter the target chamber.

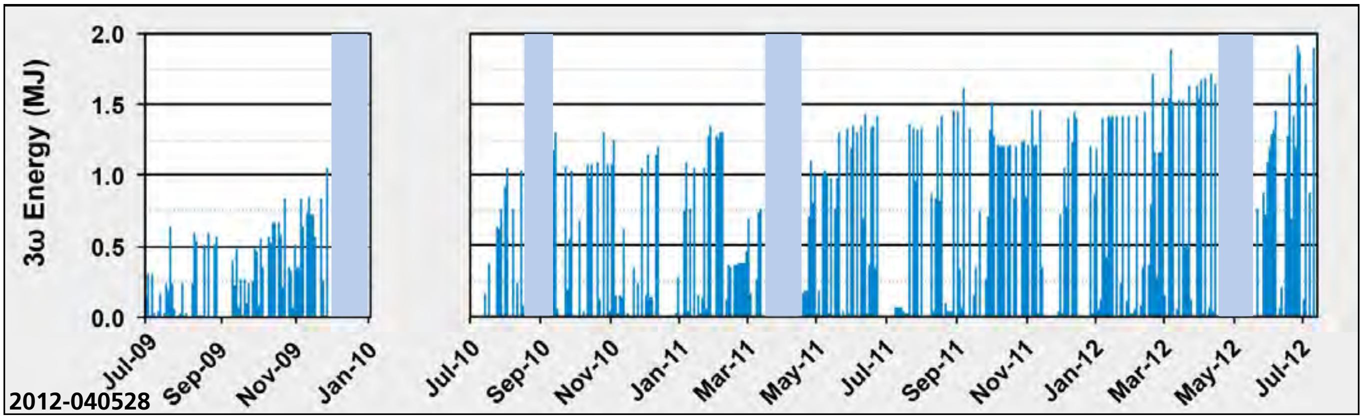


Figure 5-1: Time history of 3ω laser experiments on NIF.

The 192 NIF beamlines are grouped as follows:

- Four beamlines in a quad (numbered 1–4 for top quads, 5–8 for bottom quads)
- Two quads in a bundle (labeled T [top] and B [bottom])
- Six bundles in a cluster (numbered 1–6)
- Two clusters in each laser bay (numbered 1, 2 and 3, 4)
- Two laser bays in the facility (numbered 1, 2)

In the switchyards, each individual bundle is divided into two quads, one each for the upper and lower hemispheres of the chamber. Laser beams enter the chamber at the quad level; that is, the target chamber contains 48 individual laser beam ports (24 in the upper hemisphere, 24 in the lower) with 4 beams passing through each. The quad is the basic independent unit for experiments.

The quads are named with the cluster and bundle number and a suffix that indicates whether the quad is the top (T) or bottom (B) quad in the bundle, such as Q13T or Q45B. Each quad is mapped to a single port on the target chamber. All top quads enter through ports on the top half of the chamber, and all bottom quads enter through ports on the bottom half of the chamber.

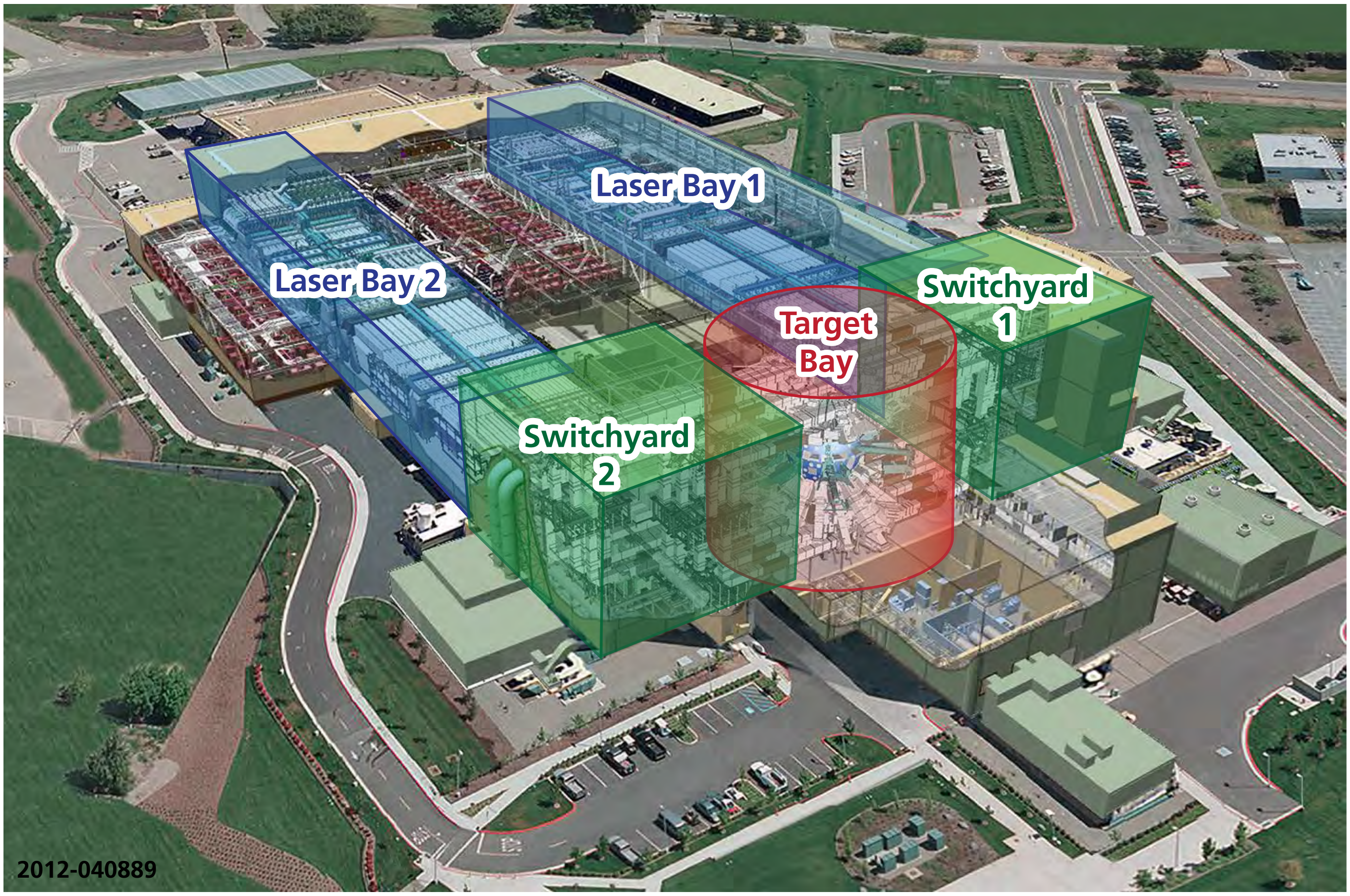
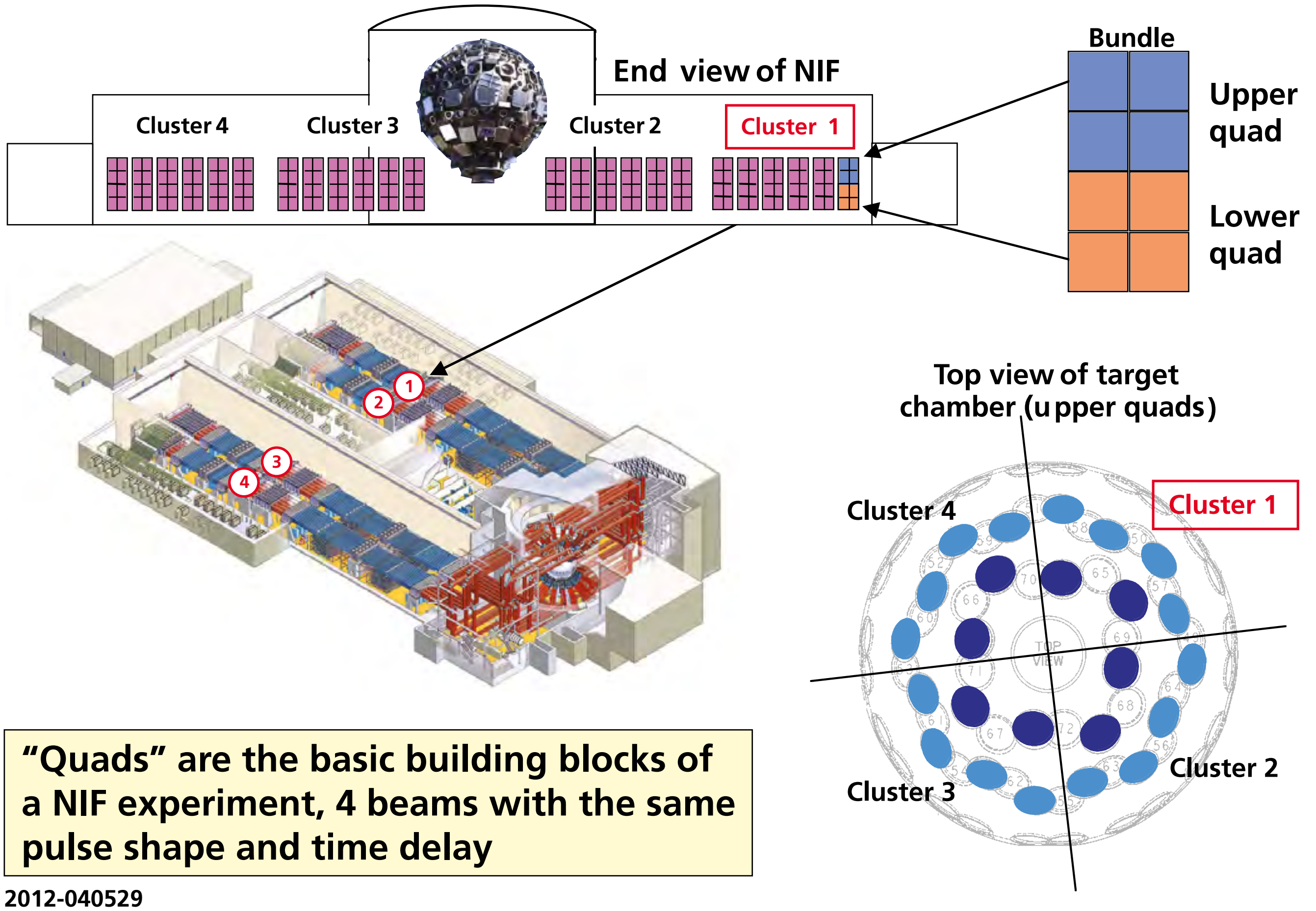


Figure 5-2: High-level architectural components of the NIF laser system.



“Quads” are the basic building blocks of a NIF experiment, 4 beams with the same pulse shape and time delay

2012-040529

Figure 5-3: NIF is organized into clusters, bundles, and quads of beams.

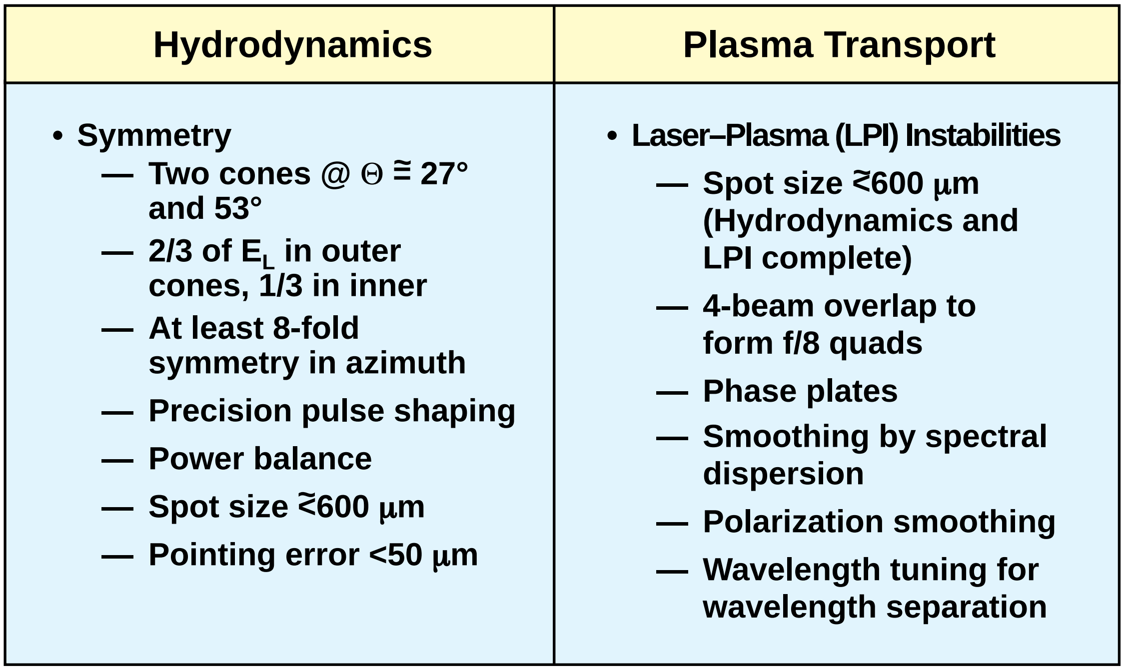
The NIF target chamber is arranged with a vertical z-axis. The quads enter the target chamber through ports that are located on four cones at 23.5°, 30°, 44.5°, and 50° polar angles. The NIF beams are oriented to support indirect-drive hohlraum experiments with the hohlraum mounted vertically. For ignition or other experiments requiring a highly uniform implosion, separate inner and outer beam cones are available to allow time-dependent control of drive symmetry. The inner and outer beam cones are produced by the (23.5°, 30°) and (44.5°, 50°) beams, respectively.

The architectural concepts shown as realized in Figure 5-2 are the results of early criteria that were set for the NIF system based on an understanding of the requirements for an ICF target, as summarized in Figure 5-4. These criteria lead immediately to a system design that included a minimum of 192 laser beams.

The NIF is based on a multi-pass amplifier architecture. Iconic views of the architecture of the master oscillator room, Laser Bay 1, and the target chamber are provided in Figures 5-5 and 5-6. The laser may be broken into three primary areas: the injection laser system (ILS), the main laser, and the switchyard and target areas.

The ILS consists of the master oscillator room (MOR), 48 individual preamplifier modules (PAMs), input sensor packages (ISPs) and preamplifier beam transport systems (PABTSs). In the MOR, a single optical pulse from the fiber master oscillator passes through an array of fiber-optical components to provide temporal amplitude and bandwidth control, and is split to drive 48 preamplifier modules located under the transport spatial filter of the main laser. Each of these 48 pulses is injected into an amplitude modulator chassis (AMC), where it is temporally shaped with an independent electro-optical modulator. The optical pulse from each AMC is fed into the PAM, where it is amplified in a ~50-pass regenerative amplifier and a 4-pass rod amplifier. It then passes the ISP, a diagnostic suite to which 1% of the laser energy is diverted. Here, the total energy, temporal shape, and near-field spatial shape from each PAM is measured; ISP measurements are important for both validating and normalizing numerical models for laser performance and for ensuring that the ILS is properly configured prior to a main laser shot.

Pulses from the ILS are split four ways in the PABTS, supplying each of four main beamlines with energy that is adjustable from millijoules to more than a joule. As shown in Figure 5-6, the pulse from the ILS is injected near the focal plane of the transport spatial filter (TSF). It expands to the full beam size of 37 cm by 37 cm (at the level of 0.1% of the peak fluence) and is collimated by the spatial filter lens. It then passes through the power amplifier (PA), reflects from a mirror and polarizer, and enters the cavity spatial filter (CSF). It traverses the main amplifier (MA), reflects off a deformable mirror that is used to correct wavefront distortions, and then goes through the MA and CSF again. By the time it makes this second pass through the CSF, a plasma-electrode Pockels cell (PEPC) switch has been fired to rotate the beam polarization by 90°, allowing it to pass through the polarizer and be reflected back for another double pass through the CSF and main amplifier. When it returns to the PEPC, the cell has switched off, so it now reflects from the polarizer, and passes a second time through the PA and CSF. After the CSF, a beamsplitter reflects a small sample of the output pulse back to the central CSF area, where it is collimated and directed to an output sensor package (OSP) located underneath the TSF. OSP diagnostics record the beam energy, temporal pulse shape, and near-field profiles.



Hydrodynamics	Plasma Transport
• Symmetry — Two cones @ $\Theta \cong 27°$ and 53° — 2/3 of E_L in outer cones, 1/3 in inner — At least 8-fold symmetry in azimuth — Precision pulse shaping — Power balance — Spot size $\lesssim$600 μm — Pointing error <50 μm	• Laser–Plasma (LPI) Instabilities — Spot size $\lesssim$600 μm (Hydrodynamics and LPI complete) — 4-beam overlap to form f/8 quads — Phase plates — Smoothing by spectral dispersion — Polarization smoothing — Wavelength tuning for wavelength separation

2012-041008

Figure 5-4: NIF design criteria established in 1993 based on ICF target requirements.

The main pulse proceeds to the switchyard where four or five transport mirrors direct it to one of a number of FOAs symmetrically located about, and mounted on, the target chamber. Each FOA contains a 1ω vacuum window, focal-spot beam conditioning optics, two frequency conversion crystals to reach 351 nm wavelength, a focusing lens, a main debris shield that also serves as a beam diagnostic pickoff to measure energy and power, and a 1–3 mm thick disposable debris shield. The debris shields are used to protect the optics from target debris.

The beam is focused onto the target with a 7.7 m focus lens that is wedged slightly to separate the best focus 0.35 µm laser light from the residual 1.05 and 0.53 µm unconverted light. The focal lengths for the 1.05 and 0.53 µm light are 8.16 and 7.92 m, respectively. The effective aperture is 1250 cm².

With this short architectural overview as background, subsequent subsections will discuss features of the NIF laser that were included in its design basis for the purposes of meeting specific user needs. Many of its design features were chosen to address the needs of ICF because the ICF mission is the most demanding of the various NIF missions.

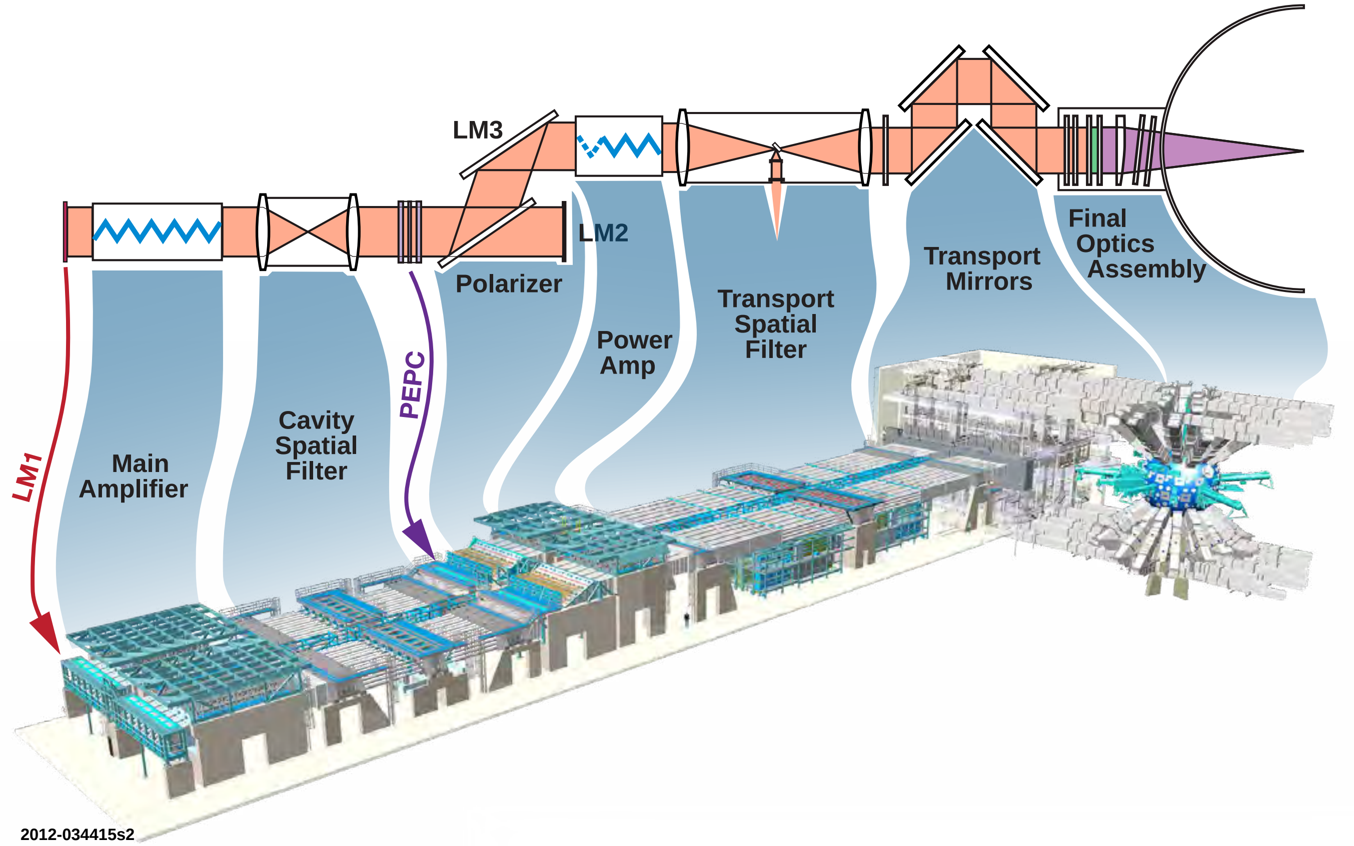


Figure 5-5: An iconic view of the high-energy components within Laser Bay 1 and the target chamber area of NIF.

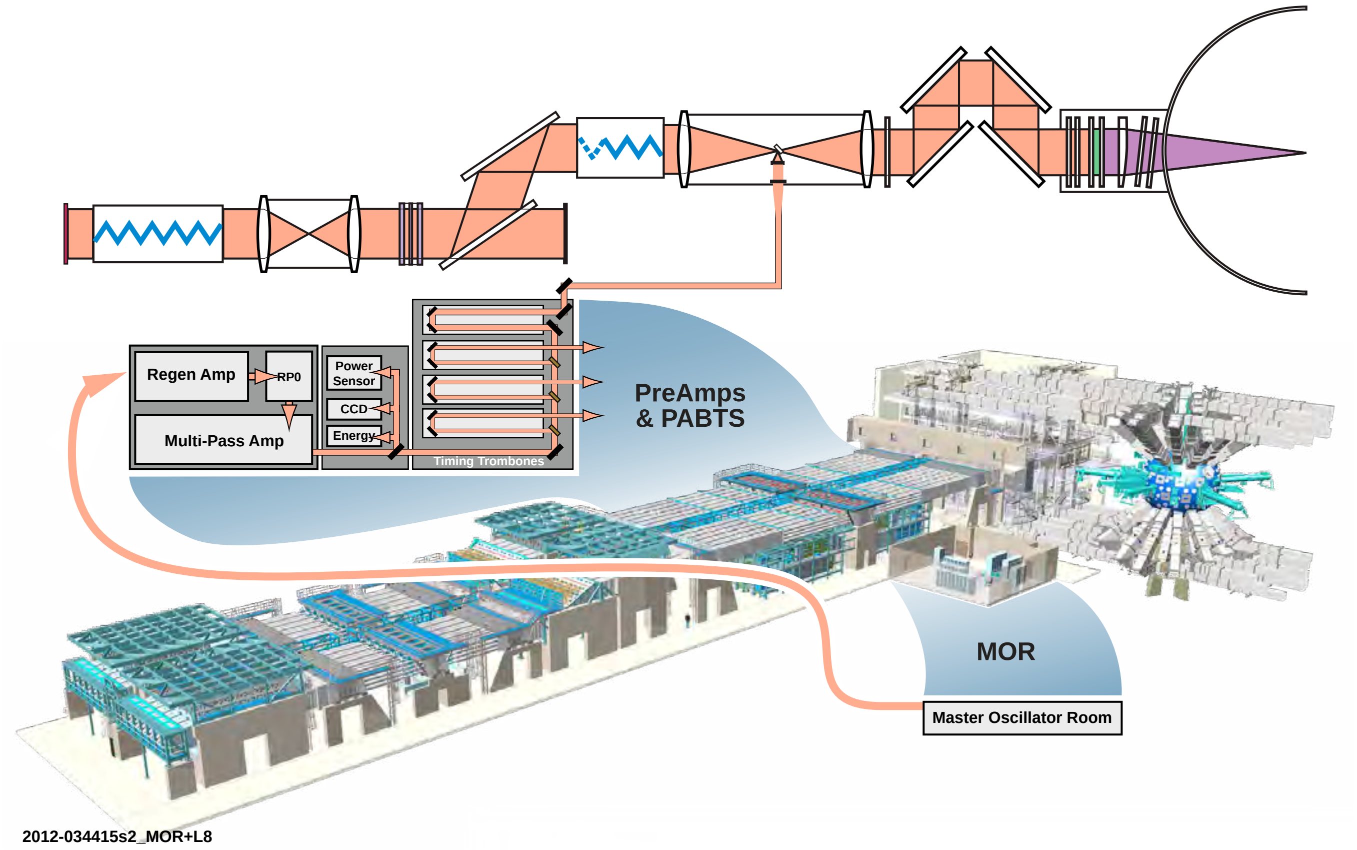


Figure 5-6: An iconic view of the lower-energy components within Laser Bay 1 and the master oscillator room (MOR) illustrating the path of 1ω light from the MOR through the power amplifier.

5.2. Energy and Power

The design of the NIF laser, including the pulse shaping system, provides a great deal of flexibility in pulse length, pulse shape, and pulse energy. Energy limits depend on the details of the pulse shape. The energy available for a specific pulse shape may be limited due to energy stored in the main amplifier slabs, intensity dependence of the frequency conversion, and potential damage to the 1ω and 3ω sections of the laser. Damage may occur due to fluence on optical surfaces or B-integral effects resulting in filamentation in the optics themselves.

Optical damage, primarily of the wedged focus lens (WFL), is a factor in determining the maximum power and energy available at NIF. Each NIF beam has its own statistical distribution of intensities within its beam profile. This distribution varies with requested power, energy, and pulse shape. Consequently, the risk of optical damage varies from beam to beam and changes as more or less damage-resistant optics are installed. The NIF laser system is able to operate routinely above the damage initiation and growth limits because it utilizes the Optics Recycling Loop Strategy described in Section 8.14. Approval of user-requested energies for a particular experiment depends on the current configuration of the laser system, the number and distribution of blocked damage sites, the damage initiation probability distribution functions, $\rho(f)$ for installed optics, and the workload in the optics mitigation facility.

Consider two examples of the maximum available energy and power. First, for the Haan ignition pulse, the actual pulse length is 21 ns, but due to the long, low-intensity foot, the overall performance and response of the laser is similar to that for a 3 ns Gaussian pulse. Under these conditions, the pulse energy is limited by the fluence at 8 J/cm^2 on the final optics. The second example is a 1 ns square pulse. In this case, the pulse energy is limited by the peak intensity, and NIF must operate below 750 TW total power, or 3.125 GW/cm^2.

Figure 5-7 shows the sustainable operational energy and power limitation overlaid on delivered pulse energy and corresponding power as of July 2012. As optical damage initiation levels are improved and mitigation capacity is increased, the sustainable energy and power levels also increase.

It is usually true that user experimental requirements can be accommodated by one or more of the NIF platforms described in Section 10. LPOM and the loop tools, available through the CMT, can help provide users with more guidance on whether a specific pulse shape design is within the current allowable operating range for NIF.

5.3. Beam Conditioning/Beam Smoothing

Without beam smoothing, an individual focused NIF beam will produce a small, high-contrast (100%) intensity profile consisting of speckles whose size is set by the diffraction limit of the beam aperture (Figure 5-8). These high-intensity spikes are able to drive laser–plasma interactions in a target. For example, for an ICF target this would mean that energy could be removed from the beams before their energy could be deposited in the walls of the hohlraum. Beam smoothing is used to reduce the intensity of the spikes, lower the contrast, and shape the beams in a manner that meets target size and irradiance requirements.

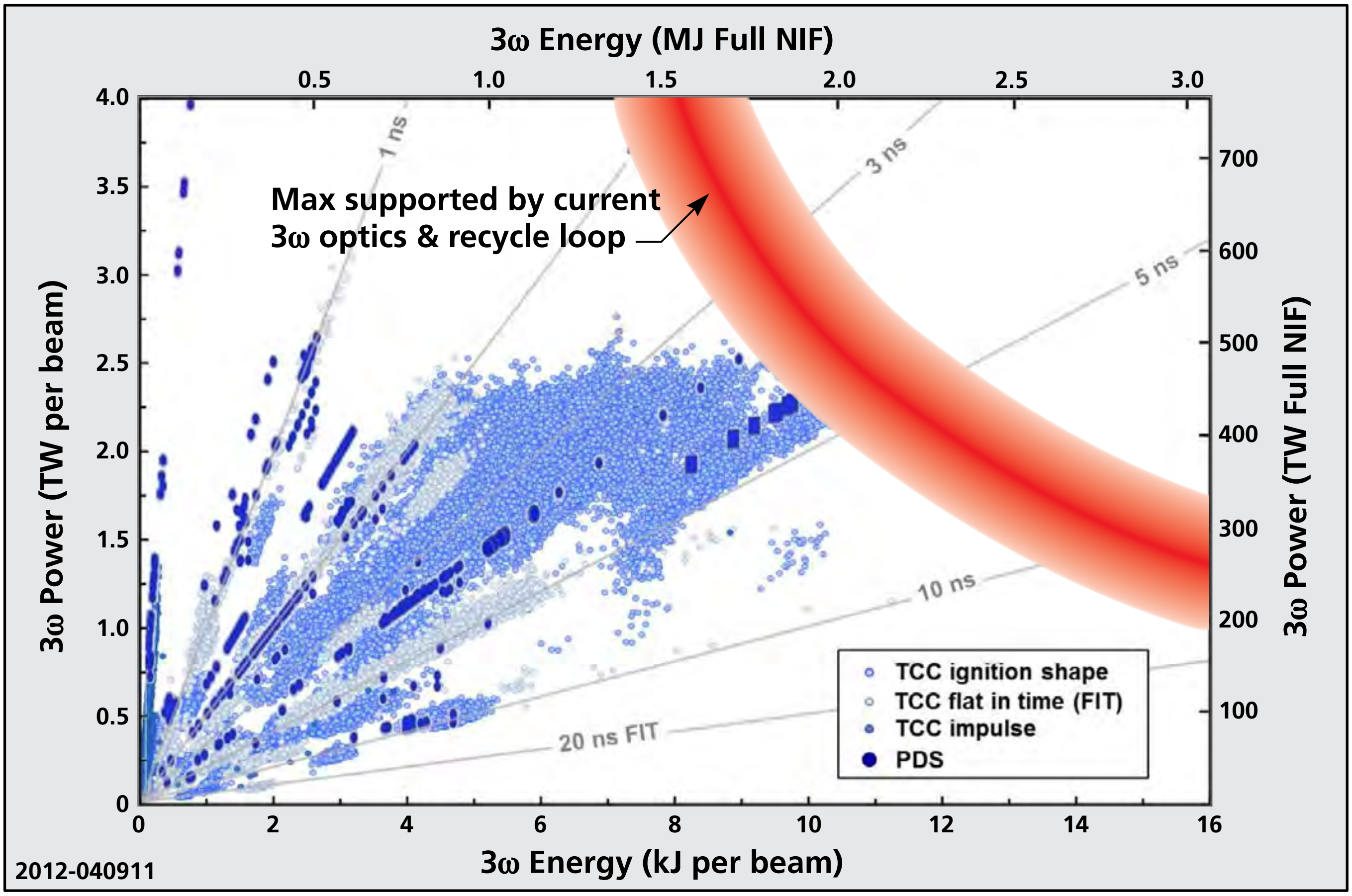


Figure 5-7: NIF sustainable operational energy and power limitation overlaid on delivered pulse energy and corresponding power as of July 2012.

A very important component of the NIF smoothing strategy is inherent in the quad and cone-based architecture of the laser. The four beams in a quad are focused on the target with an f/8 quad f-number. Typically, the foci of the four beams are overlapped on the target. Because each of these beams is only randomly phase-coherent with respect to each other in both time and space, this overlap results in very rapid twinkling of the resultant speckles in the four-beam focus. When the foci of multiple quads in a cone also overlap on a target, even more intense twinkling in the region of the overlap can be expected to occur.

To reduce the peak intensity of the light on the target, smoothing is also available via several techniques:

- Use of continuous phase plates (CPPs) in the FOA to spread the area covered by the speckles in the focused beams
- Use of smoothing by spectral dispersion (SSD) to rapidly move the locations of speckles on target
- Orthogonal polarization of two beams in each quad to reduce the time-dependent coupling of random coherency that can occur between the focused beams in a quad

As described in Figure 5-8, a CPP is a continuous aggregation of small lenses, each with a small independent wedge angle. When a semi-coherent NIF beam is transmitted through a properly designed CPP, the focused beam is spread into an elliptically shaped spot formed of lower-intensity speckles than were found in the beam focus without the CPP.

CPPs are considered to be a user-supplied set of optics for specific experiments. A number of sets of CPPs have already been purchased by users and these are listed in Table 5-1. The four sets (in bold) were deployed in NIF as of September 2012 for ignition campaigns.

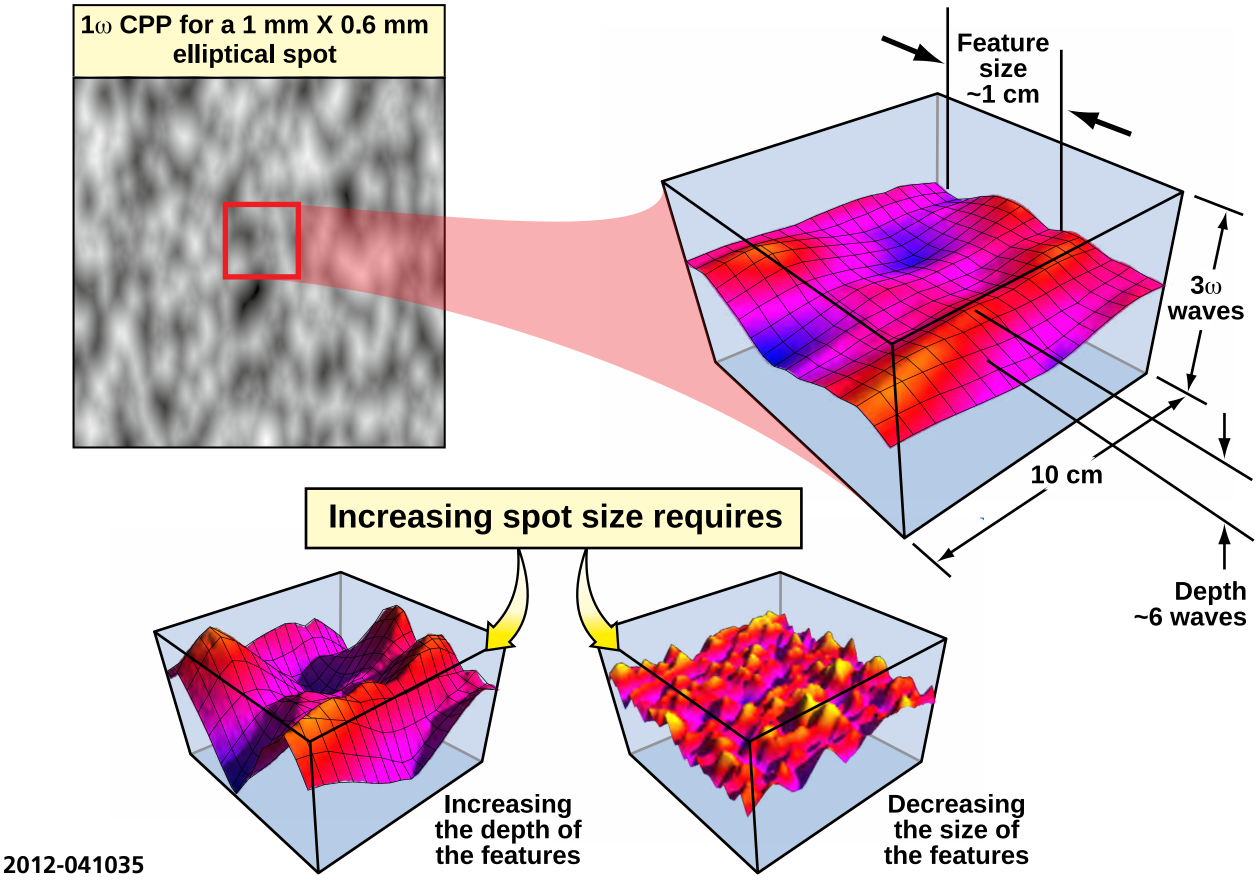


Figure 5-8: Features of a continuous phase plate.

Table 5-1. Features of continuous phase plate sets that were available for use on NIF as of September 2012.

Drawing Tab	Type	Scale	Quantity	Major axis diameter FWHM (a) (mm)	Minor axis diameter FWHM (b) (mm)	Ellipticity b/a
-08	**1.0 Outer**	**1**	**64**	**1186**	**686**	**0.58**
-12	**1.0 Inner**	**1**	**32**	**1648**	**1180**	**0.72**
-17	1.07 Outer	1.07	64	1270	734	0.58
-16	1.07 Inner	1.07	32	1764	1262	0.72
-14	**1.175 Outer**	**1.175**	**64**	**1394**	**806**	**0.58**
-13	**1.175 Inner**	**1.175**	**32**	**1936**	**1386**	**0.72**
-07	0.7 Outer	0.7	4	830	480	0.58
-15	0.7 Inner	0.7	4	1154	826	0.72
-18	400 µm Round		4	400	400	1.00

5.4. Spot Size

The term “spot size” at NIF refers to the size of the focused beam without a CPP in the beamline. Spot size provides a measure of the beam quality being delivered by the laser. In general, it does not represent the size of the beams as they irradiate the target.

Before beams are directed toward the target, they are “smoothed” to reduce the peak intensity at the laser entrance hole (LEH). Reducing the intensity reduces the likelihood of laser–plasma interactions, which can cause the laser light to be reflected rather than absorbed.

Geometric constraints at TCC make it impossible to directly measure beam size in the target chamber. Instead, beam size measurements have been made at an equivalent target plane, in the NIF precision diagnostic system (PDS). Based on single-beam PDS measurements, 80% of the focused energy at 500 TW is contained in a spot 330 µm in diameter; this compares to the NIF Project completion criteria of 600 µm.

Beam smoothing at NIF is accomplished by a combination of SSD and CPPs, as discussed above. SSD is implemented via a lithium niobate crystal in the MOR that adds frequency modulation to each beam, coupled with a grating in the PAM that leads to a small 1D wobble in the pointing direction of the modulated beams. Figure 5-9 illustrates that the CPP and SSD can be combined to provide a beam focus with a controllable diameter made up of individual speckles that are smeared with time.

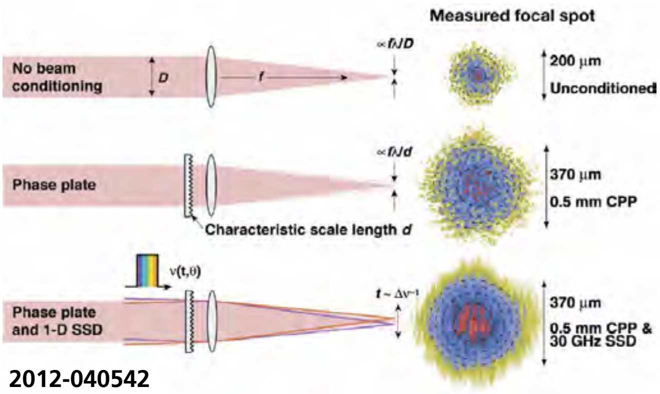


Figure 5-9: Beam conditioning can be used to improve the focal spatial uniformity of the laser focal point.

An additional smoothing technique implemented at NIF is polarization smoothing (PS). PS is implemented on a quad basis in the 1ω section of the FOA; the relative orientation of the orthogonal polarization for the beams in the inner and outer quads as they were in place in September 2012 is shown in Figure 5-10. Half-wave plates in two of the four FOA apertures of a quad are used to rotate the polarization of the incoming beam by 90°. Half-wave plates require collimated beams and will work in either the 3ω or 1ω section. As of September 2012, the half-wave plates are in the 1ω section because this location does not expose the optic to 3ω light and thus can be expected to have a longer life and lower operating costs. In addition, the SRS gain coefficient in the 1ω section is 2/3 of that in the 3ω section.

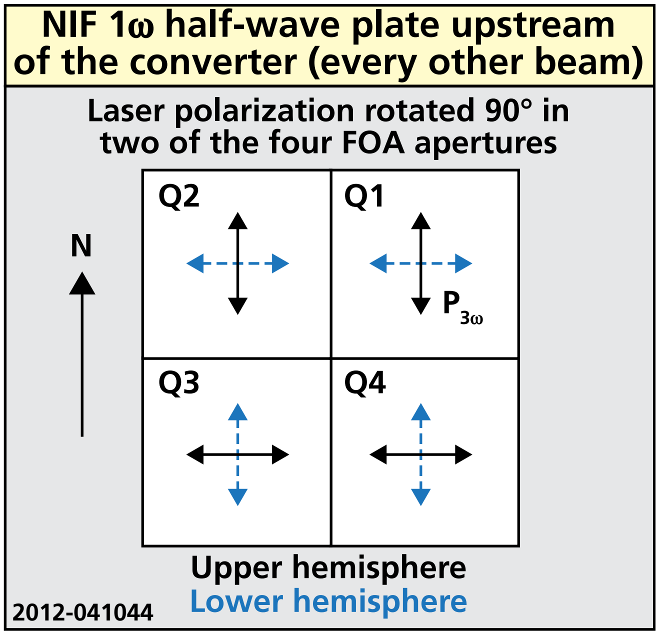


Figure 5-10: Orientation of the orthogonal polarization rotators in place on NIF as of September 2012.

5.5. Temporal Pulse Length and Pulse Delays

To date, NIF has produced high-energy shaped pulses with lengths up to ~23 ns. The pulse length limit for a temporally shaped pulse on NIF is close to 35 ns.

The MOR has an independent pulse shaping AMC for each quad of beams. The delay of any of the 48 quads of beams may be independently adjusted through settings in the CMT. For delays that contain the start and stop of the pulse within the 0–30 ns absolute time window, the NIF system can handle the timing changes automatically. Timing changes beyond the 30 ns window should be accommodated with hardware/software upgrades during calendar year 2013. The maximum allowable time delay will be 1 μs but the nonlinear effects within the fiber delay beyond a few hundred nanoseconds have not yet been evaluated. Negative delays are not allowed, as there is no light for pulse shaping before absolute “0” NIF time.

Two quads within a common bundle must have a relative delay that is ≤100 ns due to coupling of the amplifiers and electrical grounding of the PEPC. The exact allowable delays will be different for each bundle, as the individual beamlines within the bundle may be more restrictive than the PEPC time window listed above.

The MOR includes phase modulation on all beamlines for stimulated Brillouin scattering (SBS) and SSD. The SBS phase is modulated at 3 GHz, with a modulation index of 5.5. SSD is modulated at 17 GHz, with a modulation index that can be selected by the user but must always be greater than 1.32. The maximum phase modulation for SSD has not yet been determined. Phase modulation for SSD with a modulation index of greater than 1.5 will require additional review before a campaign can start. The SBS phase is fixed such that the “0” phase will always be at the 50% rise of a pulse with the leading edge at NIF absolute “0” time. This time is also known as TCC 0 time. The phase of the SBS modulation at TCC does not change with pulse timing (i.e., the SBS phase is static, while the pulse timing may vary with respect to this phase through the requested delay). The SSD phase is not locked and will change with each shot.

5.6. Available Temporal Pulse Shapes

The pulse shape and timing is common for all four beams within a single quad. Each quad may be independently configured for timing and pulse shape.

From its conception, NIF was designed to meet a very broad band of user requests for pulse shape. The AMC for each quad consists of an arbitrary waveform generator (AWG), 140 amplitude impulse generators spaced ~ 250 psec apart, and a square wave generator. The output from the amplitude pulse generators can be automatically adjusted and summed to create a best quadratic fit to a requested pulse shape. Instructions for how to instruct the AMC to generate a pulse shape of interest are available from the NIF operations staff.

Within the bandwidth constraints of the 1 GHz filter, the AMC can produce nearly any pulse shape from 0.4 to 30.5 ns in duration with a large dynamic range. For the Haan point-design ignition pulse, this is a 280:1 contrast in the ILS, corresponding to a 50:1 contrast at 0.35 µm. Near-Gaussian impulses may be generated separately with the impulse generator switched in place of the AWG.

Examples of pulse shapes that have been generated in the MOR to illustrate the range of flexibility of the AMCs are given in Figure 5-12. The dynamic range—the ratio of the peak to minimum value of the intensity along a pulse—has been demonstrated for ICF pulses to be greater than 300. The dynamic range that would be expected for other pulse shapes would need to be evaluated by the NIF Systems Engineering organization.

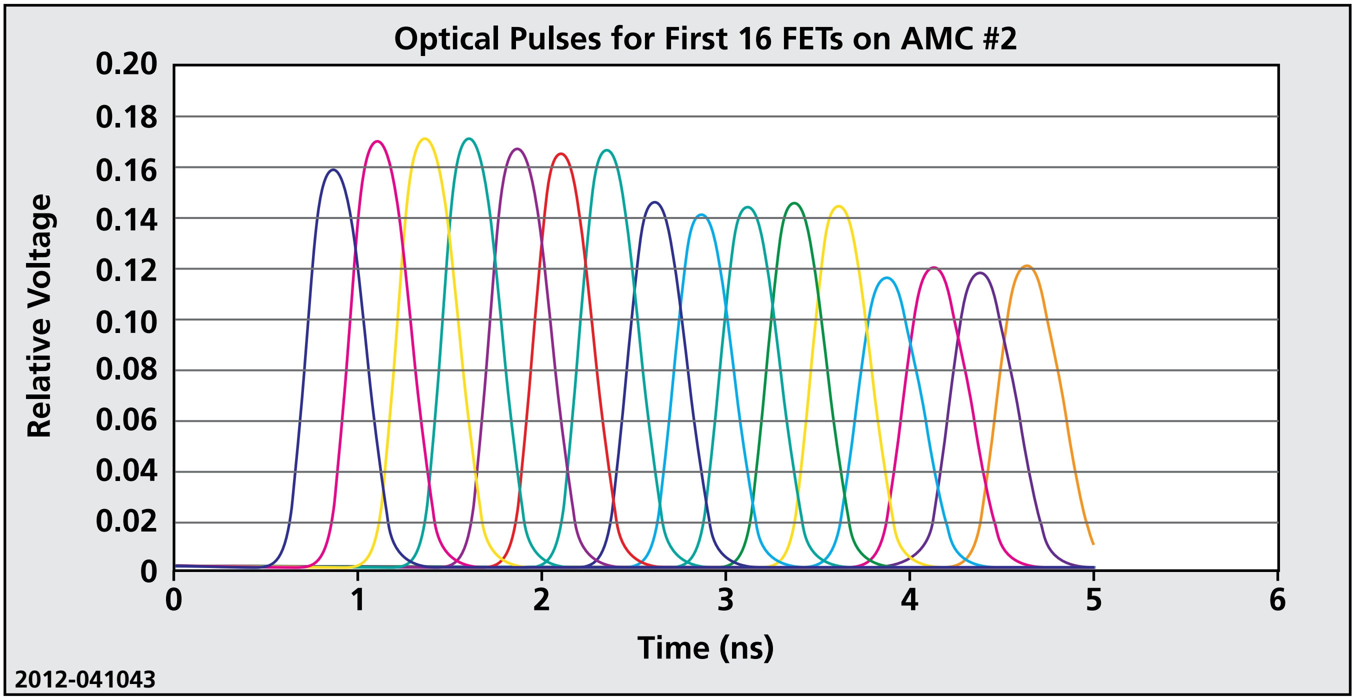


Figure 5-11: Sample outputs of the amplitude impulse generators that can be adjusted and summed to create arbitrary pulse shapes over a wide range of interest.

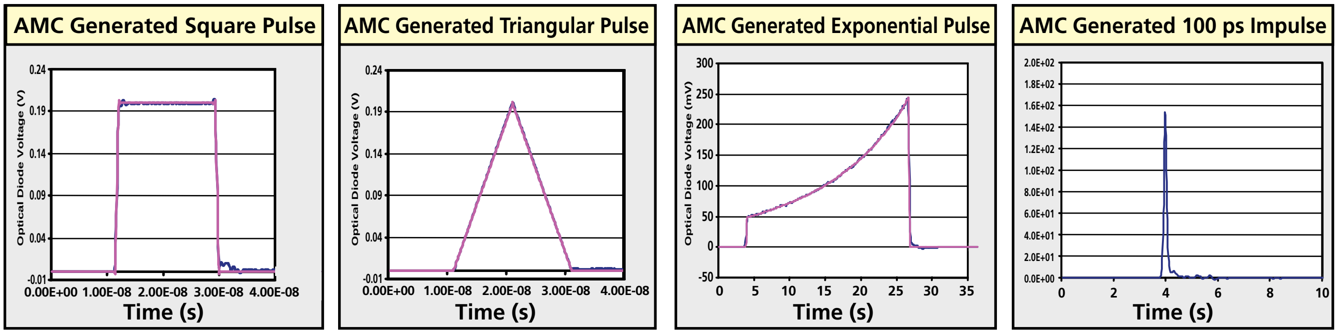


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Figure 5-12: Examples of pulse shapes generated in the MOR.

5.7. Available Wavelengths

The NIF laser can operate simultaneously at a number of wavelengths. As of September 2012, it could operate at three individually tunable wavelengths using three separate master oscillators and associated modulators and pre-amplifiers, all located within the MOR. As of this date the three separate master oscillator subsystems were each driving distinct quads within the inner and outer cones. The two reddest wavelengths were being sent to the inner cones and the bluest wavelength was sent to the outer cones (see Figure 5-13). The expanded broad, flat gain profile of the Regen pre-amplifier gives target designers significant freedom for planning experiments with individually tunable wavelengths. As of September 2012, the extent of wavelength tuning was set by management of back-reflected light from the conversion crystals at ±0.71 nm at 1ω. For more on tuning with three wavelengths, see *A three wavelength scheme to optimize hohlraum coupling on the National Ignition Facility*.[13]

5.8. Synchronization

The four beams within each quad are synchronized to arrive simultaneously at target chamber center. The separate quads are synchronized with respect to each other using a separate fiducial pulse as a cross-timing reference. The beams are synchronized at nominal t_{zero} to within 30 ps rms, but multiple quads may be synchronized at a fixed delay if accurate relative beam timing is required at a large delay.

5.9. Prepulse

The NIF is a glass laser at 1.05 μm with frequency conversion crystals that frequency triple the light to 0.35 μm. As a result of the frequency conversion process, the primary source of prepulse is 1.05 μm light. This is controlled at the 3ω focus by the dispersion of the WFL. There is an offset of the footprint of 1ω unconverted light from the 3ω focus with a 4.8 mm clearance.

The effect of prepulse on a target depends on the composition and orientation of the target surfaces. As a general guideline, intensities above about 10^8 W/cm^2 will begin to form weakly ionized plasma on a metal surface. The NIF prepulse will exceed 108 W/cm^2 of 1.05 μm light approximately 3–5 ns before the nominal start of the laser pulse shape.

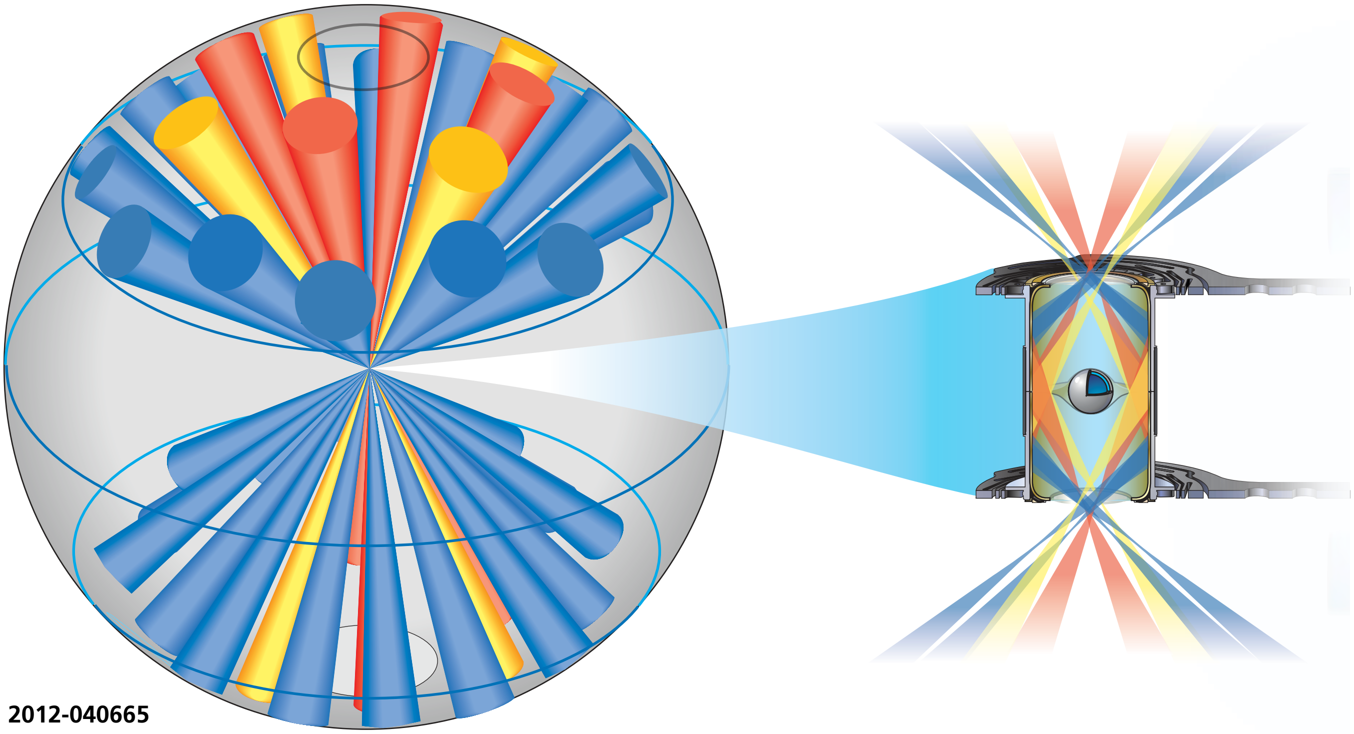


Figure 5-13: NIF beams are arranged to support vertically mounted, indirect drive hohlraums/targets. Three individually tunable wavelengths are available to control implosion shape.

5.10. Beams and Beam Alignment

The NIF beam is nominally 37 cm square with a 7.7 m focus to TCC. The effective beam area is 1250 cm^2. A two-by-two group of four beams composes a quad. These beams are located with a center–center spacing of 55.7 cm in the azimuthal direction and 63.2 cm in the polar direction. The f/# of an individual beam is 20.7, and the f/# of a quad of 4 beams is 7.9.

The quads of beams enter the target chamber through ports that are located on 4 cones at 23.5°, 30°, 44.5°, and 50° polar angles on the target chamber. Additional ports at 77.5° polar angle are designated for future use in a direct-drive configuration for NIF. A full listing of the beam port angles and cross-reference to the quad numbering is provided in Table 6-1.

Individual beams are pointed near chamber center by tilting the LM5 and LM8 turning mirrors. The expected range of pointing for each beam is ±30 mm up/down and ±5 mm left/right in beam coordinates and ±30 mm in Z (along the beam direction) about target chamber center. The goal for pointing range along the beam direction is –46 mm (towards the focus lens) to +38 mm (away from the focus lens).

5.11. Final Optics Assemblies

The primary optics performance goal for the 3ω NIF laser was to provide very high-performance, highly available FOA units that could frequency convert the incoming 1ω light to 3ω and then focus that light on a target at TCC. The FOAs also house two of the components central to meeting user requests for beam conditioning and spot size control: a 1ω or 2ω CPP and, in half of the beamlines, a polarization rotator. The FOAs include stepper motors to move the WFLs along their lines of sight to allow the light to be focused over a range distance on either side of TCC. They also allow a range of pointing angles (established at 1ω by LM5 and LM8) such that the light can be focused over a range of distances from TCC in a plane normal to the line of sight. Hardware in the FOAs also provides local diagnostics for 3ω performance of each beamline.

Figure 5-14 summarizes performance goals that were set for the FOA and the techniques used to accomplish them.

	Functional Responsibility	Design response
Performance	Efficient conversion efficiency over the full dynamic range of the drive pulse	Type I/Type II converter
	Focus the 3ω light, with effective wavelength separation on target	Aspheric 7.7-m focal length wedged lens
	Less than 5% fluence contrast adder at 3ω	High-precision, low-scatter optical surfaces
	Meet user requirements for spot size and smoothness on target	Phase plates, Polarization Smoothing crystals

Figure 5-14: A summary of the primary performance responsibilities of the NIF 3ω laser.

The FOA for each beamline contains a 1ω vacuum window, a CPP, doubler and tripler frequency conversion crystals, the wedged focusing lens, a 1 cm thick main debris shield that also serves as a diagnostic pickoff for measuring energy and power, and a thinner (1 or 3 mm thick) disposable debris shield (DDS) for protection of the optics from target blowoff. Visualization of the optics in a typical FOA is given in Figure 5-15. These optics are the last components encountered by the NIF beams before they hit the target. They exist in a 10 Torr environment where the fluence is almost always over the threshold for 3ω damage growth (~4 to 5 J/cm^2). Routine shots taken in July 2012 put over 10 J/cm^2 mean fluence on these optics.

The NIF frequency converter represents a design that has been optimized from several points of view. It utilizes a Type I/Type II sum-frequency phase-matching scheme (seen in Figure 5-16) that was chosen after comparison with a Type II/Type II converter because the selected scheme is relatively insensitive to 1ω electric field depolarization and because of crystal size availability issues. At the time of NIF design, techniques for large crystal growth were still being developed.

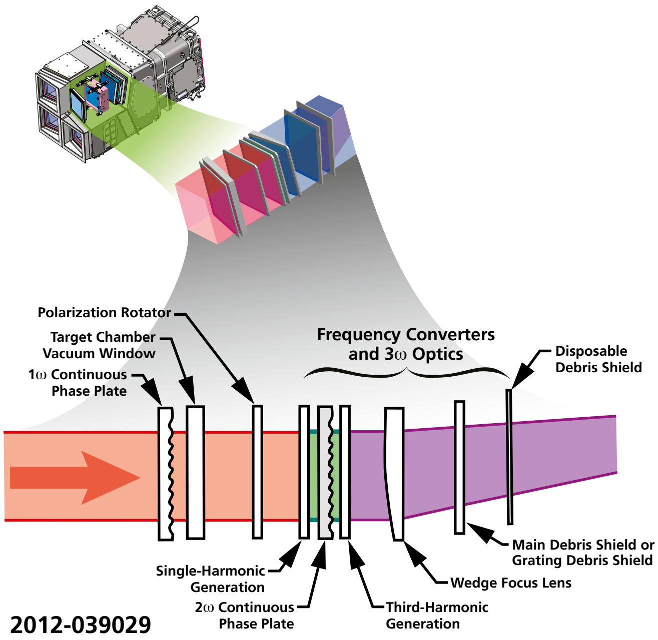
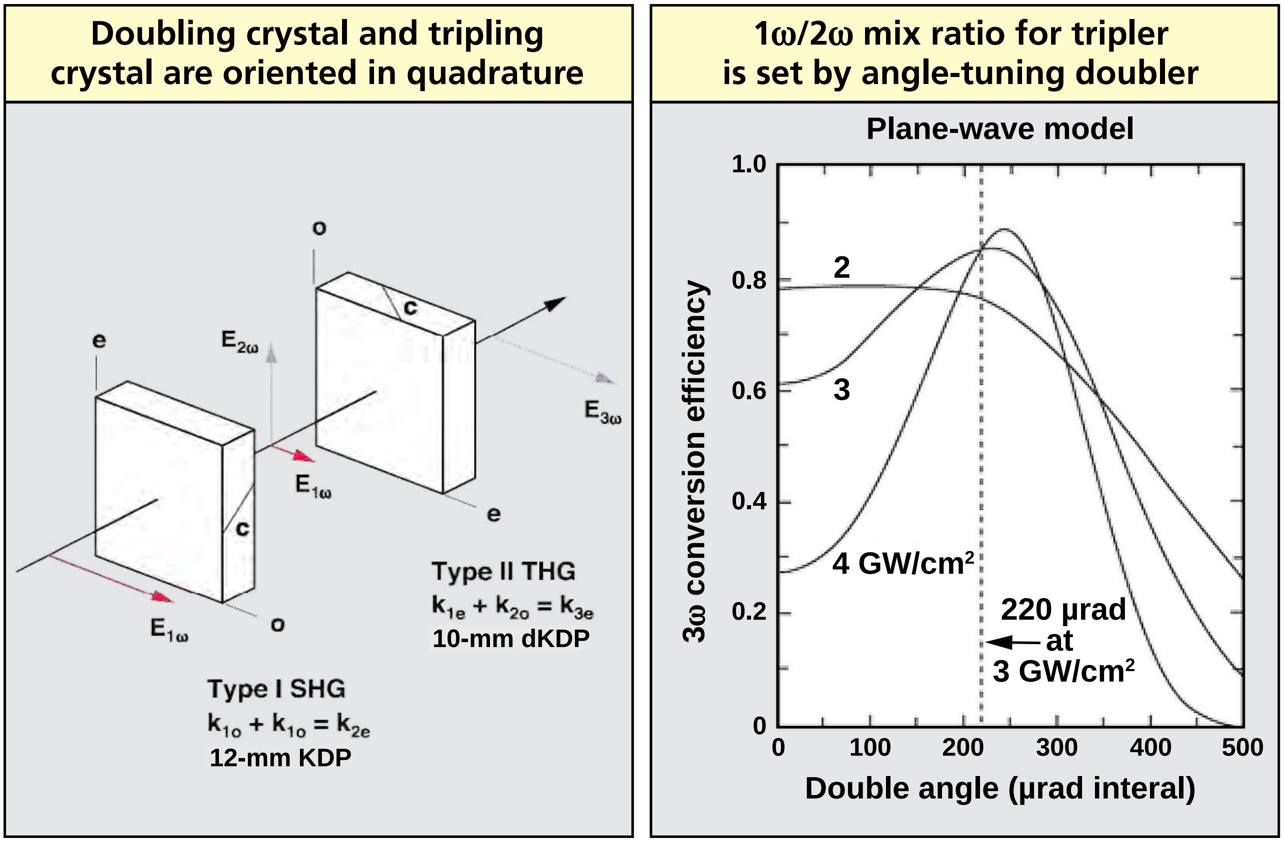


Figure 5-15: Schematic layout of NIF's final optics assembly. This mechanical system mounts to the NIF target chamber and contains the final set of optics for four NIF beamlines.



Doubling crystal and tripling crystal are oriented in quadrature

1ω/2ω mix ratio for tripler is set by angle-tuning doubler

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Figure 5-16: The frequency converter geometry for the NIF Type I/Type II design.

The NIF frequency converter is asked to work over a broad dynamic range. Shots in the summer of 2012 demonstrated a dynamic range of greater than 300 at 3ω. With a 12 mm doubler and a 10 mm tripler, the selected design provides optimum conversion efficiency over the full dynamic range of the drive pulse from <0.3 to >3 GW/cm^2, with ~80% conversion efficiency at the peak of a point-design ICF pulse.

The selected design for crystal thicknesses balances optimum conversion efficiency over the full dynamic range of the drive pulse with maintenance of acceptable operational tolerances for angular errors of the incident beams, variations in crystal thickness, and variations in the precise value of the input wavelength within the tuning range of the 1ω laser.

The off-axis WFL shown in Figure 5-17 is the highest value optic in NIF. It has a 7.7 meter focal length, with an aspheric input surface and a flat output surface. It has a full dimension of 43x43 cm^2 and a hard aperture of 40x40 cm^2, and transmits nominal beam dimensions of 37x37 cm^2. On its thick edge, it is ~4.5 cm thick.

The wedge of each WFL serves two purposes. It is designed to physically separate the residual 1ω and 2ω light from the 3ω light focused on the center axis of the four lenses in a quad. The focal lengths for the 1ω and 2ω light are 8.16 and 7.92 m, respectively. Also, as seen in Figure 5-17, the angles of the wedge are chosen to deflect the ghost foci from top and bottom pairs of WFLs to off-axis locations. The WFL and other FOA optics are shielded from target debris by a DDS assembly, which allows debris shields to be changed remotely. DDS changeout can occur as often as every 2–3 shots during high-energy operation.

The NIF FOA has proven to be a versatile, robust system for maximizing NIF performance at 3ω.

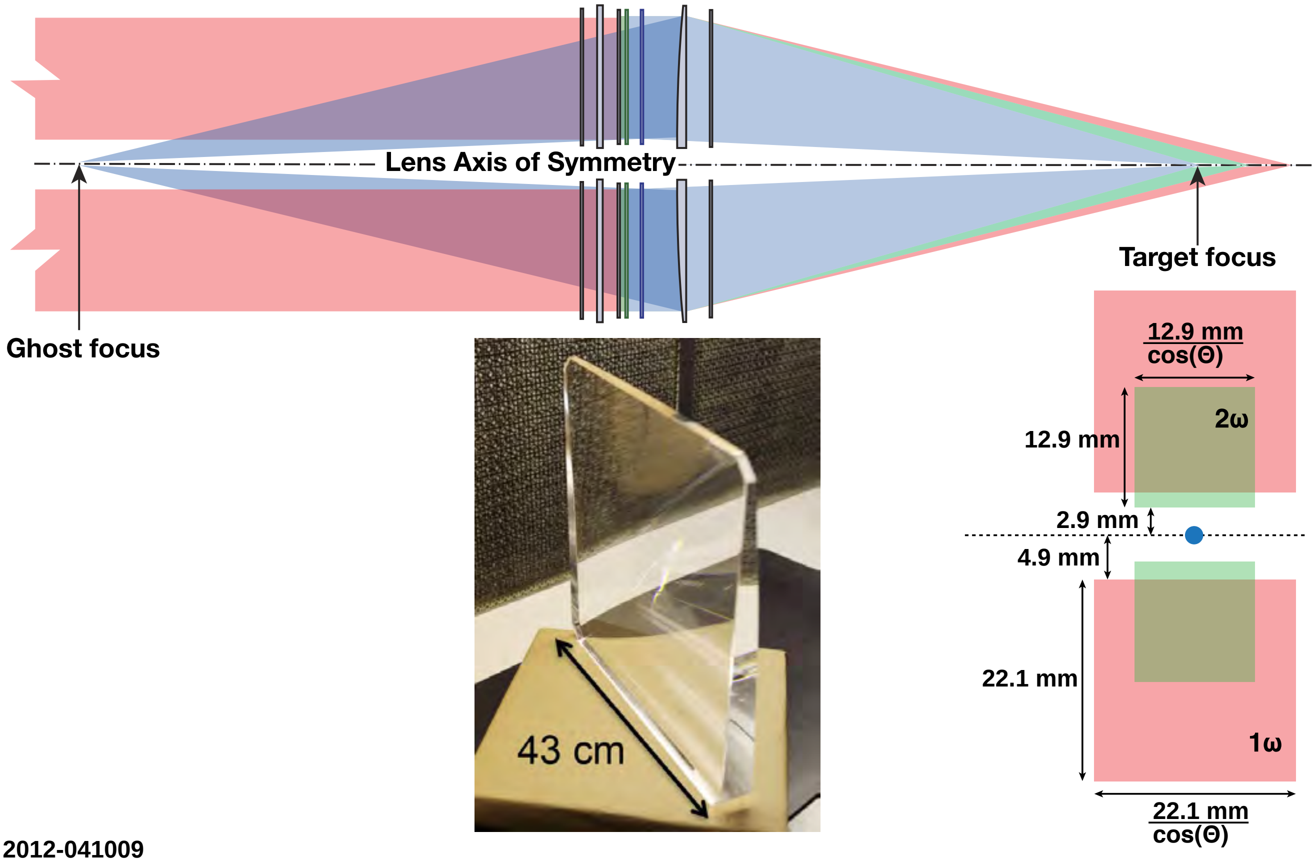


Figure 5-17: The NIF wedged focus lens.

5.12. Laser Cycle Time

Figure 5-18 illustrates that the 8-hour goal for the cycle time between shots on NIF has been achieved. The cycle time is not limited by the laser system but rather by all of the other preparations that are needed for a shot.

For shots of a similar type, the controlling laser factor for shot-to-shot cycle time is the residual heat still present in the laser slabs and the clean air surrounding those slabs. With the use of the deformable mirror and automatic alignment systems, the laser can be ready to shoot again in 1.5–2 hours. As seen in Figure 5-19, the NIF focal spot requirements are met in <2 hours after first shot. With the closed loops operating, the small added distortion above the "cold" system value is acceptable for taking the next shot.

5.13. Laser Performance Operations Model

LPOM is an integrated computational system that automates the calculation of the laser setup required to achieve experimental goals. LPOM is built around a physical optics propagation code, the VBL. VBL is able to provide laser beam intensity profiles and spatially resolved temporal pulse shapes at each optical surface in the NIF laser limited by the available beamline-specific data models, optical component measured phase fronts, losses, and system configuration. In particular, laser data acquired by laser diagnostics packages may be simulated in advance and then compared to measured data acquired on a shot. Post-shot laser data is fed back into LPOM to improve precision for models of the ILS, the main amplifier, and the final optics.

LPOM is operated from the control room, where it communicates with a software supervisor, integrating it directly with the NIF integrated computer control system (ICCS). In addition to supplying shot setup information, the LPOM helps protect NIF equipment and archives shot data and analysis for future study. The LPOM may also be run in an off-line mode (not in the control room) for pre-shot setup and target design studies and can be invoked from the CMT suite described in Section 9. Together with the optics loop tools, LPOM is a valuable asset for designing NIF experiments.

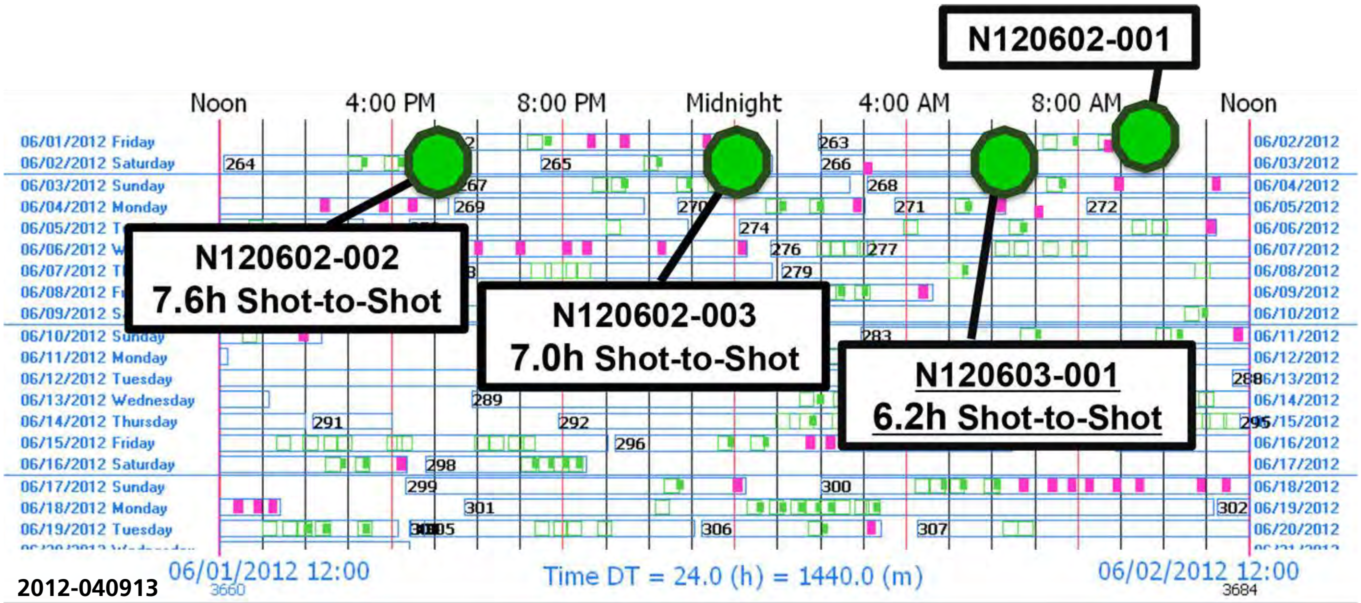


Figure 5-18: An example of the cycle time between full-system shots that have been completed on NIF for shots in the early June 2012 time frame.

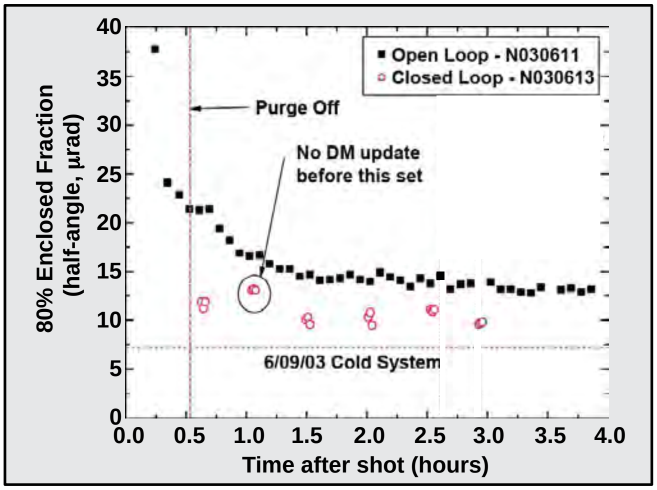


Figure 5-19: Time for the optical quality of the laser to recover after a full-system shot, with the deformable mirror system operational.

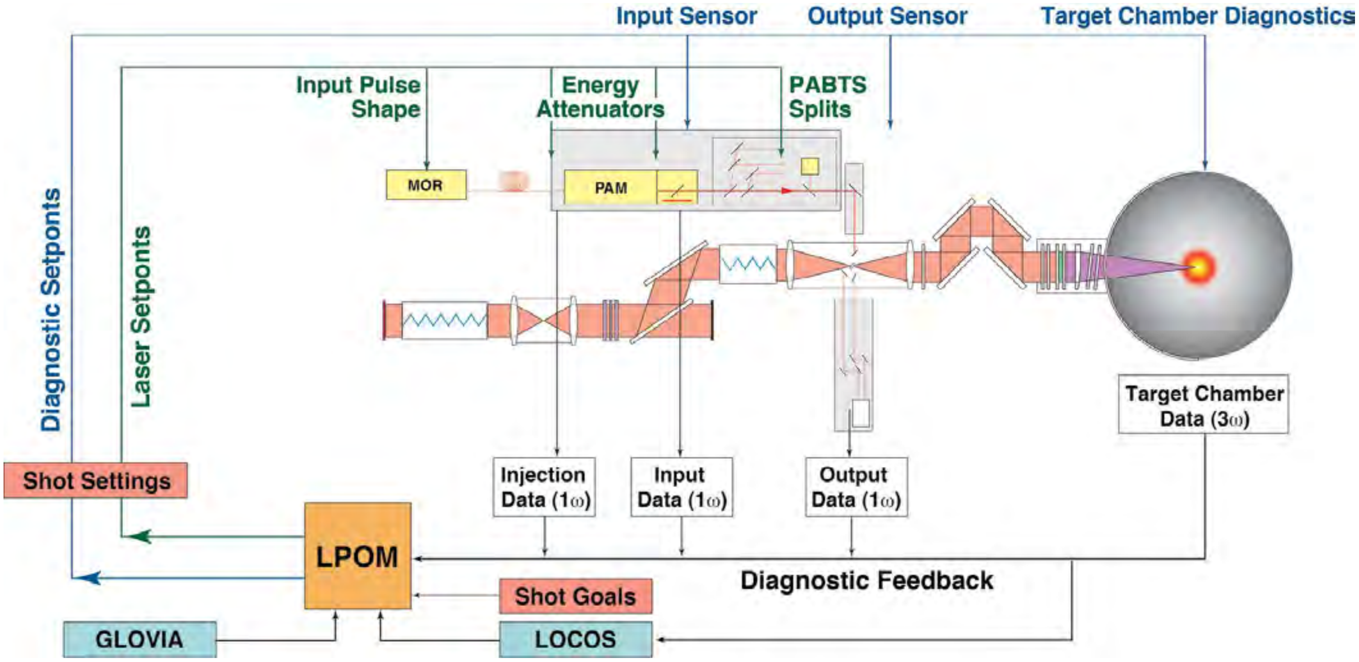


Figure 5-20: LPOM contains a detailed model of each beamline. Propagation calculations using the VBL model provide predicted energy and power throughout the laser, information that is used for equipment protection and to configure diagnostics via ICCS. Data results are presented in a web-browser format, with a series of linked web pages that provide successive levels of detail for each quad.

In order to maintain an accurate model of each beamline, LPOM requires feedback at the conclusion of each shot from each diagnostic. A suite of laser diagnostics provides data on the performance of NIF. The measured data from individual beams are processed to determine the total power and energy on target and the power and energy balance, for any given shot. When the predictions of the model begin to deviate from measured data, LPOM uses a set of measured data to improve its model of the laser. Revisions and upgrades to VBL and LPOM occur at frequent intervals as new features are added to the facility and new configurations must be modeled.

Real-time adjustments of the code's energetics parameters have allowed LPOM to predict total energies within 3%, and provide beam-to-beam power balance better than 15% for full system shots with energies and powers as high as 1.8 MJ and 500 TW. In addition to the ILS settings, LPOM also predicts the energies and powers at each of the laser diagnostic locations in NIF, thereby ensuring that each diagnostic is configured to accurately measure the results of the shot.

5.14. Operations Loop and Optics Recycling Strategy

The NIF operations loop integrates all the tasks required to execute a systems shot on NIF. The loop ensures that predefined laser performance configurations are appropriately matched with each desired shot, and that similar shots are scheduled in a manner that minimizes reconfiguration time. It also includes checkpoints to confirm that the selected laser configuration will safely meet shot goals. Through this loop, new capabilities are incorporated into a new or existing laser configuration, as appropriate, before configuring the laser for a shot. Figure 5-21 is a schematic illustrating the process for setting up NIF to execute laser shots. All the nested loops of activities flow through the act of firing the laser at bottom right in the figure.

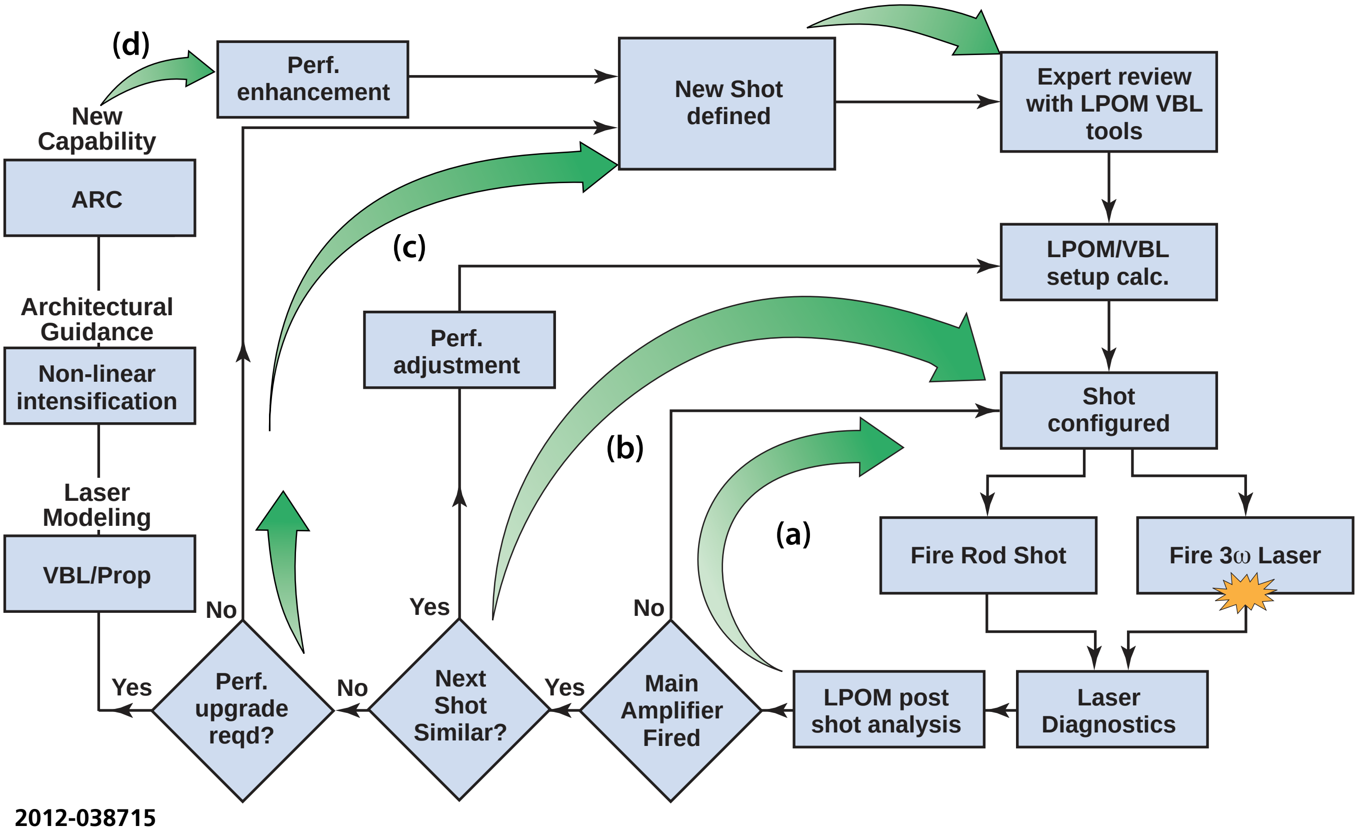


Figure 5-21: NIF Operations Loop illustrates the flow of shot execution tasks at NIF.

a At bottom right are the actions of configuring the laser for a shot, executing a full system shot or a low-energy rod shot, and analyzing the laser performance data. Those actions are shown as part of a loop that operates on a timescale of minutes to hours.

b A second, wider loop operating on a timescale of hours to days illustrates setup and execution of additional shots of a similar type, incorporating performance adjustments based on previous shots.

c A third, wider loop operating on a timescale of days shows the process of setting up and performing expert review for a different shot type.

d Finally, the outermost loop shows the path for laser experiments that require significant performance enhancement or extension of current capabilities to new areas of performance. This loop operates on a timescale of weeks to months.

All of these operations paths rely on the ability to model and hence predict the performance of the NIF laser and have that model respond to observed performance of the laser on previous shots. Thus, a key part of the operations loop is LPOM, described in the previous subsection.

Through LPOM, the operations loop works in concert with a second loop—the 3ω optics recycling loop. NIF is unique compared to all other 3ω lasers built to study HED and ICF science. Previous ICF lasers typically operated with a fluence of about a third of their design point; even when they were used at this fluence, useful knowledge came from their work. When NIF was approved for pursuit of ICF ignition at 8 J/cm^2, this practice could not be continued. It was absolutely imperative that NIF operate at its design point, which necessitated the development of a new strategy that would allow the high-cost optics that are subjected to 3ω light to operate consistently and predictably at a level significantly above their damage growth threshold. The resulting strategy (shown in Figure 5-22) was the 3ω optics recycling loop. NIF is now operated regularly in the range of its point design because all of the elements of this loop are in place.

The recycling is actually an assembly of loops, with decision points for moving from one loop to another. The innermost loop allows the laser to be fired repeatedly, with in-situ optics inspection between shots, without any other action required until the size of any observed damage site has reached the point where action has to be taken to prevent that site from reaching an unmitigatable size. At that point, if the operating situation of the laser allows, a shadow blocker can be electronically placed (in the ILS) to protect the site location, as identified by the in-situ optics inspection system. The laser can then continue to be fired, with optics inspection between each high fluence shot. In the September 2012 configuration of NIF, added blockers affect all beamlines in a quad. Future configuration changes to the laser could allow a blocker to affect only one beamline at a time. In any case, when the number of shadow blockers begins to significantly reduce the energy that can be delivered by the laser, it becomes necessary for one or more of the optics in the quad of interest to be removed, sent to a mitigation facility for repair, and replaced by a near-perfect optic. If an optic has reached a damage state that cannot be mitigated at LLNL, it must be sent back to the vendor for refinishing, or discarded and replaced by a new optic.

Once recycling loop capabilities were in place at a minimal level, the loop could to used to support operation of the laser and allow its performance to be incrementally improved as the capabilities of the loop improved. This same characteristic that allows utilization of evolutionary improvements in capability can also provide flexibility for operations planning. A choice can be made between lowering operating cost and operating the laser at higher performance levels.

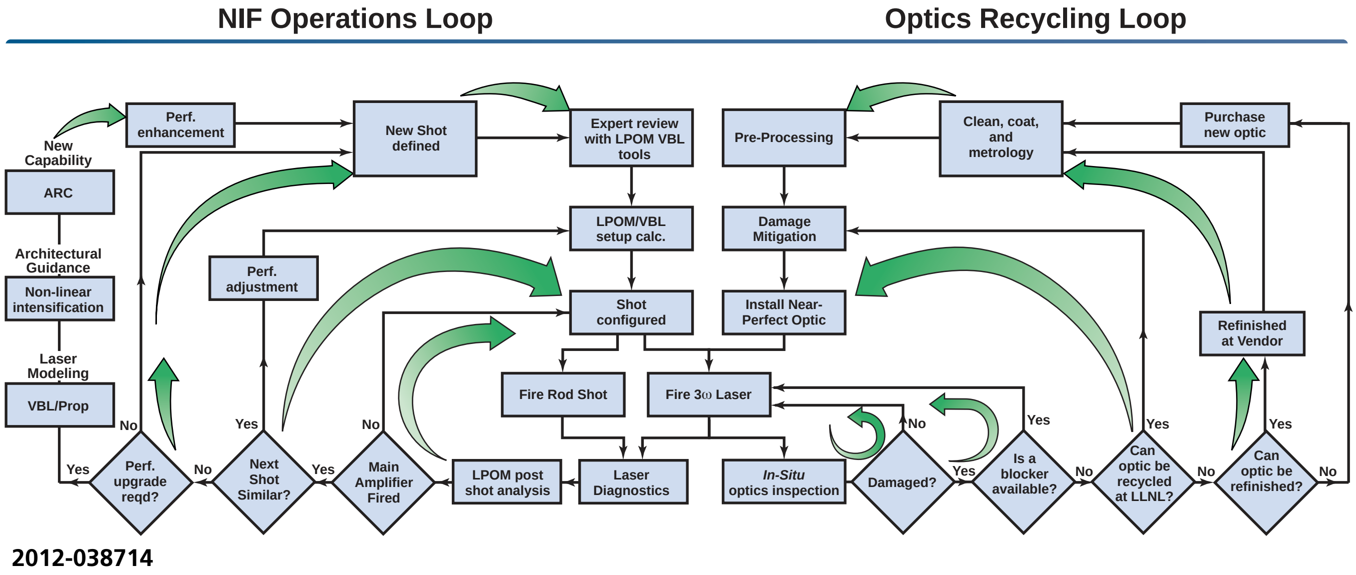


Figure 5-22: The operations loop works together with the optics recycling loop to ensure safe and cost-effective operations at NIF.

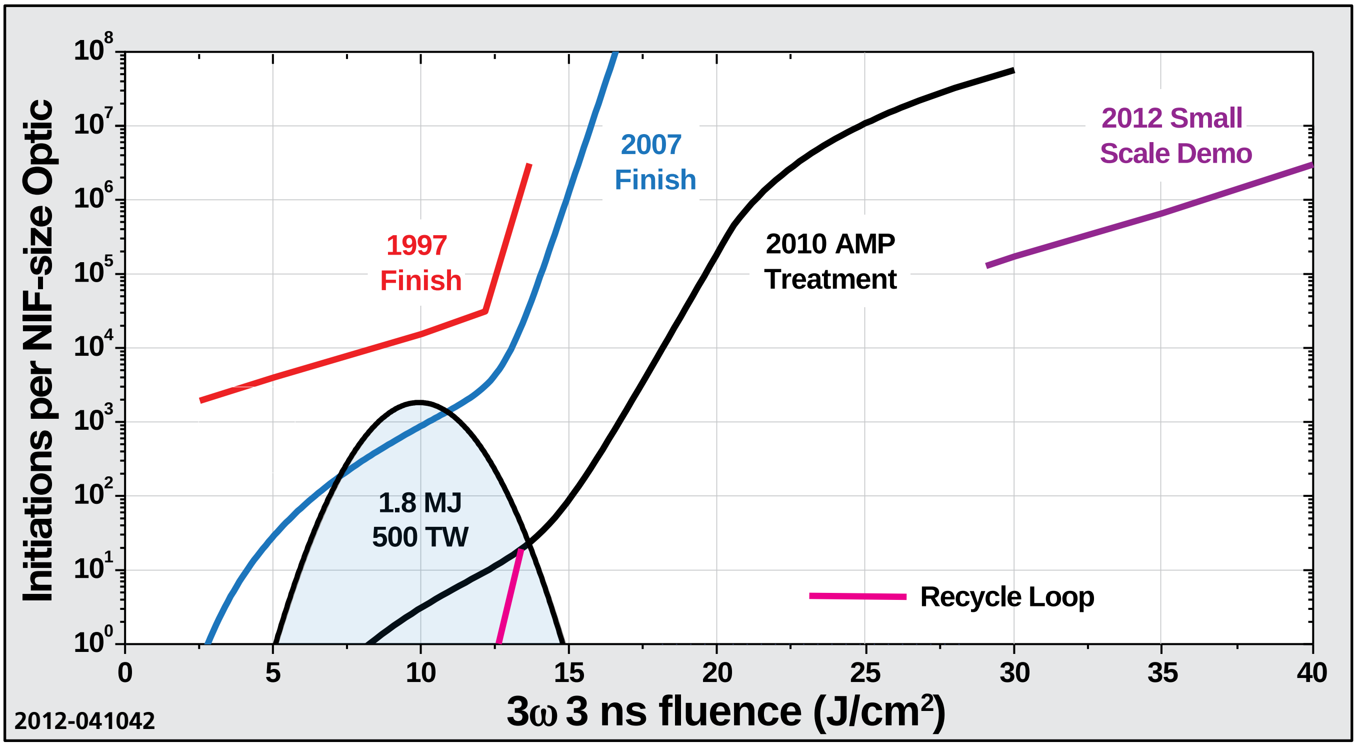


Figure 5-23: Improvements to damage resistance at 3ω for fused silica from 1997 to 2012 cover more than four orders of magnitude.

It may be helpful for the user to understand the time frames of the various internal loops within the recycling loop. The inner two loops, inspection and decisions regarding the placement of the electronic shadow blockers, take hours. The cycle time for the recycling loop is about 2 weeks. As of September 2012, recycle of fused silica optics (the WFLs and the grating debris shields [GDSs]) through the mitigation loop was being done at a rate of about 150 optics per month. There is a total of ~400 WFLs and the GDSs in NIF; thus, about a third of these optics are being sent through the mitigation loop each month. Some of the NIF fused silica optics have been through this mitigation recycling loop as many as 7 times. If an optic accumulates more damage than can be readily handled with blocking and mitigation, it is sent out for refinishing. Refinishing saves the cost of a new optic blank. About 15 optics/month are sent into this route. The cycle time for refinishing is about 6 months. Finally, completely new optics are purchased to replace those that cannot be refinished, at a rate of about 10 per month. The cycle time for receiving a new optic from a currently contracted vendor is about one year.

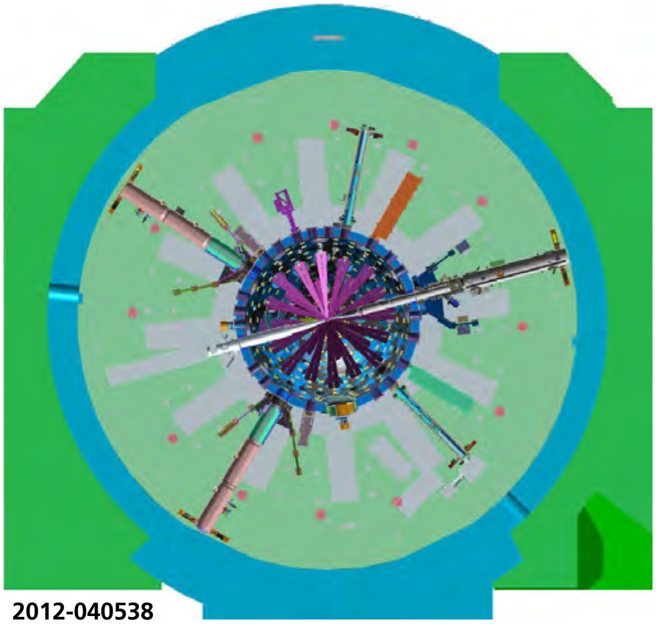
The 3ω optics recycling loop has been very effective in supporting NIF operations. In the late summer of 2012, the full NIF was operated at an average fluence of 10 J/cm^2 in the FOA, beyond its original goal of 8–9 J/cm^2. Improvements in the critical technologies needed for operating the loop, the surface finishing of fused silica optics, rapid and accurate in-situ optics inspection, the availability of electronic shadow blockers, and the ability to effectively mitigate growing sites has allowed NIF performance to steadily increase from about 300 kJ in July 2009 to almost 2 MJ in July 2012.

6. Target Area

A description of the target area is provided, with information on port allocation, target handling, and target and beam alignment capability.

6.1. Target Chamber Area

The NIF target chamber is located in a cylindrical section of the LTAB. The target area is approximately 100 feet in diameter and 100 feet high. There are 7 floor levels in the target area spanning –33’9” to +50’6” (relative to nominal ground level). Two views of the target area are shown in Figures 6-1 and 6-2.



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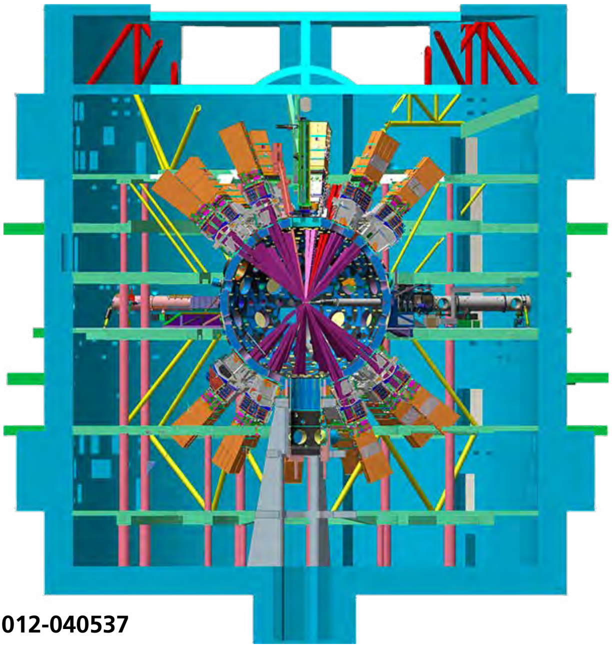

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Figure 6-1 (left): Top view of the target area at the waist level. Figure 6-2 (right): Elevation view of the target area.

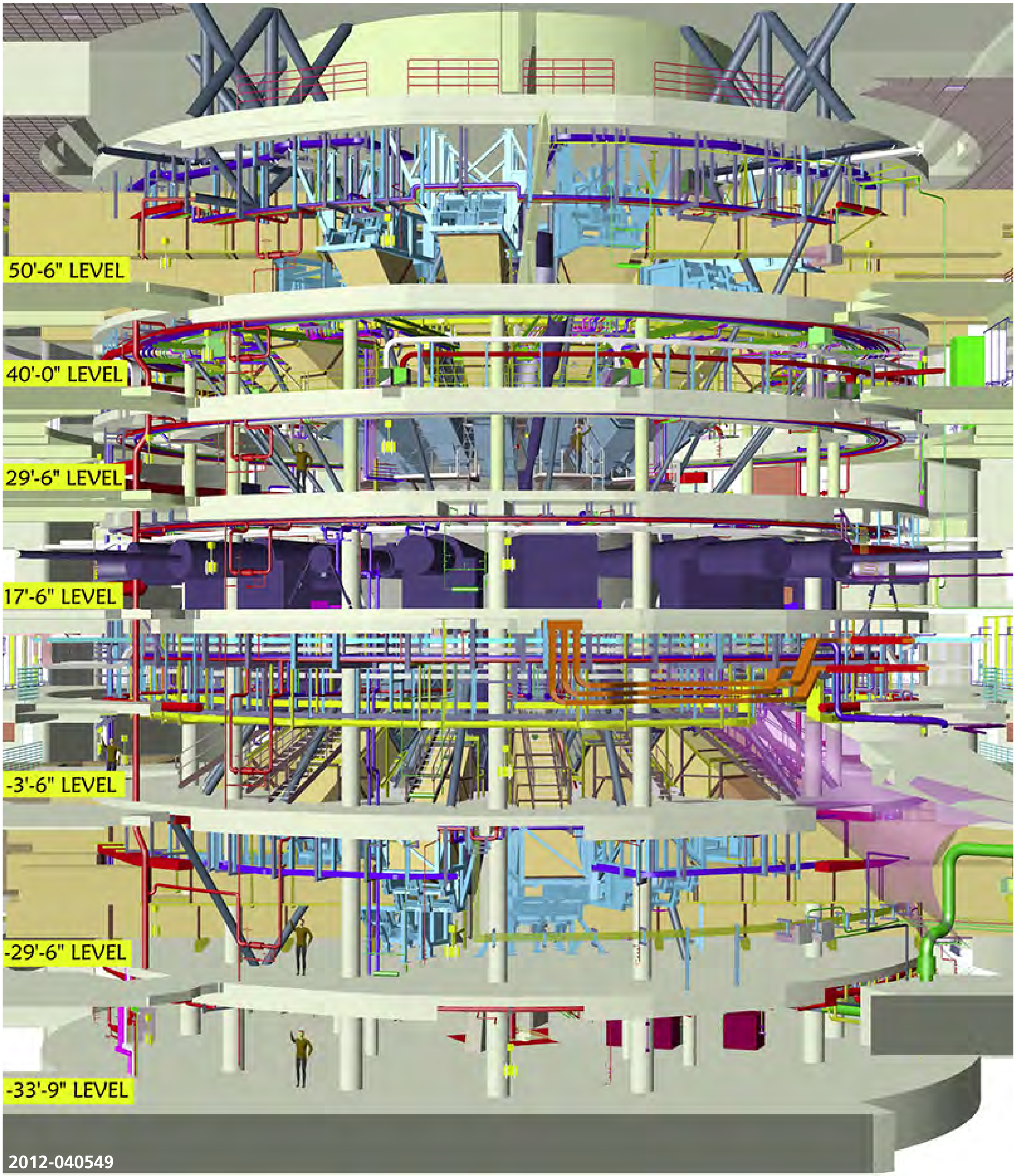

Figure 6-3: A more detailed cutaway view of NIF's target chamber levels.

6.2. Target Chamber Ports

The target chamber has an inner radius of 5 m. Beam and diagnostic ports cover the full surface. These are distributed for laser irradiation uniformity for both indirect- and direct-drive targets, and for convenient diagnostic access. The port locations are specified in spherical coordinates, Θ–Φ. The coordinates for the top of the chamber are 0-0. The elevation angle, Θ, increases to 180° at the bottom of the chamber. The azimuthal angle, Φ, goes from 0 to 360° counterclockwise around the chamber.

There are 72 ports designated as beam ports (see Figure 6-4). These are located on cones with angles 23.5°, 30°, 44.5°, 50°, and 72.5° from both the top and bottom poles of the target chamber. The 4 cones from 23.5° to 50° are for the indirect drive NIF beam configuration, and the ports at 72.5° from the poles will be used for a symmetric direct drive NIF configuration. A complete listing of the beam ports is provided in Table 6-1.

There are diagnostic ports from 18 cm to 53 cm in size distributed around the target chamber. These ports are shown on Figure 6-4. Most of these ports are located around the waist of the target chamber and between the upper and lower cones of beams. There are some ports between the different beam cones (37° from the poles) and at the top and near the bottom of the chamber. A listing of the diagnostic port locations is provided in Table 6-2.

There are also access ports, a large port for future experiments, and ports designated for the alignment systems, including the target positioner (TARPOS). These are described in Section 6.4.

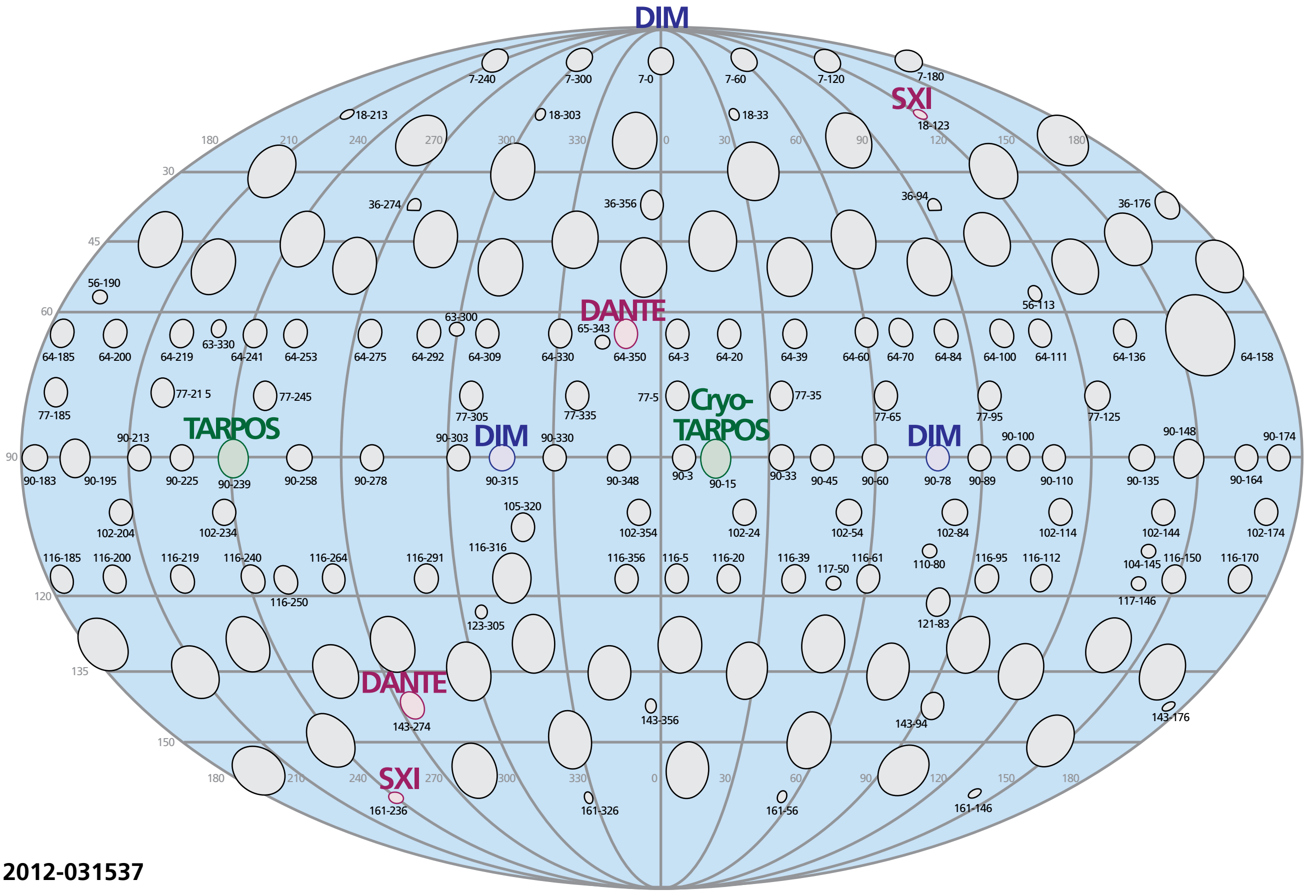

Figure 6-4: Projection of the target chamber with the ports marked.

Table 6-1. Beam ports on the NIF chamber.

NOTE: Ports that are marked as ID are for indirect-drive configuration only. The ports that are marked as DD are for direct-drive configuration only. The others are common for both configurations.

Port	Θ	Φ	**Port**	Θ	Φ	**Port**	Θ	Φ
1	23.5	78.75	25 (DD)	77.5	24.38	49 (ID)	130	5.62
2	23.5	168.75	26 (DD)	77.5	54.38	50 (ID)	130	50.62
3	23.5	258.75	27 (DD)	77.5	84.38	51 (ID)	130	95.62
4	23.5	348.75	28 (DD)	77.5	114.38	52 (ID)	130	140.33
5 (ID)	30.58	34.33	29 (DD)	77.5	144.38	53 (ID)	130	185.62
6 (ID)	30	123.75	30 (DD)	77.5	174.38	54 (ID)	130	230.62
7 (ID)	30.58	214.33	31 (DD)	77.5	204.38	55 (ID)	130	275.62
8 (ID)	30	303.75	32 (DD)	77.5	234.38	56 (ID)	130	320.33
9	44.5	16.29	33 (DD)	77.5	264.38	57	135.5	27.54
10	44.5	62.46	34 (DD)	77.5	294.38	58	135.5	73.71
11	44.5	106.29	35 (DD)	77.5	324.38	59	135.5	117.54
12	44.5	152.46	36 (DD)	77.5	354.38	60	135.5	163.71
13	44.5	196.29	37 (DD)	102.5	5.62	61	135.5	207.54
14	44.5	242.46	38 (DD)	102.5	35.62	62	135.5	253.71
15	44.5	286.29	39 (DD)	102.5	65.62	62	135.5	297.54
16	44.5	332.46	40 (DD)	102.5	95.62	64	135.5	343.71
17 (ID)	50	39.67	41 (DD)	102.5	125.62	65 (ID)	150	56.25
18 (ID)	50	84.38	42 (DD)	102.5	155.62	66 (ID)	149.42	145.67
19 (ID)	50	129.38	43 (DD)	102.5	185.62	67 (ID)	150	236.25
20 (ID)	50	174.38	44 (DD)	102.5	215.62	68 (ID)	149.42	325.67
21 (ID)	50	219.67	45 (DD)	102.5	245.62	69	156.5	11.25
22 (ID)	50	264.38	46 (DD)	102.5	275.62	70	156.5	101.25
23 (ID)	50	309.38	47 (DD)	102.5	305.62	71	156.5	191.25
24 (ID)	50	354.38	48 (DD)	102.5	335.62	72	156.5	281.25

Table 6-2. Diagnostic port sizes and locations.

NOTE: The space available behind any one diagnostic port depends on the individual port due to building and utility interferences.

Port	Θ	Φ	Size (mm)	Port	Θ	Φ	Size (mm)
P 0-0	0	0	533.4	P 90-110	90	110	533.4
P 7-0	7	0	482.6	P 90-123	90	123.75	533.4
P 7-60	7	60	482.6	P 90-135	90	135	533.4
P 7-120	7	120	482.6	P 90-164	90	164	533.4
P 7-180	7	180	482.6	P 90-174	90	174	533.4
P 7-240	7	240	482.6	P 90-183	90	183	533.4
P 7-300	7	300	482.6	P 90-213	90	213.75	533.4
P 18-33	18	33.75	254	P 90-225	90	225	533.4
P 18-123	18	123.75	254	P 90-258	90	258.75	533.4
P 18-213	18	213.75	254	P 90-303	90	303.75	533.4
P 18-303	18	303.75	254	P 90-315	90	315	533.4
P 36-94	36.75	94	254	P 90-348	90	348.75	533.4
P 36-176	36.75	176	533.4	P 102-24	102.5	24.38	482.6
P 36-274	36.75	274	254	P 102-54	102.5	54.38	482.6
P 36-356	36.75	356	533.4	P 102-84	102.5	84.38	482.6
P 56-113	56	113	254	P 102-114	102.5	114.38	482.6
P 56-190	56	190	254	P 102-144	102.5	144.38	482.6
P 63-70	63.2	70.5	533.4	P 102-174	102.5	174.38	482.6
P 63-230	63	230	177.8	P 102-204	102.5	204.38	482.6
P 63-300	63	300	177.8	P 102-234	102.5	234.38	482.6
P 64-5	64	5	533.4	P 102-354	102.5	354.38	482.6
P 64-20	64	20	533.4	P 105-320	105	320	533.4
P 64-39	64	39.38	533.4	P 110-80	110	80	254
P 64-60	64	60	533.4	P 110-145	110	145	254
P 64-84	64	84.38	533.4	P 116-5	116	5.62	533.4
P 64-100	64	100	533.4	P 116-20	116	20	533.4
P 64-111	64	111	533.4	P 116-39	116	39.38	533.4
P 64-136	64	136	533.4	P 116-61	116	61	533.4
P 64-185	64	185.62	533.4	P 116-95	116	95.62	533.4
P 64-200	64	200	533.4	P 116-112	116	112	533.4
P 64-219	64	219	533.4	P 116-129	116	129.38	533.4
P 64-241	64	241	533.4	P 116-150	116	150	533.4
P 64-253	64	253	533.4	P 116-170	116	170	533.4
P 64-275	64	275.62	533.4	P 116-185	116	185	533.4
P 64-292	64	292	533.4	P 116-200	116	200	533.4
P 64-309	64	309.38	533.4	P 116-219	116	219.38	533.4
P 64-330	64	330	533.4	P 116-240	116	240	533.4
P 64-350	64	350	533.4	P 116-264	116	264.38	533.4
P 65-343	65	343	254	P 116-291	116	291	533.4
P 77-5	77.5	5.62	482.6	P 116-316	116	316	950.8
P 77-35	77.5	35.62	482.6	P 116-335	116	335	533.4

Port	Θ	Φ	Size (mm)	Port	Θ	Φ	Size (mm)
P 77-65	77.5	65.62	482.6	P 116-350	116	350	533.4
P 77-95	77.5	95.62	482.6	P 117-50	117	50	177.8
P 77-125	77.5	125.62	482.6	P 117-140	117	140	177.8
P 77-185	77.5	185.62	482.6	P 116-250	116.8	250.5	533.4
P 77-215	77.5	215.62	482.6	P 121-83	120.5	83	533.4
P 77-245	77.5	245.62	482.6	P 123-305	123	305	254
P 77-305	77.5	305.62	482.6	P 143-94	143.25	94	533.4
P 77-335	77.5	335.62	482.6	P 143-176	143.25	176	254
P 90-3	90	3	533.4	P 143-274	143.25	274	533.4
P 90-33	90	33.75	533.4	P 143-356	143.25	356	254
P 90-45	90	45	533.4	P 161-56	161	56.25	254
P 90-78	90	78.75	533.4	P 161-146	161	146.25	254
P 90-89	90	89	533.4	P 161-236	161	236.25	254
P 90-100	90	100	533.4	P 161-326	161	326.25	254

6.3. Diagnostic Instrument Manipulator

A diagnostic instrument manipulator (DIM) is provided on several different port locations for inserting diagnostics to diagnose a target experiment on NIF. The DIM is a two-stage telescoping system that provides for positioning of the diagnostic package and enables exchange of manipulator diagnostics.

For more information on DIM and designing diagnostics for DIM, see Section 7.3.

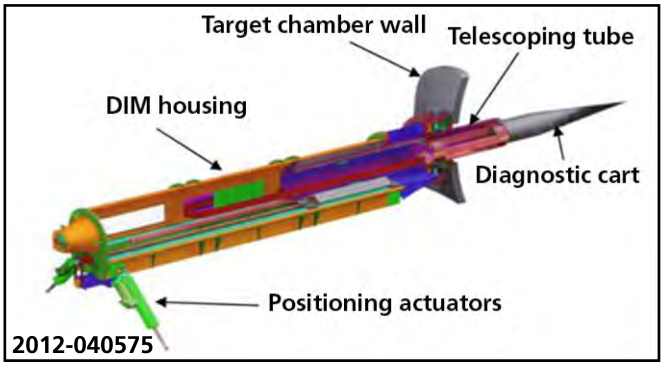

Figure 6-5: Diagnostic instrument manipulator showing the housing, extension tube, and diagnostic in an extended mode.

6.4. Target Handling Capabilities

NIF is equipped with two target positioners (TARPOS), located at 90-239 and 90-315, which are capable of holding cryogenic and non-cryogenic targets, including gas targets. The TARPOS at 90-315 is also designed to handle layered targets, including those containing tritium.

TARPOS provides for positioning a target within ±5 cm of target chamber center. Translation in the vertical direction by ±5 cm is achieved by a combination of rotation about the gimbal and an opposite bend approximately 2 m from chamber center (see Figure 6-6). These same motions allow up to 1° tilt of the target axis. Translation in the horizontal direction is achieved by a rotation about the gimbal. An offset of 5 cm results in a rotation of approximately 0.5° about the vertical. No correction is provided in this direction.

The TARPOS also provides ±14° rotation about the axis of the positioner itself; the limit is due to internal cabling.

The TARPOS is outfitted with a cable harness that includes wires for temperature control of a cryogenic target system, gas fill lines, fiber optics, and other power cables. This offers flexibility; if a user requires an additional degree of freedom, it may be built onto the target assembly as control cables are available. Additionally, the fiber optics may be used for fiber-optic light sources as diagnostic alignment aids at target chamber center.

For more information on the cryoTARPOS, see *Design of the NIF Cryogenic Target System.*[14]

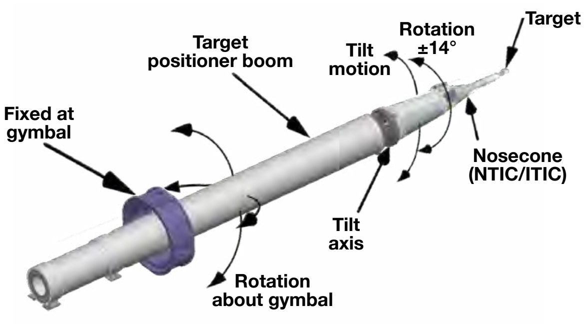

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Figure 6-6: Diagram of the target positioner showing the degrees of freedom for positioning a target.

6.5. Tritium Handling Capabilities

NIF is capable of shooting tritium-containing targets on the CryoTARPOS (90-015) and TARPOS (90-239) target positioners. Due to differences in hardware systems associated with each positioner, different limits on the packaging and quantity of tritium allowed apply to the two positioners.

TARPOS (90-239) can only accept targets containing integral tritium inventories, and a limited quantity of tritium (currently limited to <100 mCi per target).

CryoTARPOS (90-015) is set up to accommodate fuel (including various mixtures of tritium, deuterium, and hydrogen) in small pressure vessels known as reservoirs (Figure 6-7). These reservoirs may be configured to be mounted directly on the target positioner nose cone or outside the target positioner vessel in a specially designed glove box. Maximum tritium inventory is limited by various facility safety basis and environmental limits. Typical targets contain up to about 20 Ci of tritium; targets containing up to about 60 Ci of tritium currently may be accommodated for special applications. Reservoirs are filled at the LLNL tritium facility to fuel drawing specifications provided by experimenters. These mixes must meet both tritium facility and NIF limits and system capabilities.

For both positioners, the mix and pedigree of fusionable-gas fills (including tritium, deuterium and helium-3) are controlled along with the target design to manage the potential neutron yields that are possible for a given shot. These are used as an input to facility safety setup considerations.

Due to the presence of tritium (and potentially other radioisotopes), targets and equipment installed or connected to the target positioners are considered radiologically contaminated until proven otherwise. Note, it is sometimes not feasible to verify components are not contaminated.

Figure 6-7: Technician prepares a NIF reservoir.

6.6. Target and Beam Alignment

Target and beam alignment are done using the chamber center reference system (CCRS), the target alignment sensor (TAS), and the TARPOS, positioned around the target chamber as illustrated in Figure 6-8. Details on the individual components and procedures are available elsewhere, but a summary is provided here.

Target chamber center is defined by the intersection of two orthogonal optical axes, called the chamber center reference system. An optical telescope is situated to view anywhere within ±5 cm of target chamber center along these axes. These telescopes are used to position the target alignment sensor at any specific location near target chamber center to within about 10 µm.

The target alignment sensor consists of a frame with four optical views of target chamber center from the top, bottom, and two from the side. These views are 1:1 optical images onto charge-coupled devices (CCDs). One side view is fixed centered on the focal plane of the top view and one is centered on the focal plane of the bottom view. The bottom view may be translated up or down independently from the top view but is always colinear with the top view line of sight (Figure 6-9).

TAS also has two annular mirrors positioned to reflect the alignment beams directly onto the top or bottom CCD, which are located at the equivalent focal plane of the target views. As a result, a target can be positioned within the framework of the TAS and viewed with the three alignment views. At the same time, laser alignment beams reflected off the mirrors are detected on the same image. This allows for simultaneous alignment of the beams with respect to the view of the target.

Scientists should work with the alignment group to ensure that targets incorporate alignment features.

NIF target alignment is described further in *An overview of target and diagnostic alignment at the National Ignition Facility*[15] and *Beam and target alignment at the National Ignition Facility using the Target Alignment Sensor (TAS).*[16]

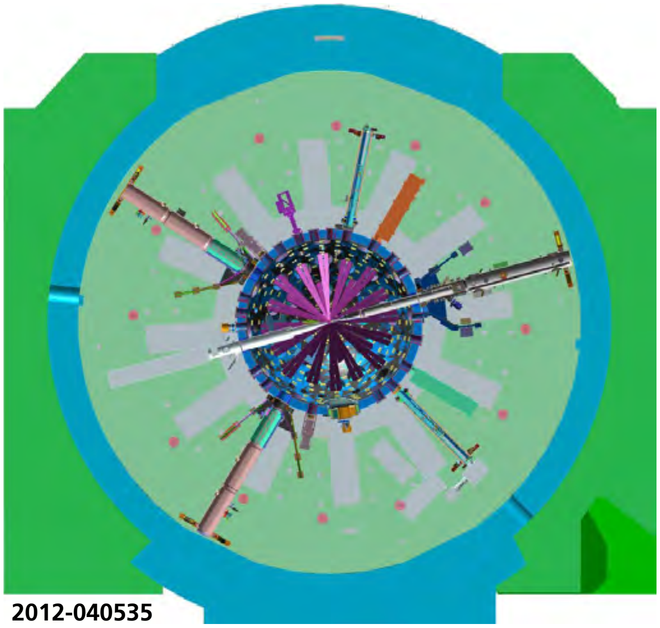

Figure 6-8: Top view of waist ports on the target chamber showing the TAS, CCRS, and TARPOS.

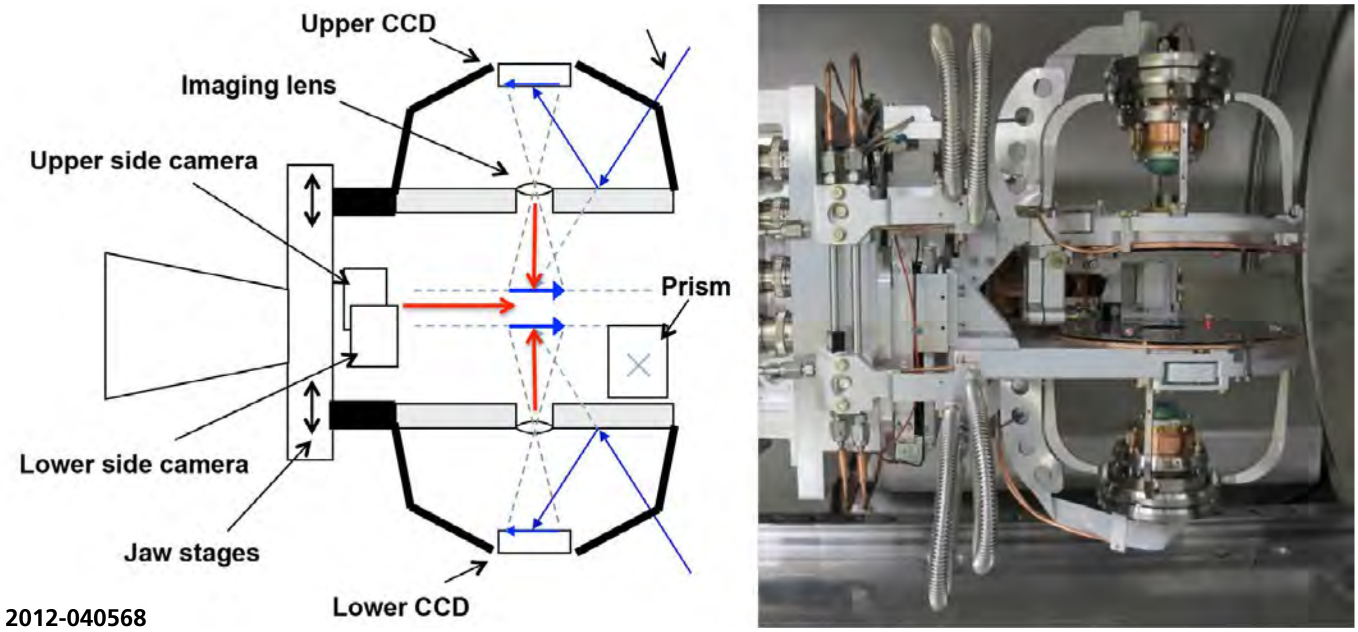

Figure 6-9: Diagram of the TAS showing the three directions for viewing the target (red arrows) and the mirrors for equivalent plane beam alignment.

6.7. Beams to Target

6.7.1. Unconverted Light

The NIF is a glass laser at 1.05 µm with frequency conversion crystals that frequency triple the light to 0.35 µm. There is residual 1.05 and 0.53 µm (1ω and 2ω) light that must be taken into account in experiment design.

The final focus lens is wedged with the dispersion direction in the horizontal (azimuthal) direction. As a result, the residual unconverted 1ω and 2ω light is offset from the position of 3ω best focus. The footprint of the unconverted light due to a single quad of four beamlines is shown in Figure 6-10. The 1ω footprint is approximately 22 mm square with a minimum 4.8 mm clearance from the 3ω focus. The 2ω footprint is approximately 12 mm square with a minimum 2.9 mm clearance.

The overlap of unconverted light from all beamlines has a clear region down the axis of the target chamber. An ignition-scale hohlraum fits nearly within this clear region. The envelope of unconverted light extends out to a radius of about 32 mm from target chamber center, potentially affecting target or backlighter structures or diagnostics.

The majority of this unconverted light propagates past the target and strikes the inner wall panels of the target chamber. The footprints of unconverted light at the opposite wall impose a limit on pointing for each beamline in order not to damage near-opposite FOAs by propagating high-intensity unconverted light into the FOA hardware or optics.

6.7.2. Counterpropogating Light

The NIF target chamber is set up to avoid direct propagation of the 1ω laser past target chamber center into opposed beamlines. In addition, the design incorporates a wedged final focus lens so that the unconverted 1ω and 2ω light is offset from the 3ω focus at the target plane. Some targets have extended components that fall within the envelope of the 1ω light. This puts the laser at risk, as scattered 1ω light may be imaged back up other beamlines and potentially reach and damage the front end.

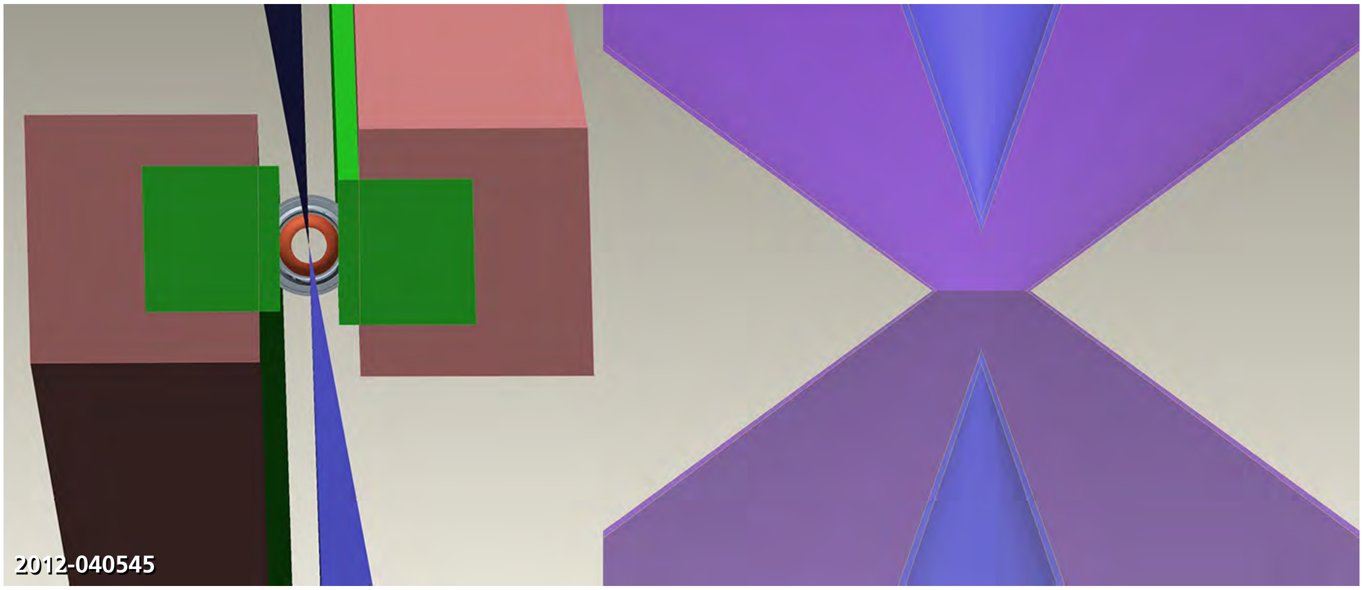

Figure 6-10 (left): Distribution of unconverted light relative to the point of best focus for the 3ω beam. Single beam view, viewing the hohlraum from above. Figure 6-11 (right): View of the overlap of all beams. Blue represents 3ω light, green 2ω light, and peach 1ω.

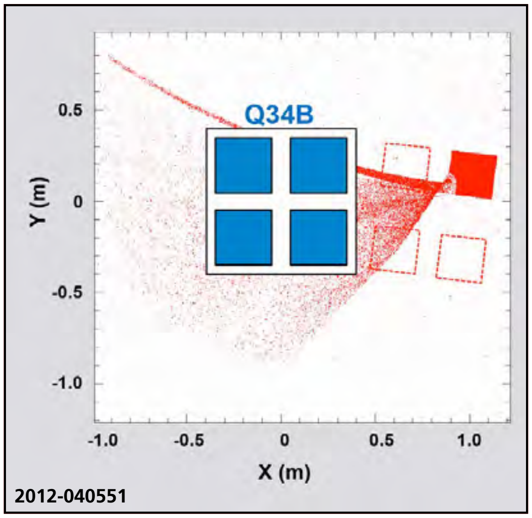

Figure 6-12. Refracted light can enter a far-wall port and counter-propagate back towards the laser. Simulations such is the one shown here indicate that a small amount of refracted light can enter a far-wall port.

There are several specific examples where image relay of the 1ω light is a concern. For planar targets located horizontally in the chamber, there are conjugate beams on the same hemisphere. For planar targets located vertically in the chamber, there may be conjugate beams on the opposite hemisphere. Separately, the generation of large-scale plasmas from extended target components may result in the refraction of the 1ω light that propagates through these plasmas, steering the light into nearly-opposed beamlines.

In order to mitigate 1ω scattered light reflecting off target structures and being imaged up the laser, target components that fall within the footprint of the unconverted 1ω light must meet the following surface shape requirements:

- Surfaces must be curved to disperse the 1ω reflected light. This can be a 1-dimensional curvature (cylindrical) with a radius not larger than 2 mm, or a 2-dimensional curvature (spherical) with a radius not larger than 5 mm.
- Larger extended surfaces may be created by dimpling flat surfaces with a curvature that meets these specifications, but with a periodicity that is not too short. For the 2-dimensional dimpled surfaces, a ratio of the half-side of the dimple to the radius cannot be smaller than 0.25.

In order to field a target that has large flat surfaces, such as an ignition target with flat silicon cooling arms, unconverted light management is required. The flat cooling arms are covered with thin dimpled aluminum sheets that are patterned with a spherical dimple pattern. These dimpled sheets are attached both on the inner and outer surfaces of both cooling arms. There are additional beehive shaped shields added over the wire connections between the cooling arms at the thermal mechanical package. For a VISAR target, the cone shield that protects the VISAR line of sight to the physics package from closing due to plasma blowoff from unconverted light has a surface shape that a beehive with a small radius of curvature in one dimension, and larger conical shape in the other.

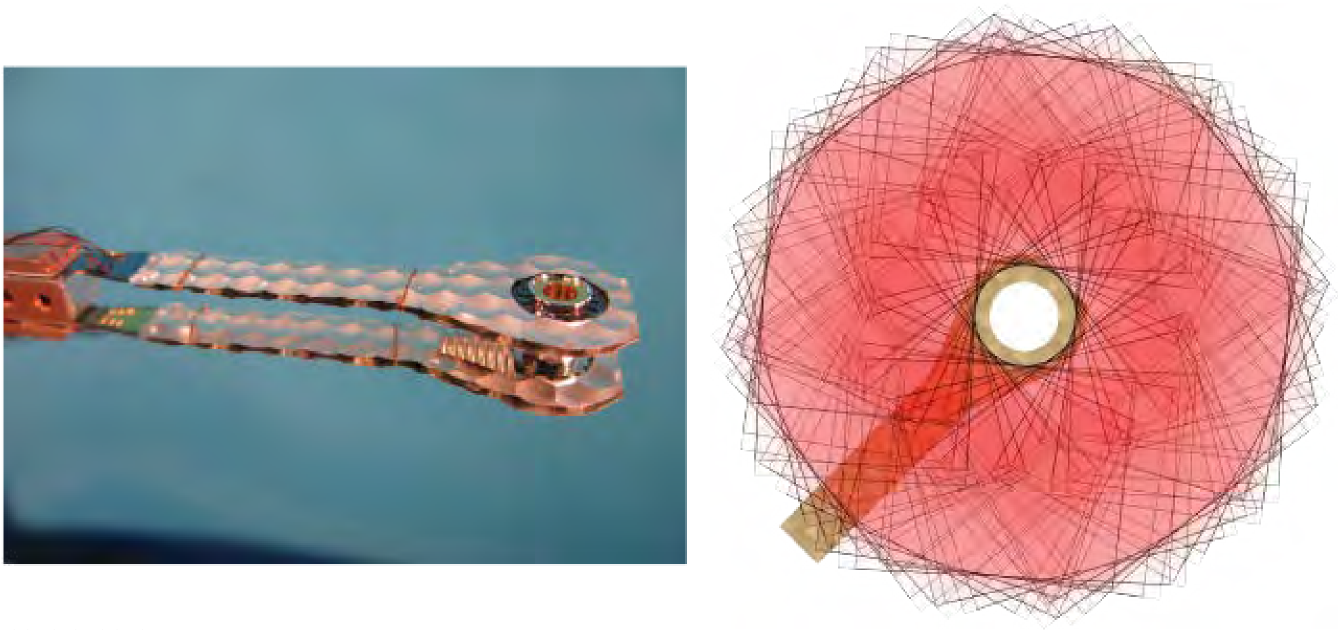

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Figure 6-13. (left) Cryogenic target with dimpled 1ω light shield. (right) Residual 1ω light footprints at the plane of the shield.

6.7.3. Timing and Fiducial Capability

The NIF integrated timing system is a distributed system consisting of a master clock with a number of slave clocks located in different areas of the facility. It is based on a standard communications frequency of 155.52 MHz.

This system provides precision electrical triggers with <20 ps rms stability and <100 ps overall drift due to environmental conditions. Precision triggers are available for all diagnostics with independent delay control via computer control.

The fiducial system provides critical timing reference markers in the form of optical pulses throughout the NIF facility. The optical fiducial pulses are generated within the MOR and are distributed via fiber optic to the various areas of the facility. Optical fiducial pulses will be provided via fiber optic at 1.05 µm and 0.53 µm wavelengths (1ω and 2ω). In addition, electrical fiducial pulses derived from the optical fiducial pulse will be provided.

Details on the fiducial system may be obtained from *Component Specifications for Fiducial Generation and Distribution Subsystem*[17] or *NIF Fiducial System Architecture*.[18]

7. Diagnostics

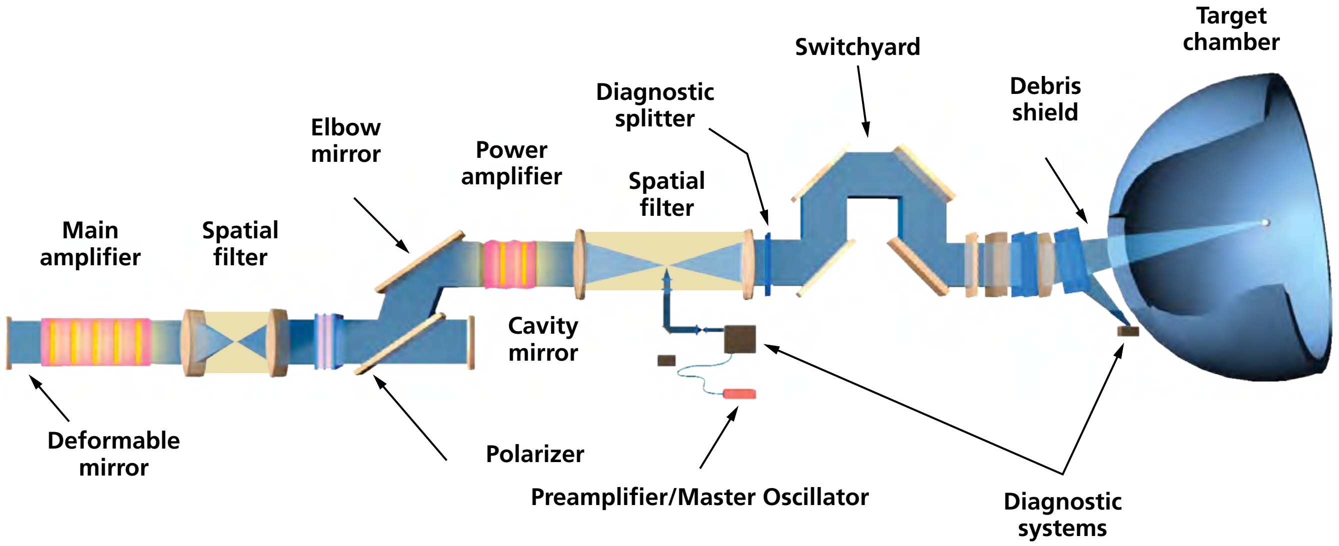
7.1. Laser Diagnostics

A suite of laser diagnostics is in place to provide data on the performance (i.e., power, energy, etc.) of NIF on each shot. The data from individual beams are used to determine the total power and energy and the power and energy balance on any given shot. The diagnostics have been designed to be consistent with the requirement that the rms power imbalance be 8% or less for a 1.8 MJ Haan ignition pulse. The rms energy balance for that pulse is on the order of 5%. The power and energy balance for different pulse shapes and energies will vary slightly. To accurately measure power and energy balance, the 3ω power is measured to within 4% and the 3ω energy to within 3%.

The specific measurements that are made on each shot are listed in Table 7-1. The locations for these measurements are shown in Figure 7-1. Note that the 3ω and 1ω power are measured on only half of the beams (two per quad) on any given shot. There is a switch that selects one of the two beams in the top half of the quad to have its 3ω power recorded and a similar switch for selecting one of the two bottom beams. The 1ω power measurements are selected in the same way (but independently of the 3ω selection). Typically, half of the beams will have the 1ω power recorded, while the other half will have the 3ω power recorded.

Table 7-1. Laser diagnostics measurements made on each NIF shot.

Measured Quantity	Instrument	Location	No. of Measurements
3ω energy	Calorimeter	FOA	192
3ω power	Diode array	FOA	48
3ω nearfield	Camera	FOA	8
1ω energy	Calorimeter	Output sensor	192
1ω power	Diode array	Output sensor	96
1ω nearfield	Camera	Output sensor	192



2012-040670

Figure 7-1: Schematic of a NIF beamline showing the locations for laser diagnostics.

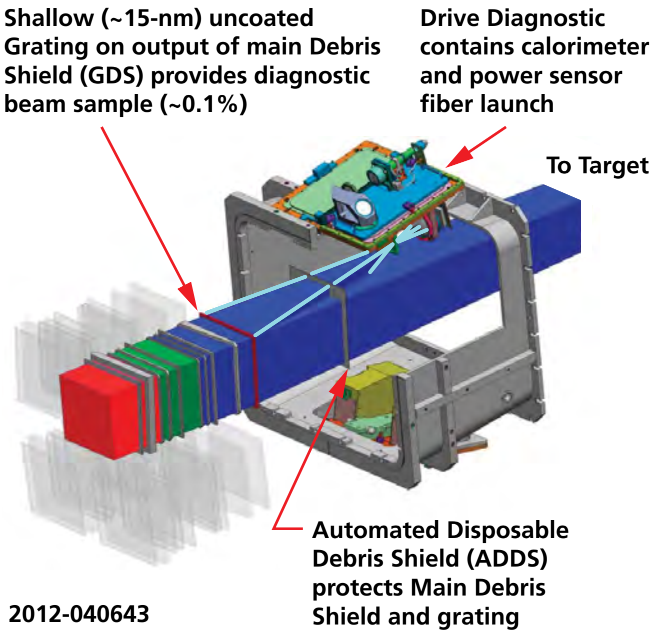


Figure 7-2: Each of the 192 beamlines is equipped with a drive diagnostic that measures the 3ω pulse exiting the NIF final optics upstream of the target.

7.2. Target Diagnostics

Plans for NIF diagnostics began with the Nova Technical Contract in the mid-1990s. At that time, the Joint Central Diagnostic Team was formed to coordinate efforts, working with their home laboratories, to develop NIF diagnostics funded through ICF program funds at the various NNSA laboratories. The resulting strategy called for a national effort to develop and implement a comprehensive suite of diagnostics on NIF. Further, these diagnostics would be implemented in a phased manner and, when possible, multiple diagnostics would be available to meausure key ovservables. The need for multiple complementary and redundant diagnostics was recognized as an essential requirement since no single diagnostic makes a perfect measuremet. For example, thermonuclear yield is measured by three absolute and independent diagnostics.

NIF is now equipped with close to 60 nuclear, optical, and x-ray diagnostics that together provide 300 channels for experimental data. Optical diagnostics measure the light's power, spectrum, and angular distribution of visible light to determine the energy balance of an experiment as well as the implosion velocity of the fuel capsule, laser–plasma interactions, and instabilities that affect the target performance. Hard and soft x-ray emission detectors with micron-scale and picosecond-scale resolution characterize laser and target performance by measuring target self-emission or by using the x-rays to probe or radiograph dense matter. Nuclear diagnostics signal the presence of high-energy neutrons and measure physical properties such as neutron yield, ion temperature, bang time, core temperature, and reaction history.

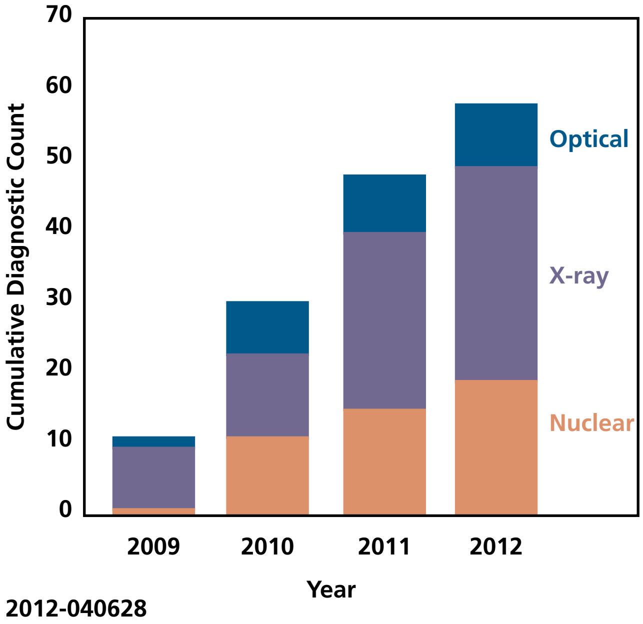


Figure 7-3: The number of target diagnostics available at NIF has increased sixfold over NIF's four years of operation.

NIF diagnostics are either constructed and deployed to a fixed location in the target chamber/bay or are fielded on a DIM. DIMs are two-stage telescoping devices capable of inserting, retracting, positioning, and aligning a diagnostic instrument in the target chamber, from the interior wall to target chamber center. DIMs can fit in a number of designated target chamber ports, but are currently mounted in three locations: one in the target chamber pole and two on its equatorial plane. The DIMs also provide a standard set of utilities and cables to support operation of all DIM-based diagnostic instruments. The baseline diagnostic locations are listed in Table 7-2.

Table 7-2. Baseline diagnostic placement for NIF.

NIF Port	Diagnostic	Comments
0-0	**DIM**	**Top view, face-on for vertical halfraum, axial for hohlraum**
90-78	DIM	Waist view, side-on
90-315	DIM	Waist view
18-123	**SXI**	**Within 20° of vertical axis, near top**
161-236	**SXI**	**Within 20° of vertical axis, near bottom**
64-350	**DANTE2**	**LEH view for horizontal halfraum, waist view for hohlraum**
143-274	**DANTE1**	**View in LEH for vertical hohlraums**

Table 7-3 identifies the NIF diagnostics and detectors currently available. The diagnostic location is given in terms of chamber coordinates. Diagnostics labeled "DIM" may be placed in the DIMs located at ports 90-78, 90-315, and 0-0. If an instrument is fixed but requires a pinhole or filter on a DIM, this is noted. Table 7-4 lists key DIM snouts and appendages that can be used in conjunction with a DIM-based detector.

Figures 7-4 and 7-5 show the location of the DIMs, target positioners, and NIF's major fixed diagnostics.

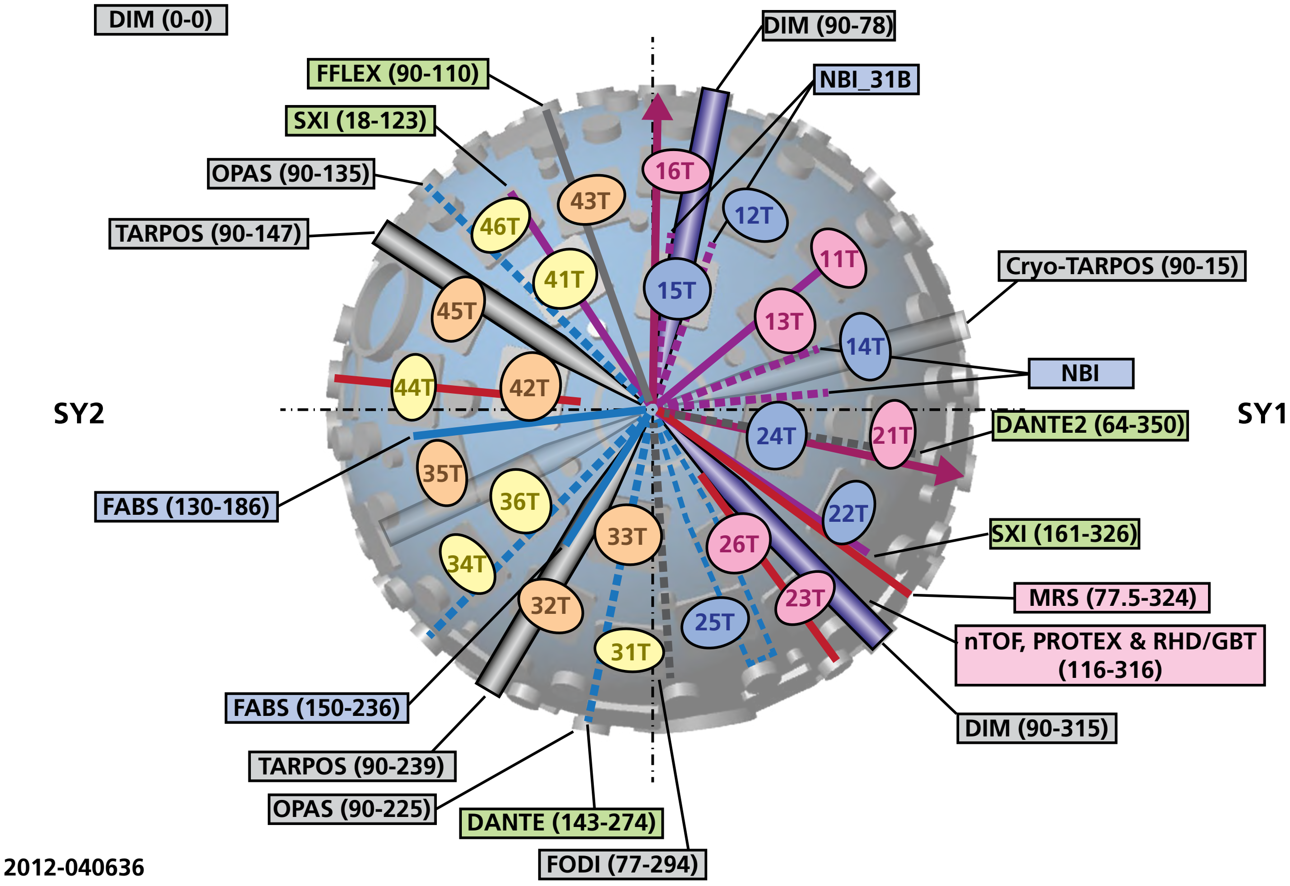


Figure 7-4: Top view of the NIF target chamber showing the location of the "top" quads and major diagnostics. Diagnostic placement may vary depending on the experimental campaign.

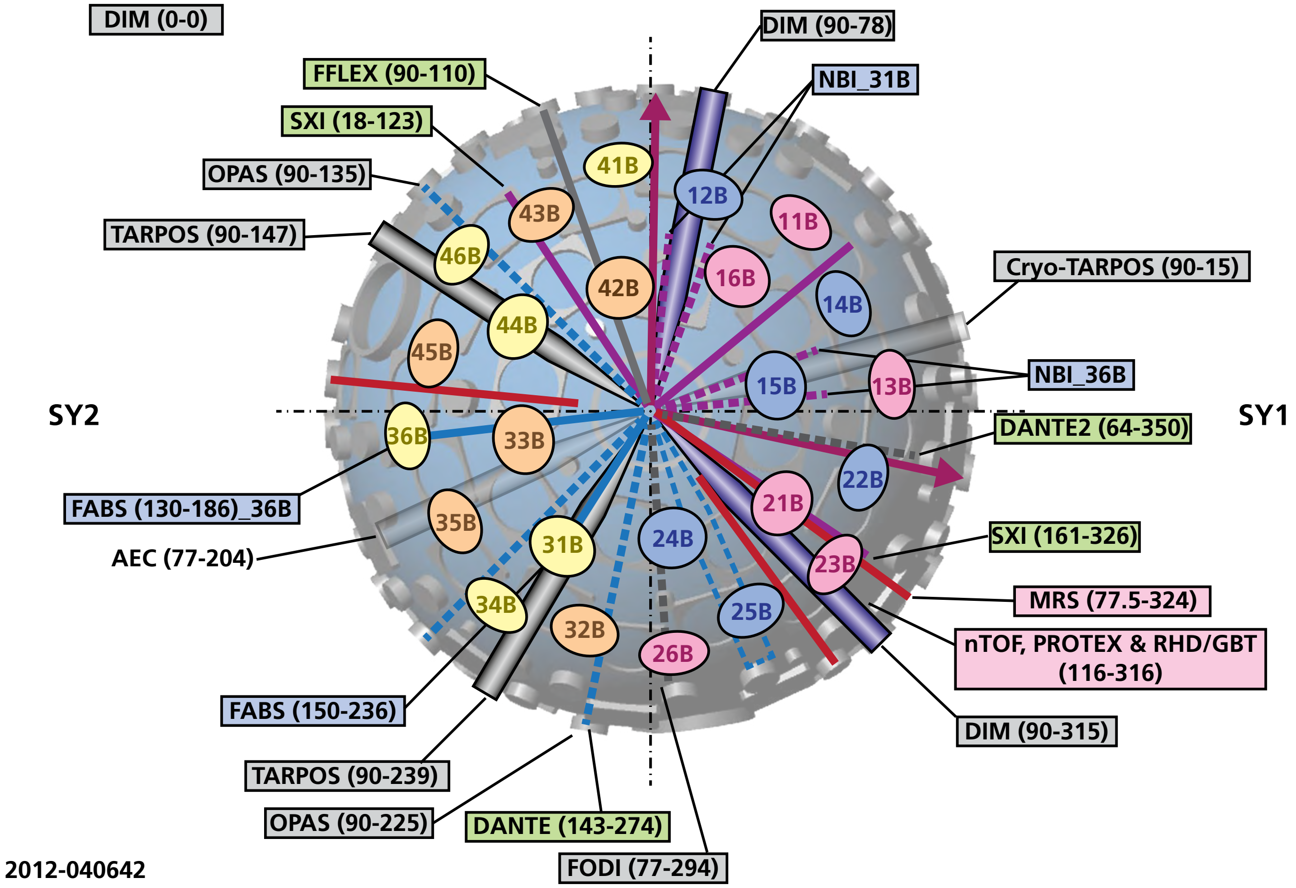


Figure 7-5: Bottom view of the NIF target chamber showing the location of the "bottom" quads and major diagnostics. Diagnostic placement may vary depending on the experimental campaign.

Table 7-3. Diagnostics Implemented on NIF.

Acronym	Diagnostic	Location	Purpose and Function	Reference
Nuclear Diagnostics				
EMP	Electromagnetic Power	102-84	EMP measures the electromagnetic frequency spectrum in the target chamber.	
GRH	Time and spectrally-resolved Gamma Reaction History	Fixed	GRH measures the spectrum and time history of the emission of target-produced gamma rays using four spectral channels (typically 2.9, 5, 8, and 10 MeV). In each GRH channel, gammas interact with a foil to produce Compton electrons, which recoil into a gas-filled cell generating broadband Cerenkov light (from 250 to 700 nm) if their velocity exceeds the local speed of light as determined by the type and pressure of the gas in the cell. For each channel, Cerenkov light is relayed to a high-speed detector using an off-axis parabolic mirror. In ignition-related experiments using DT gas, GRH is used to measure the absolute level of DT gamma-ray emission and to determine the amount of ablator remaining in the compressed capsule through observation of gamma rays from the interaction of the fusion neutrons with the carbon shell.	19–23
MRS	Magnetic Recoil Spectrometer	Fixed (but uses DIM)	MRS is a neutron spectrometer typically used in yield experiments to infer the neutron energy spectra. Neutrons interact with a plastic foil held 30 cm from the target, producing knock-on protons or deuterons. These charged particles are then energy dispersed by their momentum in a magnetic field and focused on an array of solid plastic film track detectors (CR-39) located at the focal point of the spectrometer. After a shot, the film is removed and etched and the neutron spectrum (neutrons as a function of their energy) and yield (total number of neutrons) are determined by the location and number of tracks on the detectors. Ion temperature is also recorded with lower resolution than the NTOF, dependent on the thickness of the plastic foil.	24–27
NAD—Cu	Neutron Activation Detector	Fixed	NADs are used to measure neutron yield via activation of various materials. One NAD measures the neutron yield from a DT-filled capsule by activating a copper foil in a neutron line-of-sight in the neutron alcove. After the shot, the foil is removed and the activation level is determined using standard nuclear coincidence counting techniques. Because the decay rate of the activated Cu is short (9.7 m), the foil must be removed rapidly and counted in a nearby detector system.	28, 29

Acronym	Diagnostic	Location	Purpose and Function	Reference
NAD—Flange	Neutron Activation Detector	Fixed	The flange NAD uses a set of up to 16 Zr activation samples strategically mounted on the flanges of the target chamber. The three-day half-life of the Zr activation product allows the samples to be counted in B151. The suite of Zr NADs measures the anisotropy (lack of uniformity in all directions) of neutron yield from the target. If the angular distribution is not isotropic, a variation in yield as a function of direction indicates a variation or asymmetry in the fuel areal density. To look for anisotropy in the neutron yield from an implosion requires an accurate cross-calibration because the compressed fuel areal density only downscatters about 20% of the 14 MeV neutrons.	29, 30
NAD—Flange better isotropy	Neutron Activation Detector	Fixed	NAD measures the integrated neutron yield from a DD or DT-filled capsule by activating an In, Zr, or Cu foil, removing it from the chamber, and determining the activation level using nuclear counting techniques.	29, 30
NAD—Zr in well	Well-mounted Neutron Activation Detector	Fixed	NAD uses activation of a single Zr sample inserted into a well on the NIF target chamber. Since the half-life of the zirconium activation product is three days, the comprehensive LLNL radiochemistry counting facilities in the basement B151 are used.	29, 30
NIS	Neutron Imager System	93-15 (but uses DIM)	NIS measures static neutron images of the primary (14 MeV) and the downscattered (6–12 MeV) neutrons from a burning DT capsule. The hot spot size and fuel asymmetry are determined from the image of the primary neutrons, and the cold fuel areal density is inferred from the downscattered ratio.	31
NITOF	Neutron Imager Time-of-Flight	93-15 (but uses DIM)	NITOF measures neutron yield, ion temperature, and areal density along the NIS line of sight.	
NTOF20 IgHi	Neutron Time-of-Flight	Fixed	NTOF detectors measure the time-of-flight of neutrons emitted from the target. The arrival time at the detector provides the neutron energy, and the spread of arrival times is related to the ion temperature. The NTOF20IgHi is a CVD-based synthetic diamond detector located in the neutron alcove about 20 meters from TCC. Its main function is to measure ion temperature of the hot spot in an ignition target.	33, 34
NTOF 3.9 DS NTOF 4.5 BT NTOF DTHi NTOF DTLo	Neutron Time-of-Flight	64-253 64-275 64-309 64-330	NTOF detectors measure the time-of-flight of neutrons emitted from the target. There are 4 NTOFs located at a distance of 4.5 m from TCC used to measure neutron yield, ion temperature, and neutron bang time for experiments with yields of 10^{10}–10^{13} neutrons.	33, 34

Acronym	Diagnostic	Location	Purpose and Function	Reference
NTOF20 SPEC-A NTOF20 SPEC-E	Neutron Time-of-Flight	90-174 116-316	NTOF detectors measure the time-of-flight of neutrons emitted from the target. Two NTOFs located at a distance of 20 m (alcove/equatorial) from TCC are used to measure neutron yield, ion temperature, and areal density. These are CVD-based synthetic diamond detectors.	33, 34
RAGS	Radiochemistry Analysis of Gaseous Samples	Fixed	RAGS is used to collect and measure neutron activation products that are gaseous at room temperature. For example, noble gases such as Kr and Xe can be used as activation detectors by pre-loading low-levels into the ablator. The resulting Kr and/or Xe isotopes produced can be collected and chemically fractionated very efficiently by cryogenic trapping. Isotopic analysis of the collected samples, when corrected for contributions from air, can be used to obtain quantitative data on multiple capsule performance parameters such as mix of the shell material into the fuel, asymmetry of implosion, shell and fuel areal density at peak emission, and neutron yield.	35–37
SRC	Solid Radiochemical Collection Diagnostic	DIM	Bulk target materials as well as trace elements in the targets can be activated by neutrons or possibly even charged particles to produced radioactive species. SRC units placed about 50 centimeters from TCC are used to collect the solid debris coming from the target, which may contain some of these radioactive species. The SRC units are removed post-shot, and the presence of radioactive isotopes is determined by nuclear counting techniques in B151. Using this technique, radioactive gold isotopes resulting from activation of the target hohlraums have been detected.	35, 36
SPBT Neutron Channel	South Pole Bang Time Neutron Channel	Fixed	The SPBT Neutron Channel measures through the lower LEH the time of peak x-ray emission (peak compression) relative to the laser pulse.	
Optical Diagnostics				
FABS31 FABS36	Full Aperture Backscatter Station	150-236 130-185	For coherent light sources, most of the light leaving the target is back- or forward-scattered by stimulated Brillouin or Raman scattering. Particularly for hohlraum targets, the laser energy that is not absorbed comes back into the wedge focus lenses (WFLs) and is measured by FABS on two representative quads of the inner and outer beams (at 30 degrees and 50 degrees).	38
NBI31 NBI36 NBI33	Near Backscatter Imager	150-236 130-185 Fixed for NBI33	Light is scattered in the area around the WFLs is measured by the three NBI diagnostics on representative quads: an outer cone of beams at 50 degrees and two inner cones of beams at 30 and 23.5 degrees.	38

Acronym	Diagnostic	Location	Purpose and Function	Reference
SOP	VISAR in combination with a Streaked Optical Pyrometer	90-78	SOP measures the break-out time of an optically-emitting shock.	
VISAR	Velocity Interferometer System for Any Reflector	90-78	The progress of shocks through an optically transparent material is measured by VISAR.VISAR is typically used in materials properties experiments to measure shock progress through a planar target. In ignition experiments, VISAR has been successfully used for shock timing up to the beginning of the fourth shock. A variant of VISAR technique used in the ignition program employs a tiny mirror that allows simultaneous viewing of shock progress in two orthogonal directions. This is referred to as the dual-axis VISAR technique.	39
X-Ray Diagnostics				
ARIANE	Active Readout in a Neutron Environment (gated x-ray imager)	90-89 (but uses DIM)	ARIANE is a gated x-ray detector measuring x-ray output at yields up to ~10^{16} neutrons. ARIANE uses gated MCP technology adapted to operate in this neutron regime by moving the detector to a position just outside of the target chamber. ARIANE is typically used in the ignition program to measure the time dependent symmetry of the hot central fuel region, similar to GXD and hGXI at lower neutron yields. A plan is in place to use a mirrored version of ARIANE for experiments with yields in excess of 10^{16} neutrons.	40
CR	Compton Radiography	DIM	The Advanced Radiographic Capability (ARC) on NIF will be used for time-resolved radiographic imaging of the dense cold fuel surrounding the hot spot by CR. CR is a measurement technique based on point-projection radiography at photon energies from 60 to 200 keV, where the Compton effect is the dominant contributor to the x-ray opacity of the fuel. Until ARC is available, CR with reduced resolution is being performed using time a hardened, gated x-ray detector with a broadband backlighter with energies up to about 100 KeV, produced by two focused 3ωquads of NIF.	

Acronym	Diagnostic	Location	Purpose and Function	Reference
Dante1 Dante2	Broad-band, time-resolved x-ray spectrometer	143-274 64-350	Dante1 and 2 are fixed soft x-ray power diagnostics for the upper and lower hemispheres. Each Dante has 18 different time-resolved channels; spectral ranges are controlled by the filter packs, filters, and metallic mirrors. Dante1 has five channels with mirrors, and Dante2 has eight mirrored channels. With knowledge of the size of the LEH, Dante determines the time-dependent radiation temperature in the hohlraum.	41
DISC1 DISC2 DISC3	DIM Insertable Streak Camera	DIM	DISC is used to measure time-dependent x-ray emission from a variety of targets. To monitor the fidelity of the streak rate and the timing, an ultraviolet 4ω fiducial (ultraviolet light) is displayed on the edge of the streak record. DISC is commonly employed in experiments involving x-ray backlighting. As an example, for ignition implosion experiments, DISC is used to measure the trajectory (radius versus time) and width of the imploding shell.	42–44
DIXI	Dilation Imager for X-rays at Ignition	90-89 (but uses DIM)	Core DIM-based diagnostic DIXI drifts and time dilates a photo-electron image of an implosion. The time dilation allows time resolution to better than 10 ps. This kind of time resolution is necessary because as the yield increases, the duration of x-ray emission extends well over 100 ps.	45, 46
EHXI	Equatorial Hard X-ray Imager	90-110	EHXI is a static array of pinholes that form many low-resolution hard (>40 keV) x-ray images, typically used with hohlraum targets. When used in hohlraum experiments, the EHXI provides positions of the beams in the hohlraum from the x-rays transmitted through the hohlraum walls and TMP. The low energy cut-off is typically set by the x-ray absorption in the hohlraum wall, TMP, and a thinned-out target chamber flange.	
FFLEX FFLEX TR	Filter Fluorescer Diagnostic	90-110	FFLEX measures the absolute hard x-rays energy in eight spectral bands (10 keV to 400 keV) with time resolution on some channels. The hard x-ray spectrum is typically used to determine the “temperature” and energy of hot electrons.	47

Acronym	Diagnostic	Location	Purpose and Function	Reference
GXD1 GXD2 GXD3	Time-Gated X-ray Detector	DIM	Core DIM-based diagnostic GXD records time-resolved images of the target in the x-ray spectral region. GXD uses an array of pinholes to project a series of images in time onto a detector. Typically, these detectors are located about 1 m from TCC. An electrically gated microchannel plate (MCP) coated with a microstrip, in conjunction with a CCD detector and phosphor, is used as the detector. The use of this GXD is limited to yields up to approximately 10^{13} neutrons. For experimental campaigns involving capsule implosions, such as the ignition program, GXD is typically used study to study time-dependent symmetry of the hot central emission region of a compressed ICF target.	48
hGXD1 hGXD2 hGXD3 hGXD4	Hardened Gated X-ray Diagnostic	DIM	hGXD measures spatially and temporally resolved x-ray emission from a imploding core containing DT/THD fuel to determine core temperature and shape using an active readout detector for data recording.	49
hGXI1 hGXI2	Hardened X-ray Imager	DIM	hGXI records time-resolved images of the target in the x-ray spectral region using an array of pinholes to project a series of images in time onto a detector. Typically, these detectors are located about 1 m from TCC. An electrically gated MCP coated with a microstrip, in conjunction with optical film and phosphor, is used as the detector. HGXIs can operate at yields up to about 10^{15} neutrons. For experimental campaigns involving capsule implosions, such as the ignition program, hGXI is typically used study to study time-dependent symmetry of the hot central emission region of a compressed ICF target.	28, 50, 51
ROD-BT	RadOptic Diagnostic Bang Time		ROD-BT measures x-ray bang-time and fusion reaction history at picosecond resolution.	52
SPBT	South Pole Bang Time	0-180	SPBT has a fixed x-ray detector measuring the x-rays diffracted off an x-ray crystal spectrometer at a distance of about 2 meters from target chamber center. This instrument is typically used in ignition-related experiments to measure the time of peak x-ray emission relative to the laser pulse, as seen through the lower LEH. This interval, which is on the order of 20 nanoseconds from the start of the laser pulse for ignition implosions, is referred to as the “bang time.” Because the signal is relayed through several tens of meters of cable to an electrical recorder, the SPBT can measure the bang time to an accuracy of only about 50 ps. Therefore, the SPBT cannot accurately measure the x-ray emission history of an implosion, the duration of which is on the order of 150 picoseconds.	53

Acronym	Diagnostic	Location	Purpose and Function	Reference
SPIDER	Streaked Polar Instrumentation for Diagnosing Energetic Radiation	Fixed	The x-ray burn history from an implosion is measured by SPIDER. This is a fixed instrument that views the x-ray emission from an implosion at about 10 keV through the upper LEH at a viewing angle of 7 degrees off vertical. The detector is a DISC x-ray streak camera, with a 4ω ultraviolet timing fiducial.	44, 54
SXI-L SXI-U	Static X-ray Imager	131-326 18-124	Two SXI diagnostics, mounted on retractable positioners, perform pinhole imaging. On some channels, spectral selection is accomplished with filters and mirrors that provide low-resolution x-ray imaging at 900 eV. Other channels merely use filters, providing 3– 6 keV spectral imaging. The images are recorded on either image plates or CCDs, depending on the expected neutron yield. For hohlraum experiments, the positions of the SXIs are chosen to view the x-rays from inner walls of the hohlraums through the LEH. The time-integrated size of the LEH (taking into account closure during the laser pulse) is measured by the SXIs. For planar target experiments, these instruments can also measure the position of the laser spots by measuring the resulting x-ray emission with respect to fiducial markings on the target.	55, 56

Table 7-4. DIM-based diagnostic snouts and appendages.

Acronym	Name	Type	Purpose and Function	Reference
CCXI	Charge Coupled X-ray Imager	Detector	CCXI is a CMOS detector with an active readout time-integrated x-ray imager.	
HEMPI	High Energy Multipinhole Imager	Snout	HEMPI images high-energy x-rays with a large field-of-view using an array of 18 pinholes with four independent filter combinations. By analyzing the differentially filtered images, a spectrum of the hard x-rays emitted from different regions of the hohlraum can be constructed.	57
NAD—DIM indium (In) zirconium (Zr) Copper (Cu)	Neutron Activation Detector	Appendage	NAD measures the integrated neutron yield from a DD or DT-filled capsule by activating an In, Zr, or Cu foil, removing it from the chamber, and determining the activation level using nuclear counting techniques.	29, 30
NAD—WRF mount	Neutron Activation Detector	Appendage	Measures the integrated neutron yield from a DD or DT-filled capsule by activating an In, Zr, or Cu foil, removing it from the chamber, and determining the activation level using nuclear counting techniques.	29

Acronym	Name	Type	Purpose and Function	Reference
PTOF Proton Detector	Particle Time-of-Flight Proton Detector	Append-age	Some implosions on NIF have a gas fill of deuterium (D) and helium-3 (^{3}He) in order to produce 14.5 MeV protons from the D^{3}He fusion reaction. The emission time of the protons is measured with a synthetic diamond wafer detector made by the chemical vapor deposition (CVD) technique. Despite the relatively slow flight time of the protons compared to x-rays, the background from hohlraum x-rays is a problem for this diagnostic. Efforts are underway to reduce this background.	58
Ross Filter Pair	Ross Filter Pair	Append-age	An array of "Ross filtered" pinholes measures the temperature- and density-sensitive Bremsstrahlung emission. This data provide estimates of hot spot mass, mix mass, and pressure, as well as broadband time-integrated absolute x-ray self-emission images of the imploded core.	51
Scattering Foil	Scattering Foil	Append-age	Used with the Magnetic Recoil Spectrometer	24–27
Supersnout II (multi-wavelength)	Multi-wavelength X-ray Spectrometer	Snout	Two four-channel curved crystal Supersnout spectrometers are used to record with medium resolution K shell x-rays from dopants such as germanium and copper in the plastic ablator once they mix into the hot spot and emit x-rays.	59
WRF	Wedge Range Filter	Append-age	WRFs are used for D^{3}He gas-filled implosions. The escaping thermonuclear protons lose energy in the compressed plastic. The energy spectrum of the escaping protons is measured by passing them through a wedge of material and measuring the energy of the protons after passing through various parts of the wedge with CR-39 track detectors. These WRF units are mounted at about 50 cm from TCC. The technique yields valuable data prior to the full compression of ablator. When the density of the ablator is about 200 mg/cm^2 or higher, the protons are stopped in the ablator.	60

7.3. New Target Diagnostics or Components

The ICF Diagnostics Steering Group is chartered with coordinating development of major target diagnostics for national ICF facilities, including the NIF. This group draws its membership from General Atomics, University of Rochester's Laboratory for Laser Energetics, the Naval Research Laboratory, and Sandia, Lawrence Livermore, and Los Alamos national laboratories. To further develop national plans for major ICF/HED diagnostic systems, the steering group organizes focused, several-day diagnostic workshops once or twice a year to discuss requirements, proposed systems, and future plans. The group also works to ensure that new NIF diagnostics support a range of missions and experimental objectives.

7.3.1. Process Outline

Before a new piece of equipment can be deployed at NIF, it must undergo a formal process, including a series of reviews. These reviews can be combined as appropriate, and the review scope is adjusted according to the complexity and risk associated with the product.

A member of the NIF Diagnostic Engineering team will be assigned to assist each researcher in the design of hardware that can be readily fielded on the NIF. The NIF Diagnostic Engineering interface partner will help determine the appropriate review scope and deliverables using a risk-based graded approach.

Primary steps in the process include:

- Preparation of a written set of requirements, including clearly defined performance criteria and requirement verification methods.
- Change control board (CCB) new diagnostic project approval (Diagnostic CCB5, Chair: R. Kauffman). Requirements are reviewed and accepted, and CCB5 ensures that the program requirements are considered.
- CCB diagnostic project funding approval (NIF CCB4, Chair: R. Patterson). CCB4 ensures that the requirements are in place and fit within budget. (See *Budget/Schedule Change Request Preparation.*[61])
- Conceptual design review of:
  - System requirements (require CCB4 approval and submission into the NIF requirements management system [RMS] database)
  - Physics basis
  - System layout/one-line diagram
- Preliminary design review of:
  - Updates to system requirements
  - Updates to physics basis
  - Preliminary safety analysis
  - Draft failure modes and effects analysis (FMEA)
- Final design review of:
  - Approved and released drawings
  - Final FMEA
  - Completed safety analysis
  - Completed assembly and installation plans and procedures
- Target and laser interaction (TaLIS) review of:
  - Unconverted light check using supplied CAD model
  - Debris wind analysis
  - Shrapnel analysis
  - Alignment requirements
  - Material compatibility and cleanliness requirements
- Prototype construction and testing (recommended, in some instances, to confirm instrument will meet weight, size, maneuverability, and compatibility specifications)
- Instrument construction
- Acceptance test (offline) (See *IPRB Checkpoint Checklist.*[62])
- Work authorization plan (WAP) for diagnostic operation developed by the responsible scientist (RS) or responsible individual (RI)
- Installation qualification (IQ)/operational qualification (OQ)/performance qualification (PQ) (NIF Operations Manager/engineering responsible for IQ and a portion of OQ; remainder OQ/PQ is shots)

- After that, the diagnostic is maintained by diagnostic team and configured by the factory. The diagnostic is added to CMT.

Reviews may include NIF representatives from the steering committee, operations, TaLIS, shot setup/CMT, diagnostics, mechanical engineering, assembly, cleanliness, snouts, instrument mounting, and others, depending on the instrument's complexity and intended use.

For more information on designing diagnostics for NIF, see *Diagnostic Design Guidance for the National Ignition Facility*[63] and *Engineering Design Reviews*.[64]

7.3.2. DIM-Specific Design Requirements

For a new DIM-based snout, instrument assembly, or instrument attachment to be considered for use at NIF, it must meet a number of design, safety, and compatibility criteria.

The designer must demonstrate that:

- The design fits into the space envelope.
- The design is accessible from the side access.
- The design can be inserted /removed via the DIM side access ports.
- Removable items such as image plates, film packs, filters, etc. can be reached.
- All required tool access is accommodated.
- Human factors are considered such as handles, grips, or support areas for handling the hardware during assembly and installation.
- Cleanliness and hazardous material consideration are adequately considered in the design.

Some key design requirements for the DIM include:

- Radial positioning from the wall of the target chamber to target chamber center to a resolution of ±250 µm.
- Pointing accuracy of ±25 µm in both x and y directions (z is along the radial direction of the chamber).
- Accommodates diagnostic carts up to 300 mm diameter and 3 m in length.
- Accommodates loads up to 125 kg with a center of gravity at least 1 m from target chamber center.
- Angular pointing of ±1° is available at the point of mounting at the chamber wall, and ±3° by moving the rear mount.
- A 100 mm clear aperture along the full axis.

A CAD model of each DIM is available for designers to use. From design through deployment, developing a DIM-based diagnostic or snout typically takes nine months to a year. Details on the DIM and how to design diagnostics to be compatible with operation in a DIM are available in the Ref. 63.

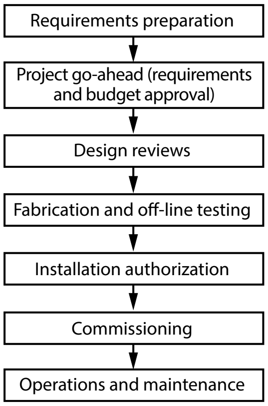


Figure 7-6: The process flow for designing, building, and installing a new diagnostic at NIF.

8. Targets

8.1. Capabilities

8.1.1. Fabrication and Assembly

A well-designed and precisely fabricated target is one of the keys to a successful experiment at NIF, and LLNL/General Atomics (GA) target fabrication has the capabilities and experience to build a wide variety of targets for investigating various areas of science on NIF. GA is an integrated partner in target fabrication for NIF. The infrastructure for making and characterizing many precision target components resides at GA along with capabilities for assembling some targets or subassemblies for targets, depending on the type. LLNL is responsible for assembly of these components and the characterization of the targets, and also fabrication of some components, again depending on the type.

New or advanced materials, engineering, and fabrication techniques are often required when constructing novel target designs for NIF experiments. When a new material structure is needed, materials scientists create the essential raw materials. Fabrication engineers then determine whether those materials, some of them never seen before, can be machined and assembled. If the new materials pass muster, components or an entire target will be assembled and tested.

GA and LLNL target fabrication capabilities include:

- **Precision machining:**
  - Diamond turning lathes, laser machining, and precision mills for fabricating hohlraums, halfraums (vacuum and gas-filled), fill tubes, diagnostics holes and patches, thermal mechanical package (TMP) components, laser entrance hole (LEH) components, keyhole cones, mirrors, and shells
  - Laser ablation for removing isolated features from capsule shells
  - Precision grinding and polishing for capsule surfaces

Figure 8-1: Cleanroom for fabrication and characterization of target components at General Atomics (top); cleanroom at LLNL for target assembly and characterization (bottom).

- **Capsule fabrication:**
  - Glow discharge plasma coating systems for making plastic, beryllium, carbon, silicon, gold, or glass capsules. Composite, multi-layered, and double-shelled capsules are possible as well.
  - Coating systems for depositing custom layers such as copper or germanium or silicon dopant layers used as x-ray preheat shields. Custom layering also includes the option to add small amounts of detector material at specific locations in the capsule to trace capsule material

mixing into the central hotspot region for ICF targets.

- **Hohlraums:** Equipment for fabricating hohlraums and halfraums from materials such as gold, depleted uranium, copper, or aluminum
- **Coatings and films:** Equipment for applying metallic and organic coatings and polymer films using physical vapor deposition (ion assisted), chemical vapor deposition (plasma assisted), electrodeposition, and atomic layer deposition
- **Novel materials and features:**
  - Foam fabrication: polystyrene, aerogel, nanoporous metals, divinyl benzene, doping with embedded objects, etc
  - Microwire backlighters
  - Cones
  - Shields
  - Stepped and rippled components
- **Beryllium:** Facility capable of safely handling beryllium, equipped with beryllium sputter coating systems used in fabrication of beryllium shells.

Precision target assembly is carried out at LLNL in a 3000-square-foot, Class 100 cleanroom. The cleanroom is equipped with over 40 assembly stations with customized tooling, where components arriving from GA, in-house fabrication facilities, and outside vendors are inspected, assembled, and tested to produce shot-ready targets for NIF. A suite of new assembly tools provides increased throughput with greater repeatability, while offering agility in accommodating varying size scales and novel target features. In particular, LLNL has introduced a precision robotic assembly machine that can manipulate tiny fusion target components with unprecedented precision in an operating arena the size of a sugar cube.

For cryogenic targets, LLNL also has processes and equipment in place to support deterministic layer formation and cryogenic target handling. The Livermore team has distilled a process that maximizes the probability of growing a layer from a single seed crystal. Before an experiment begins, a target is mounted on the end of the cryogenic target positioner, which sits in a large vacuum vessel just outside the NIF target chamber. There, a sophisticated system fills the capsule with fuel, characterizes the cryogenic fuel layer, and maintains the layer quality. The entire target package is kept below 20 K and is sheltered by shrouds while the layer is formed. The package is then positioned and aligned at the center of the target chamber in preparation for the experiment.

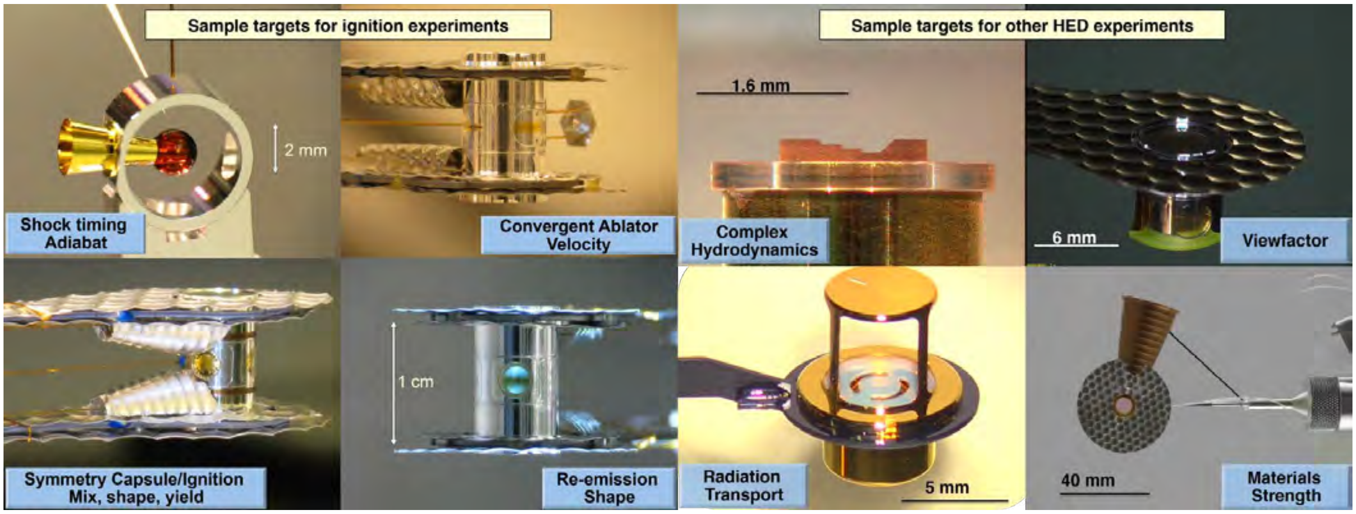


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Figure 8-2: Samples of some of the targets fabricated by GA/NIF and fielded at NIF.

For more information on target manufacturing capabilities, visit the GA target catalog: **http://www.ga.com/energy/files/IFT_Catalog.pdf**

8.1.2. Component and Target Metrology

Throughout the fabrication process, engineers inspect the target materials and components using nondestructive characterization methods to ensure that target specifications are met and that all components are free of defects. Several laboratories at GA are set up and equipped to carry out precision characterization of target components (TMP components, LEH components, keyhole cones, mirrors, mandrels, capsules, hohlraums, and subassemblies). LLNL has a suite of materials characterization techniques that have been applied to metrology and characterization of the fully assembled targets. LLNL and GA are regularly developing new characterization capabilities to meet customer needs.

GA and LLNL characterization techniques/equipment include the following:

- **Atomic force microscopy:** A molecular imaging atomic force microscope system is used to measure target material surfaces with nanometer spatial and height resolution.
- **Confocal microscope 4-pi capsule inspection system:** This system allows particles as small as a few microns introduced during assembly to be identified and their location translated to NIF target chamber coordinates for that specific target (see Figure 8-4).
- **Contact radiography (CR):** A nondestructive technique to precisely profile graded dopants in ICF shells, this quantitative CR method can detect dopant variation to better than 0.1 at. %. Contact radiography also provides accurate dimensional information.
- **Double-sided white light interferometer:** A double-sided white-light interferometer scans both sides of a sample simultaneously to provide thickness measurements over the sample area. 3D mapping of ripple and steps in target components to ~1 micron accuracy has been achieved.
- **Dual-confocal measurement system:** A dual-confocal measurement system performs thickness measurements over a sample area for opaque samples to complement its x-ray edge absorption spectroscopy unit. 3D mapping of ripples and steps in target components to ~1 micron accuracy has been achieved.
- **Energy dispersive spectroscopy (EDS):** A physics-based EDS model examines capsule contaminants and dopants by measuring low concentrations of relatively light elements in a very low-Z matrix.
- **Focused ion beam with scanning electron microscopy:** Focused-ion-beam characterization enables site-specific analysis of various capsules by conveniently cutting open the thick coating layers and revealing the internal microstructures, defects (if any exist), and composition details.
- **Ion beam characterization:** A 4 MV ion accelerator is used to characterize ion implantation doping of ICF ablator capsules with ^{124}Xe atoms and potentially other elements of interest to neutron capture experiments.
- **Micro x-ray computed tomography:** An x-ray computed tomography system images materials with a resolution of less than 1 micrometer over a 1-millimeter field of view to provide spatially resolved opacity that can be translated to density in known compositions and thicknesses.
- **Nikon Nexiv optical coordinate measuring machine:** This instrument is equipped with custom analysis software for automated mandrel dimensional metrology.
- **Phase shifting diffractive interferometry:** The interferometer uses 110 images (medallions) to capture all isolated and gently curved defects on the entire shell surface.

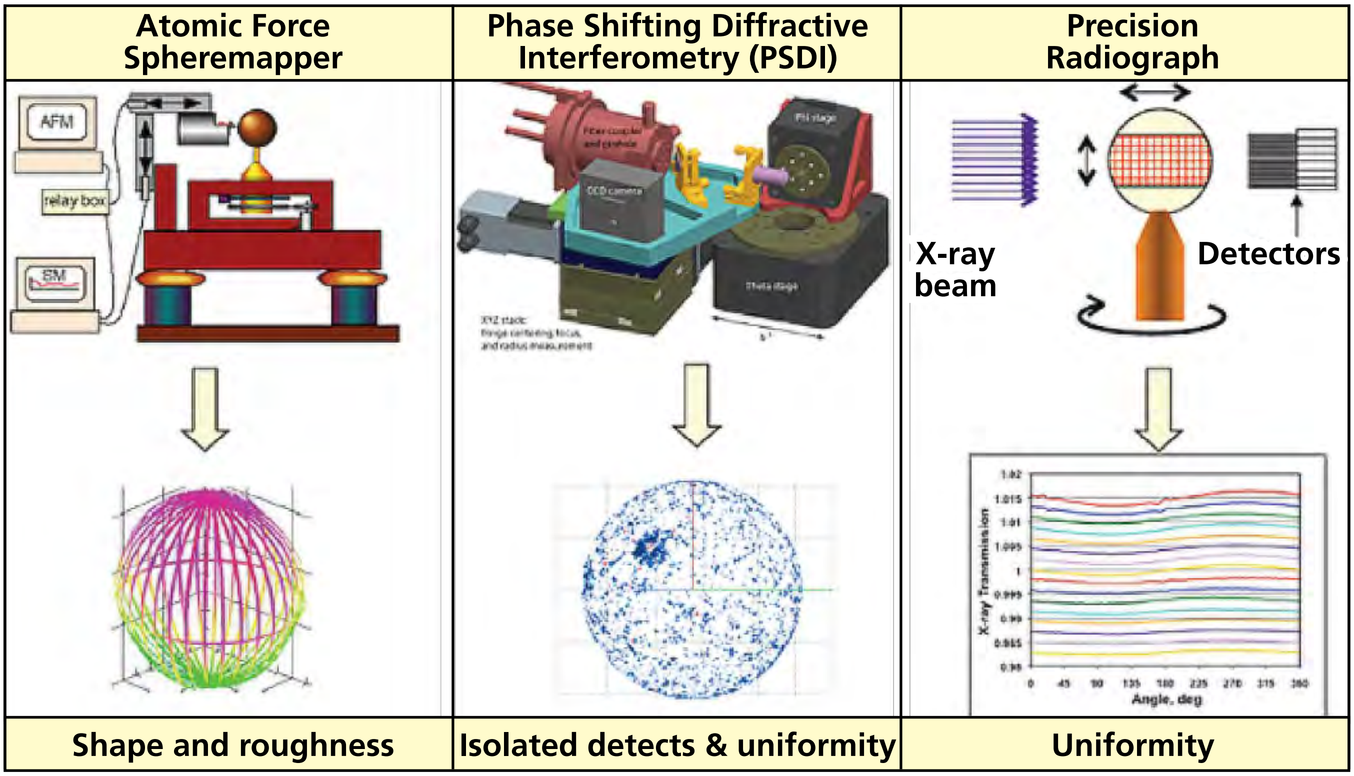

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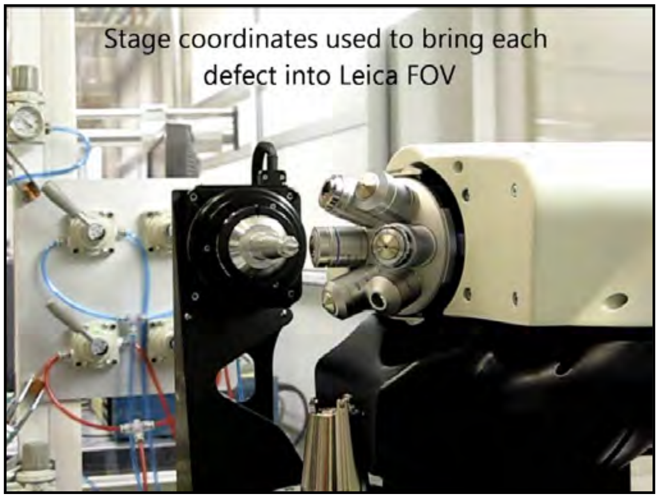
Figure 8-3: Various metrology tools are used to determine that capsule specifications are met. From left, Atomic Force Spheremapping facilitates full-surface mapping of capsule shape and roughness, Phase Shifting Diffractive Interferometry is used to look for isolated defects and uniformity, and Precision Radiography is used to confirm capsule uniformity.

- **Precision radiography:** A precision radiography system measures x-ray opacity variation in an ablator capsule to 10^{-4} accuracy at 120-micron spatial resolution; this includes variations caused by nonuniformity of the dopant layers.
- **Scanning electron microscopy:** A scanning electron microscopy with EDS is used for determining capsule dopant profiles and hohlraum microstructure.
- **Transmission electron microscopy with electron energy loss:** The transmission electron microscope with electron energy loss spectroscopy capability offers analysis at the atomic structure level and extremely high energy resolution for composition analysis of capsule materials.
- **X-ray edge absorption spectroscopy:** An x-ray absorption spectroscopy instrument measures the absorption edge to determine the concentration of elements (Z >17) in the presence of other elements. It can also be used to determine the thickness of opaque samples.
- **X-ray fluorescence (XRF):** The XRF system calculates the atomic percentage of elements in spherical samples with an accuracy of 10% for high-Z elements and has a trace detection capability at 1 ppm level for contamination control.
- **X-ray microscopy:** A commercial (Xradia) point projection x-ray microscope is used to measure/characterize laser-drilled fill hole geometries to ~1.5-micron resolution.

At LLNL, we also have access to tools, techniques, and expertise at the Nanoscale Synthesis and Characterization Laboratory and beamlines at synchrotron facilities at the Advanced Light

Source at Lawrence Berkeley National Laboratory, Stanford Synchrotron Radiation Lightsource at SLAC National Accelerator Laboratory, and the Advanced Photon Source at Argonne National Laboratory. We have made use of the tunable, intense x-ray sources to perform scattering, diffraction, absorption (near edge and fine structure), and tomography measurements of target materials and capsules.



2012-041597

Figure 8-4: Close-up view of a capsule undergoing a near–4-pi inspection using a confocal microscope.

8.2. Target Engineering Process

Targets may either be fabricated at LLNL/GA or supplied by the experimentalist. For LLNL/GA-produced targets, there is a process in place to ensure that the production of targets for NIF experiments occurs in an efficient manner and meets all design specifications and quality control requirements. Experimentalist-supplied targets must still meet certain fundamental design and materials requirements (size, hazardous materials, etc.) and must be metrologized at LLNL.

8.2.1. LLNL/GA Target Fabrication

The timeline for LLNL/GA target development depends on the complexity and novelty of the target design. If the target has been previously fabricated, then the design need only be supplied to NIF Target Fabrication for review three months before the experiment. For new designs, Target Fabrication will need at least 6–9 months before the experiment for evaluation, planning, and production. In either instance, Campaign RIs (see Section 10.4) are advised to begin working with Target Fabrication as early as possible. A Target Fabrication CCB manages changes in target schedule and development.

The general target engineering process is as follows.

Determining physics requirements/design: The Campaign RI should bring the target design and physics requirements to Target Fabrication as soon as an experiment is approved, and before it is scheduled, to discuss design feasibility. Target Fabrication will provide design feedback and a time estimate.

Performing engineering analysis and preparing drawings: Once the experiment is scheduled, Target Fabrication will assign a target engineer to work with the Campaign RI and prepare a conceptual design and drawings.

Expert review and design signoff: Target specifications must be agreed to at the Implementation Review (see Section 10.5.1), well before the target is built. The Campaign RI and target engineer must work with relevant expert review groups (see Section 10.5.2) to uncover and resolve any physics, safety, and cleanliness issues early in the process. In particular, Target and Laser Interaction Sphere (TaLIS) must be consulted regarding alignment, debris, unconverted light issues. TaLIS officially reviews and approves the target design by signing off on the drawings. The Campaign RI, together with NIF, must also develop a target alignment plan/strategy.

Target fabrication and metrology: If it is determined during target metrology that a target or target component does not meet specification, then the target will be evaluated by NIF's Material Review Board to determine if the target should still be shot, if the specification was reasonable, and whether the experiment can be performed as planned.

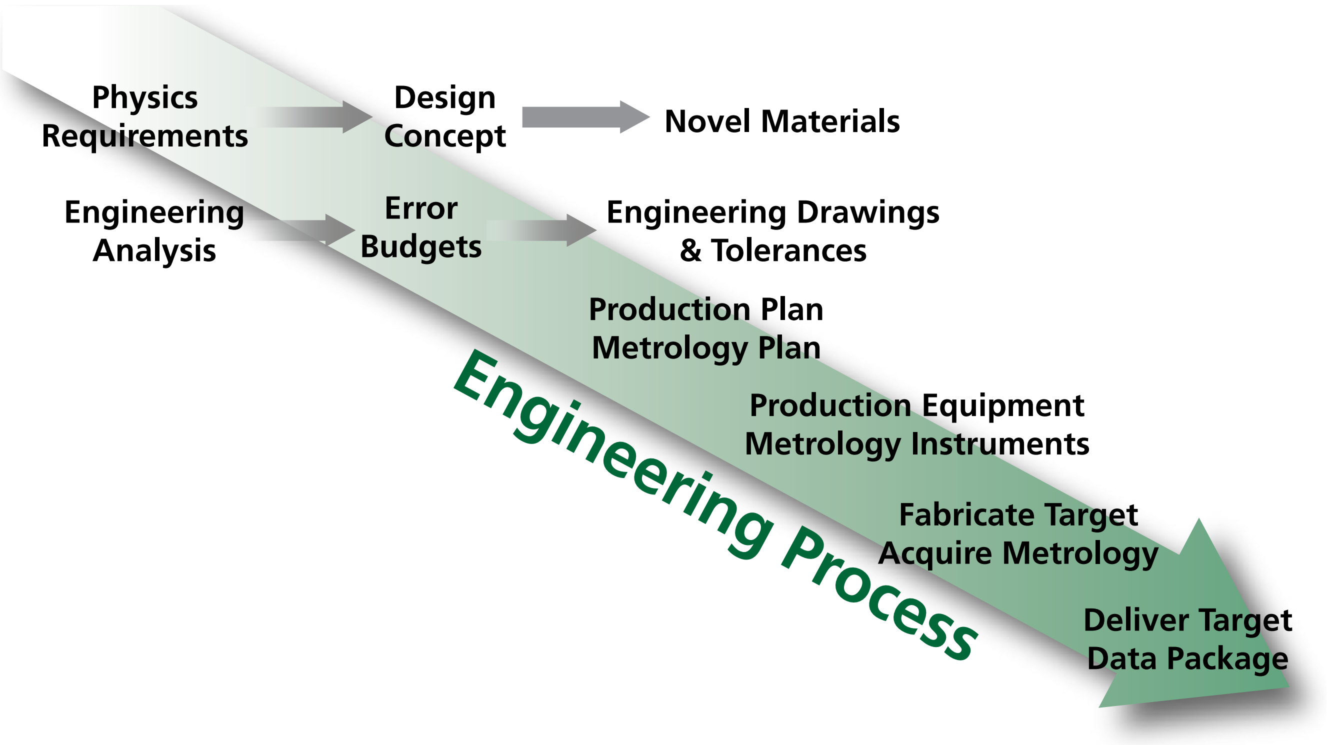


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Figure 8-5: The target engineering process. The timeline for target development depends on the complexity and novelty of the target.

8.2.2. User-Supplied Targets

Depending on the experiment, users may supply fully assembled targets or components that need assembly at LLNL. If the Campaign RI chooses to have the fully assembled target made elsewhere, then the target must:

- Match the drawings and descriptions provided in the Facility Proposal Form (see Section 10.3)
- Undergo a design review by NIF Target Fabrication
- Pass hazardous materials and TaLIS reviews
- Be safe to shoot without damaging the laser
- Undergo NIF-approved cleaning
- Be metrologized at LLNL

The materials and cleanliness of target assemblies for the NIF are rigorously controlled to minimize possible damage to the laser optics from debris and to maximize the energy delivered to the target chamber by preventing contamination of the sensitive antireflective coatings used on lenses and other transmission optics. All target materials and assemblies that are proposed for use on the NIF must be reviewed and approved before they may be used. They must also be cleaned by NIF-approved cleaning vendors using special processes that ensure compliance with NIF cleanliness requirements.

For new target designs, user-supplied targets must arrive at LLNL at least 3–4 weeks in advance of the experiment, as long as it would not be detrimental to the target or experiment.

The User Office will connect the Campaign RI with the appropriate individuals to go over the design and perform the reviews.

It is not uncommon that the users supply only some of the components of a target rather than the fully assembled target. The targets are then assembled at LLNL and the above requirements still hold. In addition, the following also apply:

- NIF Target Fabrication reviews and modifies the target assembly plans.
- The user provides final assembly drawings far enough in advance of the shot to allow required preparation for assembly at NIF. The necessary lead time is usually 4 weeks, but will vary depending on the target.
- Components arrive at NIF far enough in advance of the shot to allow proper time for assembly. Again the necessary lead time is usually 4 weeks, but will vary depending on the target.

8.3. Debris and Shrapnel

A variety of targets are fielded on NIF, from thin foils to large hohlraums with x-ray and unconverted light shields. These targets are subjected to a wide range of laser conditions. The laser interaction with the target ablates some of the target material to create plasma and debris, and for some conditions, shrapnel is generated. The debris and shrapnel may impact the debris shields, potentially causing damage that can grow on subsequent laser shots In addition, diagnostics that experience large x-ray fluences, plus the target positioner and the first wall material in the target chamber, may all become sources of debris and shrapnel.

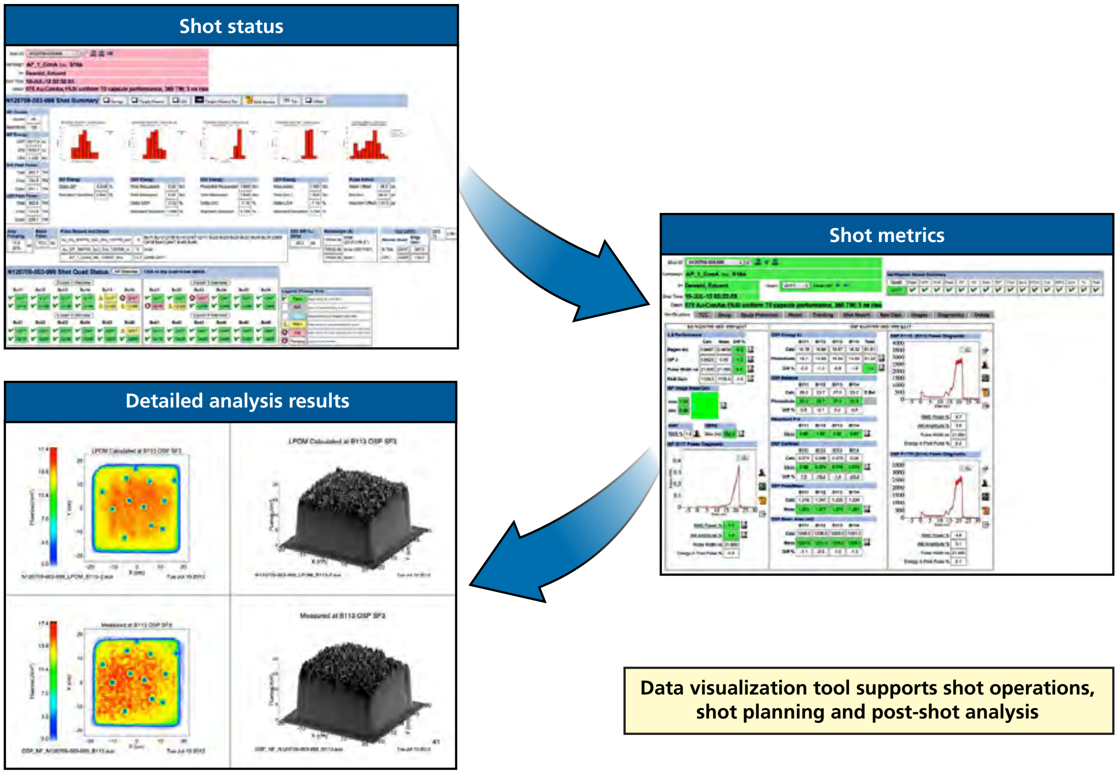
Simulation tools have been developed and benchmarked against facility data to predict the impact of specific targets on the NIF chamber. Whenever a experimental campaign calls for a target design with a new feature, the Debris and Shrapnel Working Group performs a risk assessment and experimental modeling is performed to understand debris and shrapnel generation.

Present guidance for target design is that the target should not produce more than 5–10 mg of shrapnel per shot and 300 mg of other particulates. More information is provided in the *Debris and Shrapnel Risk Management Plan*[65] and *Debris and Shrapnel Mitigation Procedure for NIF Experiments*.[66]

9. Data Handling

The main purpose of NIF is to produce high-quality experimental data that is used to validate theoretical physics. NIF software tools have been designed and constructed to manage and integrate data from multiple sources, including machine state configurations and calibrations, experimental shot data and pre- and post-shot simulations. During a shot, data from each diagnostic is automatically captured and archived into a database. Arrival of new data triggers the shot analysis, visualization, and infrastructure (SAVI) engine, the first automated analysis system of its kind, which distributes the signal and image processing tasks to a Linux cluster and launches an analysis for each diagnostic.[67] Results are archived in NIF's data repository for experimentalist approval and display using a web-based tool. A key feature is that scientists can review data results remotely or locally, download results, and perform and upload their own analysis.

Post-shot data analysis and laser performance reporting is provided by LPOM. To do this, LPOM is directly linked to the ICCS shot database and upon request, it can quickly (within minutes) provide the NIF shot director and user with a report that compares predicted and measured results, summarizing how well the shot met the requested goals of the shot. In addition, the LPOM data reporting system can access and display near-field and far-field images taken on each of the laser diagnostic locations, and provide comparisons with predicted images. The results of the post-shot analysis are displayed on the LPOM GUI, while a subset of the analysis is presented to the shot director through a shot supervisor interface.



Data visualization tool supports shot operations, shot planning and post-shot analysis

2012-040631

Figure 9-1. After each shot, a web-based format enables the detailed laser performance for any beamline to be examined using a suite of data trending and analysis tools.

Experimental data, plus data on the post-shot state of the facility, are housed in and retrieved (via the Archive Viewer) from the NIF data repository. This secure archive stores all the relevant experiment information—including target images, diagnostic data, and facility equipment inspections—for 30 years using a combination of high-performance databases and archival tapes. Retaining the data allows researchers to retroactively analyze and interpret results or perhaps to build on experimental data originally produced by other scientists. A crucial design feature of the database is that it preserves the pedigree of the data—all the linked pieces of information from a particular experiment, such as algorithms, equipment calibrations, configurations, images, and raw and processed data—and thus provides a long-term record of all the linked, versioned shot data.

9.1. Data Management Tools

Some of the NIF data management tools are used by both NIF personnel and visitors, while others are available only to NIF personnel. Contact the NIF User Office for help in setting up access the data tools available for your use.

Archive Viewer: The interface that allows NIF personnel and visitors to view data from the NIF data repository as a dashboard or in tabular form, or to download data to process offline.

Campaign Management Tools. NIF personnel use the CMT to generate the laser and facility configuration for an experiment. CMT is a suite of software applications designed to translate experimental plans and specifications into actions for the control system. Components of the CMT-managed automated shot cycle include:

- Inputting campaign shot goals
- Performing automatic alignment and wavefront correction
- Configuring diagnostics and laser performance settings
- Conducting countdown
- Assessing shot outcome and archiving shot data

Configuration Checker: These are steps behind the scene that are performed by NIF shot operations to ensure that the configuration of the NIF laser and target chamber meet your defined experimental requirements.

LoCoS: NIF personnel use the web-based location, component, and state (LoCoS) system to track installed parts from the facility level down to individual parts. It also captures and manages calibration data for target diagnostics, targets, and parts.

Shot Analysis provides access to NIF shot-related data in the Archive, including shot reports, laser diagnostics, and target diagnostic

Shot Analysis Data Visualization (SADV):

Select multiple shots to be analyzed for WFL Z-Focus

Download shot data from the following sources:

Archive Viewer:

- Best viewed on a PC with Firefox or IE8

Legacy CMS data viewer (to be removed):

Troubleshoot issues with rendering shot results in

Verify hardware processes supporting SADV are fun

Troubleshoot issues with rendering shot results in

Administer changes to the BPEL system: Download

Access your BPEL workflow inbox:

- Requires BPEL logon - Your NIF domain logon will NOT
- Please submit a support request for BPEL Manager or

Download IDL code for desktop analysis of shot dat

- Requires Wiki logon
- Please submit a support request for access to the Sh

Create spreadsheets that describes Configuration

Figure 9-2: Archive Viewer Shot Analysis screen.

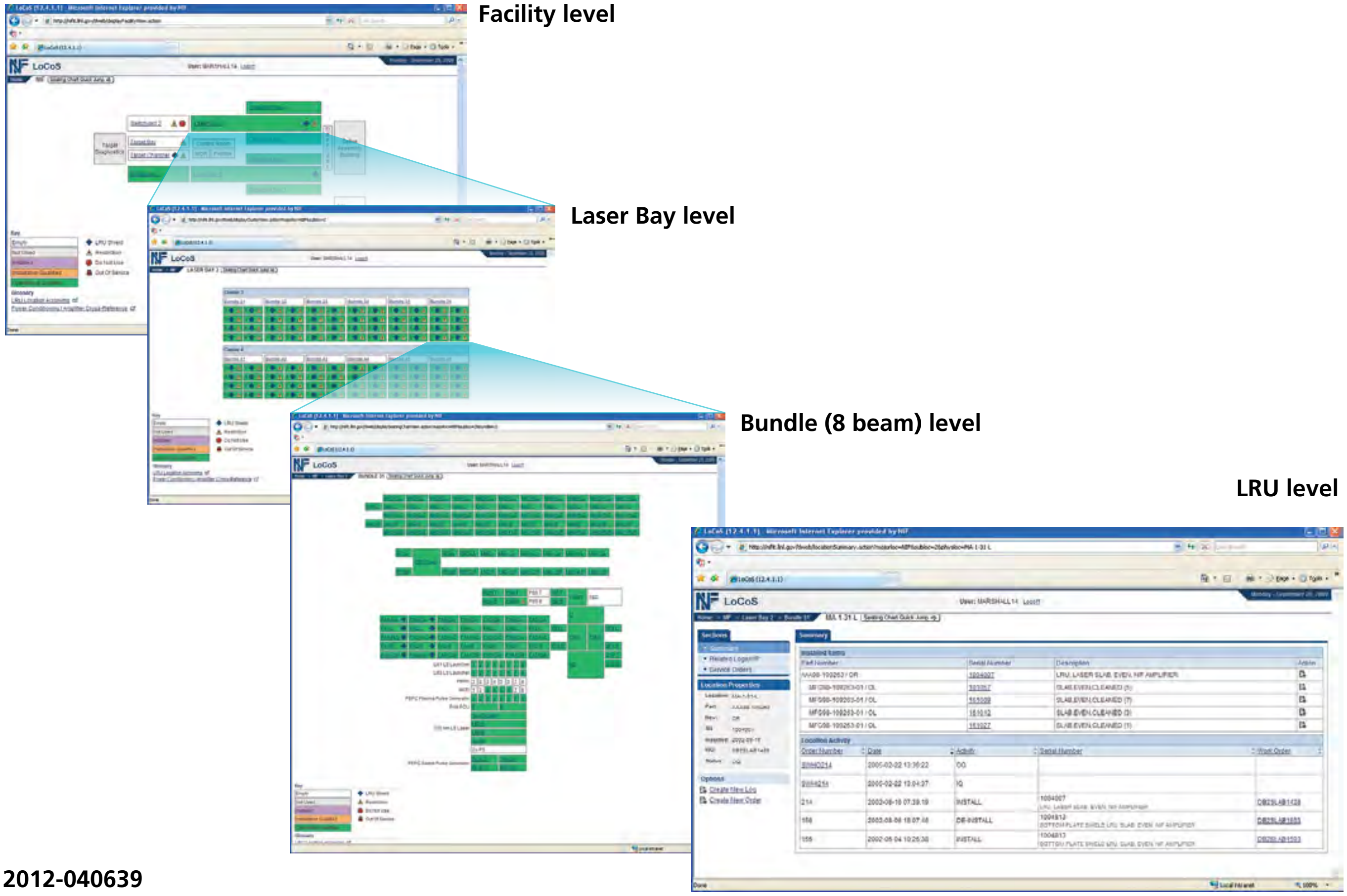
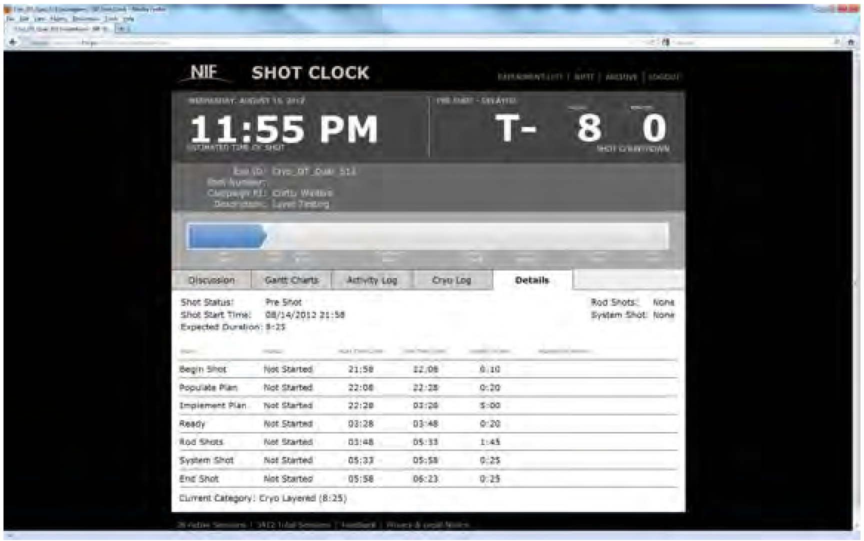


Figure 9-3: LoCoS has extensive drill down from facility level to individual parts.

NIF Wiki: The NIF Wiki (**https://nifit.llnl.gov/wiki/display/vc/Home**) was created as a tool to improve collaboration and communication amongst the scientists using NIF. It provides a single, central location for quickly storing and accessing a diverse set of information and knowledge related to experiments. The wiki stores user-generated content in a free-form format (presentations, documents, tables, charts, etc.). It is closely coupled to NIF's data repository. This connection enables users to navigate quickly and easily between official shot data and scientific analyses and interpretation. Primary features of the NIF Wiki include the shot log, shot pages, campaign summaries and performance charts, meeting pages, and presentations.

Shot Clock: The shot clock allows NIF personnel and visitors to monitor the progression of the experiment as the NIF control system implements the experimental parameters defined in the CMT.



Shot Status: Pre Shot
Shot Start Time: 08/14/2012 21:58
Expected Duration: 8:25

Rod Shots: None
System Shot: None

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Begin Shot	Not Started	21:58	22:08	0:10	
Populate Plan	Not Started	22:08	22:28	0:20	
Implement Plan	Not Started	22:28	03:28	5:00	
Ready	Not Started	03:28	03:48	0:20	
Rod Shots	Not Started	03:48	05:33	1:45	
System Shot	Not Started	05:33	05:58	0:25	
End Shot	Not Started	05:58	06:23	0:25	

Current Category: Cryo Layered (8:25)

2012-040640

Figure 9-4: Shot Clock screen.

9.2. Classified Operations

The NIF has the ability to conduct experiments at the Secret Restricted Data level. Swinging the facility and transferring control of the diagnostics and target viewing systems to a classified computer network system could take anywhere from several days to several months to implement depending on the diagnostic. The User Office can provide further information.

9.3. Data Protocol and Availability

The NIF will be a user facility where experiments are conducted by a wide range of users for many different applications. Diagnostics for these experiments will include facility diagnostics as well as user-provided diagnostics. For more on user data policies, see Appendix B.

- All core diagnostics will be integrated into the NIF data archival system.
- Data obtained from all core target diagnostics on the NIF belong to the facility.
- Data from core diagnostics will be read by the data archival system and stored along with other shot data.
- Raw data, calibration, and analysis programs will be made available to the PI and the RI, within the limitations of the classification, sensitivity, and proprietary requirements, and any other access requirements.
- The data archival system will provide the PI with access to the data.

9.4. Remote Capabilities

NIF has a geographically dispersed user base. The need to travel to the NIF to carry out experimental plans could be reduced with proven, commercial technology to provide the ability to execute and monitor many of the tasks associated with conducting experiments at remote sites. Remote implementation of experiments could reduce the personnel time commitment and travel costs and make using NIF easier and more transparent. While remote capabilities are not currently in place, NIF intends to work with its extended user base to develop these capabilities where feasible and desired.

10. Experimental Design and Execution

10.1. Platforms

NIF experiments are typically executed via experimental "platforms." A NIF experimental platform typically consists of an integrated laser, target, data analysis, classification level, and diagnostic configuration capable of providing well-characterized pressure, temperature, implosion, or other environments.

A number of new experimental platforms are commissioned each year. Once developed, an experimental platform can be customized and applied to a wide variety of physics experiments (just as configurations are). For example, a planar-radiation hydrodynamics platform, with some modifications, could be applied to both an experiment studying the formation of the Eagle Nebula pillars and one looking at the formation of Herbig-Hara jets.

Proposed NIF experiments are matched to existing platforms and capabilities, whenever possible. Because of the lead times for developing new platforms, experimentalists are encouraged to use an existing platform. The closer an experiment stays to an established platform, the less lead time is needed and the more readily data can be acquired. Any platform modifications or new capabilities needed to perform the experiment must be identified at an early stage and discussed with the relevant Platform RI.

A list of commissioned platforms is available in Appendix D. For more information on the platforms, see the Users section of the NIF website (https://lasers.llnl.gov/for_users/).

Experimental platforms have typically been associated with specific user groups. For example, the National Ignition Campaign (NIC) has commissioned several platforms to study indirect-drive ICF. Laser requirements vary for each user group, depending on the emphasis of the particular experiment being undertaken, but Figure 10-1 displays typical shots carried out up to September 2012.

The NIC user group poses the most stressful laser requirements. NIF was designed to satisfy ICF experimental needs with the expectation that other missions with generally less stressful needs could also be accommodated.

Unlike previous laser facilities, changes in the NIF laser pulse shape and energy can often be carried out within a single shot cycle. Changes to the NIF laser system may be organized into those that require months to make, those that can be accomplished in more than one shift, and those that can be fit into a single shot cycle. The list below summarizes the characteristics of some of these changes.

- Examples of laser capabilities that can be modified during the shot cycle:
  - Temporal pulse shape
  - SSD bandwidth
  - Laser energy
  - Pointing of individual beams
- Examples of laser capabilities that require multiple shifts to reconfigure:
  - >8 CPPs exchanged
  - Special laser diagnostic reconfigurations
  - Polarization smoothing changes (quite a few shifts)
- Examples of laser capabilities that are not precluded but that may require large resource and time commitments:
  - 2D SSD
  - Conversion to 2ω operation
  - Moving beams to direct-drive ports

Although unique experimental geometries for each study might be attractive, it should be remembered that the greater the number of facility modifications requested between shots, the lower the shot rate.

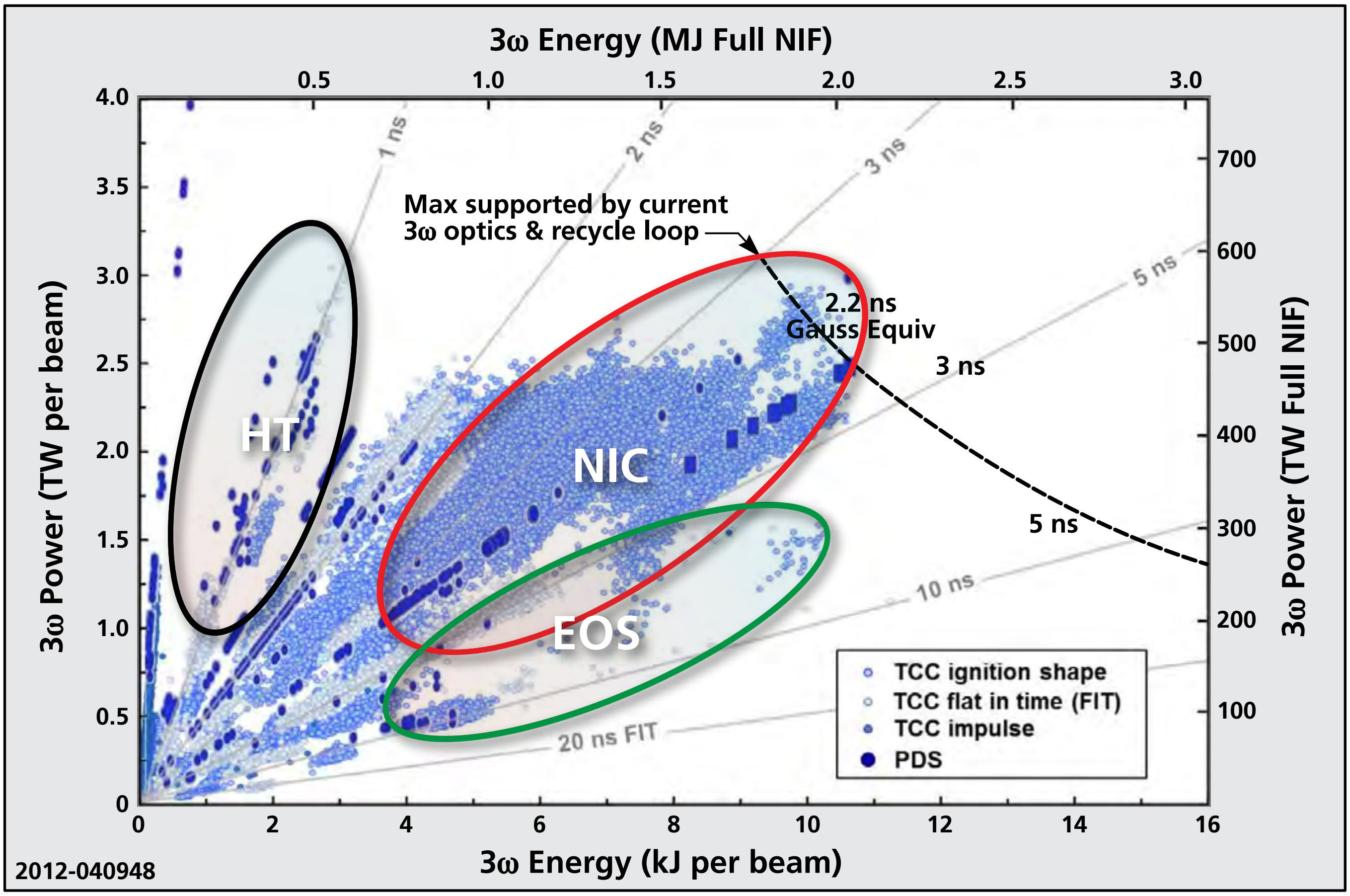


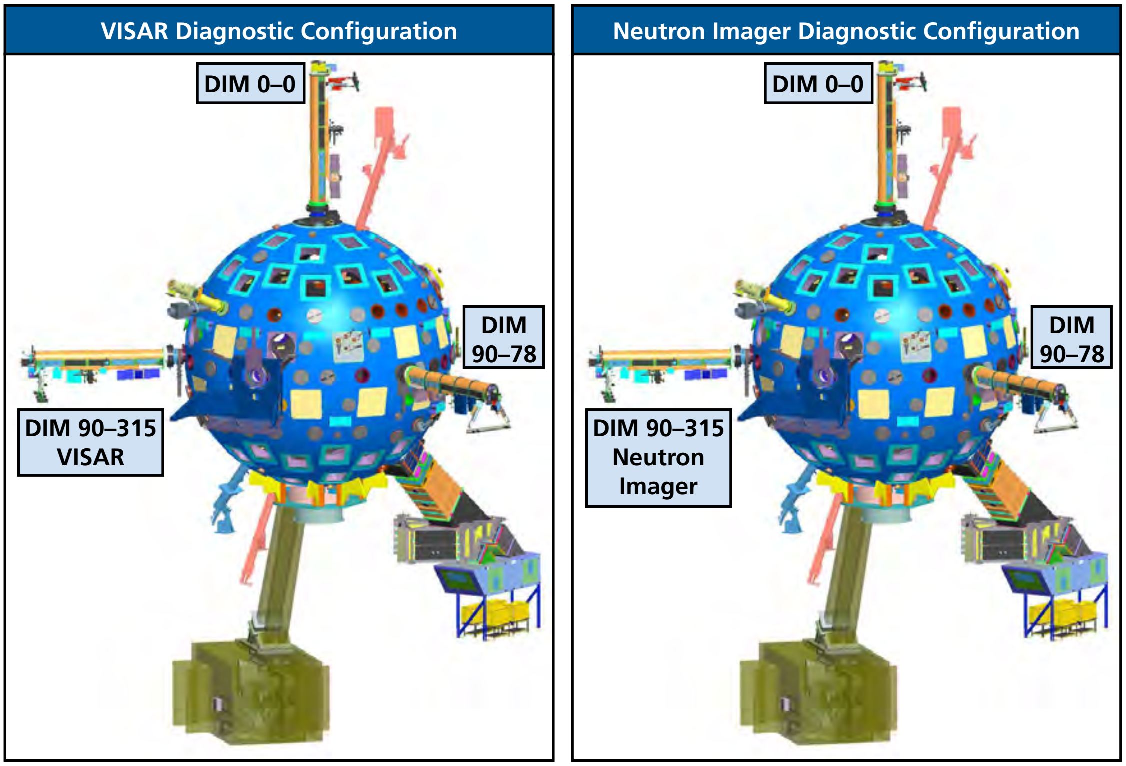
Figure 10-1: User groups such as NIC often request shots within a region in power versus energy space.

Table 10-1: Experiments requiring few or no deviations from a standard commissioned platform demand less planning and experimental development lead time.

Typical lead times prior to a NIF experiment			
Capability	**Identical to existing platform**	**Small modification to existing platform**	**New capability**
Targets	**1 – 6 months**	**6 months – 1 year**	**> 1 year**
Laser drive	**~ 1 month**	**1 – 6 months**	**> 6 months**
Diagnostics	**~ 1 – 3 months**	**3 – 6 months**	**> 6 months**
Data analysis	**Exists**	**1 – 3 months**	**> 3 months**

10.2. Diagnostic Configurations

Diagnostic configurations define the fundamental set of diagnostics used to execute one or more types of experiments. Switching between configurations typically takes several days, so the facility schedule is designed to minimize configuration changes. The EFC decides which configurations to make available each year, and FLIP defines the minimum set of configurations that meet user need and optimize facility availability.



2012-040662

Figure 10-2: Diagnostic configurations used in FY2012 on NIF. The facility aims to maximize experimental flexibility while minimizing the number of configuration changes to ensure maximum facility availability.

Currently, two primary configurations are available at NIF, both of which affect the diagnostic located in DIM 90-315:

- VISAR
- Neutron Imaging

The x-ray instrument located in DIM 90-78 might vary depending on the experiment, but this generally takes less time (roughly a day) to configure. The facility is switched between VISAR and Neutron Imaging configurations on a regular schedule.

10.3. Experimental and Facility Requirements

The first step in execution of a planned NIF experiment is completion of the standard template for planned NIF experiments. A template is provided in Appendix E. The template requests the following information:

1. **Overview:** This page includes summaries of the campaign purpose, specific deliverables, and major issues summarized at the level of a few bullets. The number of shots requested is also indicated.
2. **Experimental configuration:** A schematic drawing of the target, including any shields, backlighter targets, pinholes, is provided. Diagnostic lines of sight and critical dimensions are also indicated. Facility configuration(s) suitable for this experiment should also be provided.
3. **Laser requirements:** The table provided in the template for laser requirements should be completed. The request should include all beams—drive, backlighters, and others. Drawings of shaped pulses (power vs. time) other than square or other standard pulses should be provided. Additional pages may be used if appropriate (e.g., one page for drive beams and one page for backlighters).
4. **Diagnostic requirements:** Diagnostics requested for the experiment should be listed;

for each diagnostic, priority and type should be indicated per the table below.

Table 10-2. Diagnostic priorities and types.

Classification	Priority
1	Essential (must be on shot; delay experiment if not available)
2	Highly desirable (plan for shot, drop only if necessary to avoid loss of experiment)
3	Optional (field if available, implementation should not delay experiment)

5 **Target requirements:** If the target will be fabricated by LLNL, a drawing of the target should be provided with sufficient information for NIF Target Fabrication to assess the cost and effort required for development, production, and fielding. The drawing should include dimensions and all materials to be used; it should specifically call out the use of any hazardous materials. If the target will be fabricated at another institution, that should be stated here instead. Note that the target will still need to be metrologized at NIF and pass hazardous materials and TaLIS reviews.

6 **Other issues:** This page should describe integration and other issues specific to conduct of this experiment not covered on previous pages. Examples include:

a Assumed availability of targets, non-standard diagnostics, funding, or other items from organizations external to NIF.

b Scheduling constraints arising from considerations external to the facility.

c Personnel, support equipment, or other requirements not covered in the preceding five pages.

7 **New Diagnostics or Capabilities:** Any new capabilities or diagnostics should be described in as much detail as possible. New diagnostics should be fielded per the guidance in Section 7.3.

10.4. Roles and Responsibilities

This section describes the roles and responsibilities of key individuals involved in the experimental execution process discussed in Section 10.5.

The lead researcher (and for fundamental science experiments, the individual initiating the experimental proposal) is the **Authorizing Individual** (AI). The AI is responsible for overall formulation of the campaign and the shot plan, and oversight of the Program Review (see Section 10.5). The AI will work with the contacts shown below to develop campaign plans and monitor progress of the overall experimental program. The AI will also work with NIF management and the RI to ensure appropriate staffing of the experimental campaign.

Table 10-3. AIs by program.

Program	AI Contact for Experimental Development and Progress Monitoring
SSP (ICF and High Yield Campaign; Science Campaign; other)	Campaign management
National security applications	Sponsoring program manager
Fundamental science	PI

The **Campaign RI**, who is either the PI or liaison scientist, oversees execution of the NIF experimental campaign and is responsible for organizing progress meetings; ensures that the development of the experiment is consistent with the facility, capabilities, and schedule; develops an execution plan; provides regular updates on experimental progress to the AI; negotiates with the supporting program and NIF staff regarding capabilities and priorities as necessary to facilitate the experiment; and, if the RI is the liaison scientist, ensures experimental data is provided to the PI in a timely manner. For fundamental science and national security applications experiments, the RI will also serve as the NIF liaison scientist, the primary interface to researchers external to NIF.

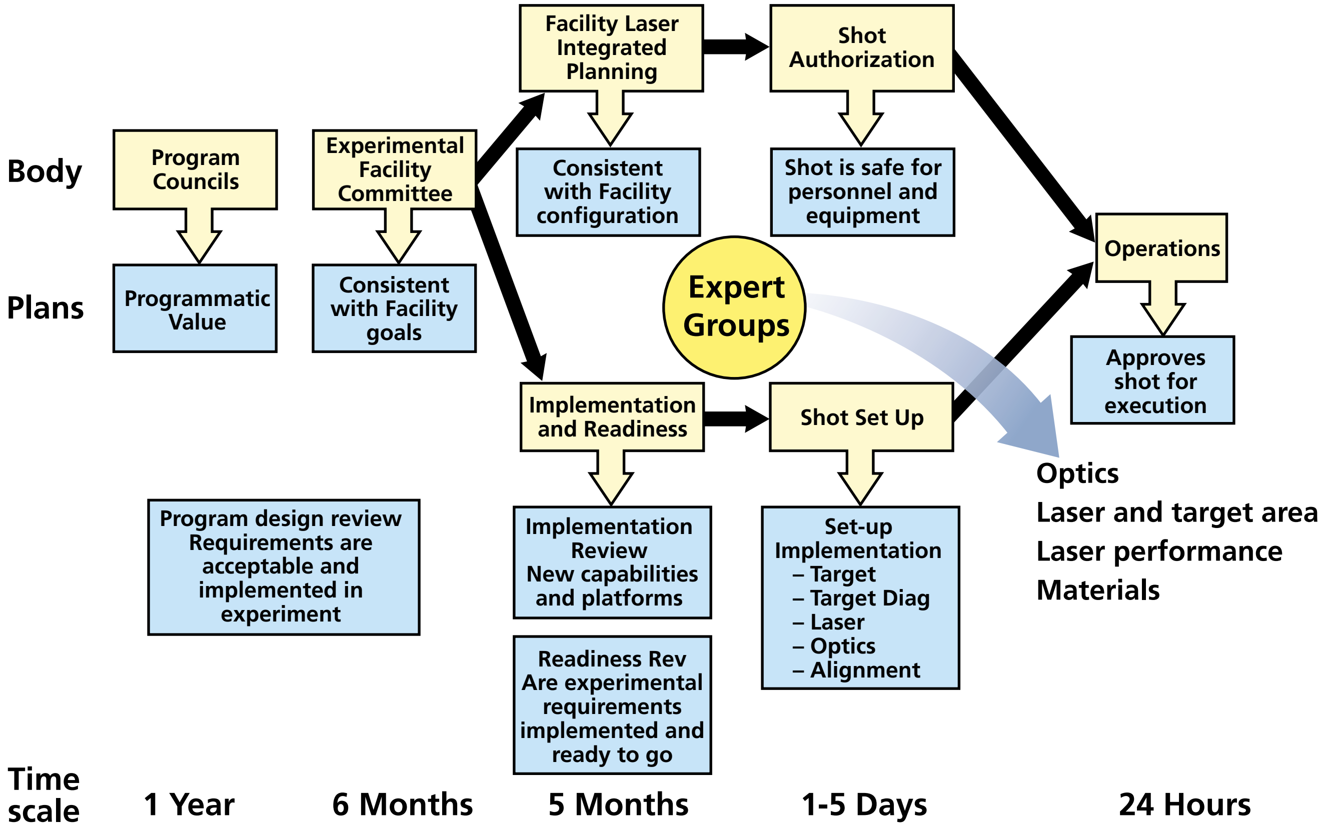


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Figure 10-3: NIF's facility allocation and shot execution process.

Each existing shot type or experimental platform will have a **Platform RI**, who is familiar with the relevant configuration/platform and provides platform expertise to the experimental team. The Campaign RI works with the relevant Platform RI. In many cases, the Campaign RI will serve as the Platform RI.

A responsible **Project Engineer** will also be designated for each experiment. For experiments using existing diagnostics, a **Diagnostic Responsible Scientist** (RS) for each applicable instrument will work with the RI. The RS is responsible for providing quality data to the RI. This includes ensuring the instrument operates as planned and acquires data. The RS will provide processed data (including calibrations and instrument responses) to the RI. Raw data will be available upon request.

The **NIF Operations Manager** (NOM) is the final approval authority for all NIF experiments.

10.5. Process

Below is a brief summary of key milestones in the NIF experiment planning and execution process. Reviews are opportunities to gauge experimental readiness and determine if the experiment needs more time to prepare. Review checklists and associated documentation are archived on the NIF server, where they are available and reviewed during subsequent reviews.

User programs develop lists of prioritized, peer-reviewed experiments. HEDSS, ICF, Fundamental Science, and National Security each have a CCB that makes decisions on shot priorities for its user community.

EFC develops facility use plan. As summarized in Section 3.0, the NIF EFC will integrate the plans from the four major user communities, as well as planned facility upgrades, maintenance and other activities, into a single recommended integrated multi-mission facility use plan for approval by the NIF Director. The EFC will also develop a sequencing of shots consistent with facility time allocations as guidance for FLIP for facility scheduling.

FLIP develops shot sequence. The FLIP committee will maintain a detailed schedule consistent with the approved facility use plan. The schedule will have one-day, one week, and one month resolution for experiments in the upcoming 3 months, 6 months, and 1 year, respectively.

Sub-FLIP develops shot plan. Sub-FLIP develops the actual shot schedule, taking the shot sequence, campaign scope, and facility needs into account. Attendance is required by Campaign RI or designee at the relevant sub-FLIP meeting.

Experiments go through review and preparation for execution. All experiments will proceed through the review process described in Section 10.5.1.

Experiment approved for execution following Readiness Meeting. Following successful completion of the Readiness Meeting, and input of all necessary setup parameters to the CMT, the experiment will be approved for execution by the NOM.

Shot is executed. The RI will also provide a pre-shot briefing to the Shot Director, and the NIF Operations staff will ensure all setup sheets are approved. The RI also attends the CCB5 meeting the morning of the experiment. NIF Operations staff performs the shot briefing and begins the shot countdown. The shot is performed.

Post-experiment operations review occurs. The day after the experiment, an operations-relevant review is performed to address any issues that arose with the laser or diagnostics during the experiment.

Campaign RI leads post-campaign review for the experiment. This involves a post-shot summary debriefing and data analysis report, as well as lessons learned. This includes a review or discussion of the data with the Diagnostic RSs.

10.5.1. Experimental Review Process

Program Review: The Program Review is led by the AI and is typically conducted approximately six months to one year in advance of the start of the experimental campaign. The primary purpose of the review is to ensure the proposed target design, and associated campaign and experimental plan, will meet the designated scientific and programmatic objectives. This review may occur more than once as dictated by the needs and progress of the campaign. The sponsoring program determines the agenda for the Program Review.

Sub-Campaign Review: This review is performed *only* for campaigns that are using preexisting capabilities, diagnostics, and platforms. The goal of the review is to identify any major issues that preclude this specific shot sequence in this time frame. The following questions are typically asked, and answered, at the Sub-Campaign Review:

- Is there a clearly defined sequence of shots and a clearly defined goal?
- Are the high-level requirements such as pulse, energy, diagnostics, and targets defined and can they be expected to be achieved?
- Have any new diagnostics or capabilities been identified so that a separate evaluation can be scheduled?
- Have possible physics failures been considered and backup targets and diagnostics identified? What is the backup plan?

Implementation Review: The Implementation Review is led by internal senior NIF staff familiar with the planned experiment and associated facility issues. The review includes members of the NIF expert groups, FLIP, and key members of the proposal team, and examines all aspects of the detailed plan for experimental execution. This review should occur roughly four months before the experiment; the timing of this review depends on the capability and development needs.

Representatives from each of the NIF expert groups attend this review. Prior to the Implementation Review, the RI should work with the NIF expert groups (see Section 10.5.2) to identify and resolve issues associated with execution of the experiment. This includes consideration of target debris, unconverted light, target manufacturability, laser and user optic specifications, and the like.

In preparation for the Implementation Review, targets with significant engineering issues may require a separate formal engineering design review. This should be arranged by the RI and the NIF target fabrication organization.

The following questions are typically asked at the Implementation Review. Additional topics may be discussed depending on experimental scope.

- Does each experiment have clear quantitative goals and deliverables with error bars?
- Are the shot simulations applicable to actual conditions? Are the simulations consistent with the actual target and backup to be used, or is there an empirical set of expectations from previous experiments?
- Has a logical shot strategy/decision tree of probable outcomes been established? Is it implementable and in line with program goals?
- Have possible physics failures been considered and backup targets and diagnostics identified? What is the backup plan?
- Has there been due diligence in examining results from prior experiments?
- Will the diagnostic(s) be able to measure with the accuracy needed?
- Are there diagnostic signal predictions for key diagnostics or prior measurements for comparison?
- Is the pulse wavelength specified?
- Is the pulse shape specified and can it be delivered?
- Are diagnostics proven or are test shots reasonably expected? Is the diagnostic calibration adequate? Is diagnostic damage expected to be an issue? Are there any drawings for new diagnostic configurations?
- Are there new capabilities, components, or specifications required for the experiment?
- What is the data analysis plan, who will perform the analysis, and what is the timeline?
- Will the experiments meet the goals as presented?

Readiness Meeting: This meeting, led by senior NIF staff, occurs approximately one month prior to the date of the experiment and is the final check to ensure that all preparations for execution of the experiment are complete. All specifications for setup of laser, diagnostics, and user optics are finalized at this time.

The following topics, at a minimum, are discussed at the Readiness Meeting. Additional topics may be discussed depending on experimental scope.

- Objectives of the experiment
- Changes to planned shot setup
- Laser pulse specifications (energy, shape, and wavelength)
- Expert group review status (particularly BLIP and TaLIS)
- “Rules of engagement” for laser beams, diagnostics, and target handling system (avoidance of interferences and other issues)
- User optic requirements (CPPs, etc.)
- Beam alignment and pointing plan
- Diagnostic (and diagnostic attachment) participation/priorities
- Approval status of diagnostic setups
- Diagnostic timing
- DIM alignment plan
- Target selection (including backup) and availability
- Target alignment plan/tolerances
- Staffing plan—ensure required experimental and facility support staff are present during entire anticipated time period for shot execution
- CMT status
- Data analysis timeline
- Post-shot data recovery plan (including when time-sensitive items [NADs, RAGS, etc.] need to be removed from the target chamber)
- Responsibility for and scheduling of the post-shot report
- Expected yield (or minimum required, if applicable)

10.5.2. NIF Expert Groups

NIF has a number of expert groups that are consulted throughout the shot preparation and execution process. The expert groups formally review experiments at the Implementation Review. Formal expert group approval is obtained via the WAP checklist process. As discussed above, it is most important that the expert groups be consulted well in advance of the Implementation Review.

Beamline and Laser Integrated Performance (BLIP): BLIP works with the RI to set final laser and user optic specifications for each experiment. This groups coordinates with the NIF Optics Loop (NOL) as needed.

Beryllium/Uranium/Tritium/Yield (BUTrY): BUTrY provides guidance and resolution on ES&H issues related to the use of beryllium and radiological safety. The working group assists in the characterization and understanding of hazards and advises whether the issue falls within safety and environmental limitations. After receiving a request to review a new operation or potential hazard, the BUTrY working group chairperson normally conducts a preliminary review using a hazards checklist. Based on the hazards checklist or other pertinent information (or lack thereof), the BUTrY chairperson may contact specific BUTrY subject matter experts or may convene the full working group to evaluate the potential impact. BUTrY advises the respective authorizing individual (often the NIF Operations Manager) or manager of its concurrence or concerns with the deployment of the new hardware, new experiment, or other new or modified activity. The group may recommend controls or alternate approaches.

Cleanliness and Materials: The NIF Operational Cleanliness Group is responsible for implementing the cleanliness and materials policies adopted by the Cleanliness Steering Committee and makes day-to-day decisions regarding materials acceptability and cleanliness. NIF Operational Cleanliness personnel conduct evaluations of materials and cleaning that are required as part of the materials review and approval process and also provide oversight of cleanrooms, cleaning vendors, and facilities in which clean assembly of equipment is perforemed to ensure compliance with NIF cleanliness protocols. In this capacity, the group leader for NIF Operational Cleanliness works directly with the RIs for systems and assemblies proposed for use on NIF to ensure the completeness of materials assessments and to arrange for any testing that may be required. The chairman of the Cleanliness Steering Committee must approve WAPs before any new equipment can be installed on NIF. The chariman is also a memeber of TaLIS and in this capacity approves all target assemblies for materials and cleanliness.

Material Review Board: This group determies if an LLNL/GA-fabricated target that does not meet specification should still be shot, if the specification was reasonable, and whether the experiment can be performed as planned.

NIF Optics Loop (NOL): NOL provides expert assessment of NIF campaign cost and feasibility with regards to final optics use and the required capacity for supporting optics loop infrastructure. The group provides estimates of final optics exchange metrics for assessing suitability of campaigns for inclusion in FLIP schedule; generates the campaign final optics exchange plan, inspection plan, and blocker plan for review during the campaign WAP process; reviews the exchange, inspection, and blocker plans and schedules to provide loop process and facility impact assessments; reports resource and schedule issues; and provides WAP approval for exchange, inspection, and blocker plans. In addition, NOL supports the decision-making required for day-to-day operation of the NIF optics loop.

Safety & Performance Review Board (S&PRB): S&PRB is a senior management review committee of experienced subject matter experts who identify the potential of introducing significant new environmental, safety, and health risks to NIF and recommend the level of review required based on the level of risk associated with the proposed work activity or operation. Experimentalists involved in the development of new diagnostics will work with the S&PRB (see Section 7.3).

Target and Laser Interaction Sphere (TaLIS): The TaLIS working group considers all issues relevant to the target chamber and target area. TaLIS provides expert group review, evaluation, and recommendations on issues in the

NIF target chamber, including experimental campaign planning and shot setup reviews and online commissioning activities, including:

- Experimental configuration of diagnostics, targets, and beams (including chamber interferences)
- Target, diagnostic, and beam alignment and readiness
- Laser–plasma interaction and backscatter source estimation
- Unconverted light interaction with targets, diagnostics, chamber and laser
- Target debris and shrapnel effects on target, diagnostics, chamber, and debris shields

The group also reviews processes for safe and effective operations in NIF target chamber and participates in target area design reviews. The TaLIS model-based expert analysis is a critical aspect of shot planning.

10.6. Shot Rate

The NIF facility is run with the goals of maximizing availability, reliability, and experimental shot time while operating safely and efficiently. While NIF aims for an eight-hour shot cycle for shots on target, the time between shots may be shortened in situations where the shots use independent bundles of beams or lengthened depending on the complexity of the experimental setup and ay possible activation due to tritium usage.

Most target shots still occur on off-hours due to competing activities on the day shift (commissioning, diagnostic reconfiguration, optics exchanges, facility maintenance, engineering support, etc.). Approximately 150 personnel involved with shot execution and direct preparation (target diagnostic preparation/recovery) and facility/utility operations are on 24/7 shifts.

Most maintenance is scheduled to fit in routinely around shots (such as routine diagnostic/optics exchanges, calibrations, and simple preventive/corrective maintenance tasks). Maintenance periods are scheduled monthly (for major LRU exchanges or major software releases, for example) or a few times a year (for target chamber entry or major utility maintenance, for example), depending on the complexity and urgency of the task.

In 2011/2012, an aggressive shot rate enhancement project was initiated to shorten the time between shots as part of an effort to increase shot rate. Shot rate complexity and the proportion of target shots are also steadily increasing. To facilitate a faster operations tempo while preserving facility reliability and availability, reliability-centered maintenance strategies have been implemented to increase efficiency and anticipate problems before they occur.

11. Performance Metrics

On an annual basis, the NIF Director will assess facility performance using published metrics. This evaluation will be made available to the user community.

11.1. Accumulation, Analysis, and Reporting of Performance Metrics

Beginning in 2013, the following metrics will be used in evaluating the performance of NIF as a user facility:

1. Compliance with environment, safety, and health regulations
2. Facility availability for experiments compared to use plan, using data collected during facility operations
3. Experimental effectiveness as measured by completion of planned user campaigns in a fiscal year and feedback from lead investigators
4. User feedback with the proposal solicitation and review processes, NIF management decisions, and experiment execution, including comments received from post-experiment observations or from directorate review reports
5. Degree of recognition obtained, including papers published and talks presented (with impact assessments) and number of meetings and workshops with NIF and NIF participants, including those in both technical and leadership roles and degree of student and postdoctoral involvement, including number of Ph.D. and M.A./M.S. degrees awarded and undergraduate theses completed based on NIF work

The NIF Operations Manager will accumulate these performance metrics, analyze facility availability and experimental effectiveness, and prepare a monthly summary of metrics that will be presented to the EFC on a quarterly basis. The NIF User Office will prepare an annual report on NIF performance for distribution to NNSA, other major NIF stakeholders, and the user community.

11.2. Review of Performance Metrics and Operation of NIF as a User Facility

Annually, NNSA and LLNL will assess performance of the operation of the NIF as a user facility using established LLNS contract performance evaluation processes. The evaluation process will include a review by the NIF DRC that reports to the LLNL Director. These reviews will include consideration of the user facility metrics. NNSA will perform periodic external reviews of operation of NIF as a user facility in a manner similar to DOE Office of Science user facilities.

11.3. Customer Feedback

An electronic customer feedback survey for NIF users is available via the NIF website (**https://lasers.llnl.gov/for_users/**). NIF will collect and use customer feedback to help determine how best to enhance and expand user facility services.

12. References

1 Class Waiver for Non-Proprietary Users, DOE Waiver W(C)-2008-003.

2 Class Waiver for Proprietary Users, DOE Waiver W(C)-2008-005.

3 NIF Governance Plan, NIF-0115829.

4 *Final Site-wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement,* DOE/EIS-0348, DOE/EIS-0236-S3, March 2005.

5 *Supplement Analysis of the 2005 Final Site-wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory,* DOE/EIS-0348-SA3, August 2011.

6 *NIF Safety Basis Document*, NIF-5019666.

7 *Facility Safety Plan*, NIF-5019665.

8 Operational Safety Plan 581.11, *NIF Laser System Installation, Commissioning, and Operation*, NIF-5017298.

9 *NIF CIS Radiological Inventory Management System*, NIF-5030388.

10 J. Verbeke et al., "Planning Tools for Estimating Radiation Exposure at the National Ignition Facility," *Fusion Science and Technology* **60**, 595 (2011).

11 C.A. Haynam, "The National Ignition Facility 2007 Laser Performance Status," *J. Phys.: Conf. Ser.* **112** 032004 (2008).

12 C. Bibeau et al., "Generating powerful ultraviolet beams with the world's largest laser," *Laser Focus World* **42** (6) 113 (2006).

13 P. Michel et al., "A three wavelength scheme to optimize hohlraum coupling on the National Ignition Facility," *Physical Review E* **83** 046409 (2011), available at: **https://e-reports-ext.llnl.gov/pdf/460646.pdf.**

14 C. Gibson et al., "Design of the NIF Cryogenic Target System," *Fusion Science & Technology* **55** 233 (2009), available at: **https://e-reports-ext.llnl.gov/pdf/362262.pdf.**

15 D.H. Kalantar et al., "An overview of target diagnostic alignment at the National Ignition Facility," in T*arget Diagnostics Physics and Engineering for Inertial Confinement Fusion, SPIE Conf. 8505 Proc.,* August 2012.

16 P. Di Nicola et al., "Beam and target alignment at the National Ignition Facility using the Target Alignment Sensor (TAS)," in T*arget Diagnostics Physics and Engineering for Inertial Confinement Fusion, SPIE Conf. 8505 Proc.,* August 2012.

17 *Component Specifications for Fiducial Generation and Distribution Subsystem*, NIF-5002565.

18 *NIF Fiducial System Architecture*, NIF-5003450.

19 D.C. Wilson et al., "Diagnosing ignition with DT reaction history," *Rev. Sci. Instrum.* **79**, 10E525 (2008).

20 A.M. McEvoy et al., "Gamma bang time analysis at OMEGA," *Rev. Sci. Instrum.* **81**, 10D322 (2010).

21 N.M. Hoffman et al., "Using gamma-ray emission to measure areal density of inertial confinement fusion capsules," *Rev. Sci. Instrum.* **81**, 10D332 (2010).

22 H.W. Herrmann et al., "Diagnosing inertial confinement fusion gamma ray physics," *Rev. Sci. Instrum.* **81**, 10D333 (2010).

23 D.B. Sayre et al., "Multi-shot analysis of the gamma reaction history diagnostic," *Rev. Sci. Instrum.* **83**, 10D905 (2012).

24 J.A. Frenje et al., "Probing high areal-density cryogenic deuterium-tritium implosions using downscattered neutron spectra measured by the magnetic recoil spectrometer," *Physics of Plasmas* **17**, 056311 (2010).

25 D.T. Casey et al., "The coincidence counting technique for orders of magnitude background reduction in data obtained with the magnetic recoil spectrometer at OMEGA and the NIF," *Rev. Sci. Instrum.* **82**, 073502 (2011).

26 D.T. Casey et al., "Measuring the absolute deuterium–tritium neutron yield using the magnetic recoil spectrometer at OMEGA and the NIF," *Rev. Sci. Instrum.* **83**, 10D912 (2012).

27 M. Gatu Johnson et al., "Neutron spectrometry—An essential tool for diagnosing implosions at the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10D308 (2012).

28 P.M. Bell et al., "Radiation hardening of gated x-ray imagers for the National Ignition Facility," *Rev. Sci. Instrum.* **81**, 10E540 (2010).

29 O. Landoas et al., "Absolute calibration method for laser megajoule neutron yield measurement by activation diagnostics," *Rev. Sci. Instrum.* **82**, 073501 (2011).

30 D.L. Bleuel et al., "Neutron activation diagnostics at the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10D313 (2012).

31 G.P. Grim et al., "A spatially resolved ion temperature diagnostic for the National Ignition Facility," *Rev. Sci. Instrum.* **79**, 10E537 (2008).

32 E.N. Loomis et al., "Progress toward the development and testing of source reconstruction methods for NIF neutron imaging," *Rev. Sci. Instrum.* **81**, 10D311 (2010).

33 V. Yu et al., "The National Ignition Facility neutron time-of-flight system and its initial performance," *Rev. Sci. Instrum.* **81**, 10D325 (2010).

34 R.A. Lerche et al., "National Ignition Facility neutron time-of-flight measurements," *Rev. Sci. Instrum.* **81**, 10D319 (2010).

35 G.P. Grim et al., "Prompt radiochemistry at the National Ignition Facility," *Rev. Sci. Instrum.* **79**, 10E503 (2008).

36 M.A. Stoyer et al., "Collection of solid and gaseous samples to diagnose inertial confinement fusion implosions," *Rev. Sci. Instrum.* **83**, 023505 (2012).

37 S.L. Nelson et al., "RAGS: The Gaseous Sample Collection Diagnostic at the National Ignition Facility," *IEEE Transactions on Plasma Science* **39** (8) (2011).

38 J.D. Moody et al., "Backscatter measurements for NIF ignition targets," *Rev. Sci. Instrum.* **81**, 10D921 (2010).

39 R.M. Malone et al, "Overview of the line-imaging VISAR diagnostic at the National Ignition Facility," *Proc. SPIE* **6342** (2007).

40 V. Smalyuk et al., "X-ray imaging in an environment with high-neutron background on National Ignition Facility *Proc. SPIE* **8144**, 81440N (2011).

41 J.L. Kline et al., "The first measurements of soft x-ray flux from ignition-scale hohlraums at the National Ignition Facility using DANTE," *Rev. Sci. Instrum.* **81**, 10E321 (2010).

42 J.R. Kimbrough et al., "Standard design for National Ignition Facility x-ray streak and framing cameras," *Rev. Sci. Instrum.* **81**, 10E530 (2010).

43 D.G. Hicks et al., "Streaked radiography measurements of convergent ablator performance," *Rev. Sci. Instrum.* **81**, 10E304 (2010).

44 Y.P. Opachich et al., "X-ray streak camera cathode development and timing accuracy of the 4ωultraviolet fiducial system at the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10E123 (2012).

45 T.J. Hilsabeck et al., "Pulse-dilation enhanced gated optical imager with 5 ps resolution," *Rev. Sci. Instrum.* **81**, 10E317 (2010).

46 S.R. Nagel et al., "Dilation x-ray imager a new/faster gated x-ray imager for the NIF," *Rev. Sci. Instrum.* **83**, 10E116 (2012).

47 E.L. Dewald et al., "Hot electron measurements in ignition relevant hohlraums on the National Ignition Facility," *Rev. Sci. Instrum.* **81**, 10D938 (2010).

48 J. Park et al., "Calibration of a flat field soft x-ray grating spectrometer for laser produced plasmas," *Rev. Sci. Instrum.* **81**, 10E319 (2010).

49 G.A. Kyrala et al., "Measuring symmetry of implosions in cryogenic hohlraums at the NIF using gated x-ray detectors," *Rev. Sci. Instrum.* **81**, 10E316 (2010).

50 A. Pak et al., "Diagnosing radiative shocks from deuterium and tritium implosions on NIF," *Rev. Sci. Instrum.* **83**, 10E507 (2012).

51 T. Ma et al., " Imaging of high-energy x-ray emission from cryogenic thermonuclear fuel implosions on the NIF," *Rev. Sci. Instrum.* 83, 10E115 (2012).

52 TS.P. Vernon et al., "X-ray bang-time and fusion reaction history at picosecond resolution using RadOptic detection," *Rev. Sci. Instrum.* **83**, 10D307 (2012).

53 D.H. Edgell et al., "South pole bang-time diagnostic on the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10E119 (2012).

54 S.F. Khan et al., "Measuring x-ray burn history with the Streaked Polar Instrumentation for Diagnosing Energetic Radiation (SPIDER) at the National Ignition Facility," *Proc. SPIE* 8505 (2012).

55 M.B. Schneider et al., "Images of the laser entrance hole from the static x-ray imager at NIF," *Rev. Sci. Instrum.* **81**, 10E538 (2010).

56 M.B. Schneider et al., "Soft x-ray images of the laser entrance hole of ignition hohlraums," *Rev. Sci. Instrum.* **83**, 10E525 (2012).

57 H. Park et al., "Characterizing high energy spectra of NIF ignition hohlraums using a differentially filtered high energy multipinhole x-ray imager," *Rev. Sci. Instrum.* **81**, 10E519 (2010).

58 H. Rinderknect et al., "A novel particle time of flight diagnostic for measurements of shock- and compression-bang times in D^3He and DT implosions at the NIF," *Rev. Sci. Instrum.* **83**, 10D902 (2012).

59 S.P. Regan et al., "Applied plasma spectroscopy: Laser-fusion experiments," *High Energy Density Physics* **5**, 234 (2009).

60 A.B. Zylstra et al., "Charged-particle spectroscopy for diagnosing shock ρR and strength in NIF implosions," *Rev. Sci. Instrum.* **83**, 10D901 (2012).

61 *Budget/Schedule Change Request Preparation*, NIF-0110251.

62 *IPRB Checkpoint Checklist*, NIF-0115853.

63 *Diagnostic Design Guidance for the National Ignition Facility*, NIF-5041482.

64 *Engineering Design Reviews*, NIF-5018587.

65 *Debris and Shrapnel Risk Management Plan*, NIF-TBD.

66 D.C. Eder et al., "Debris and Shrapnel Mitigation Procedure for NIF Experiments," *J. Physics* **112** (2008).

67 S. Azevedo et al., "Automated Experimental Data Analysis at the National Ignition Facility," presented at International Conference on Accelerators and Large Experimental Physics Control Systems, Kobe, Japan, October 13, 2009.

68 American Physical Society, "Guidelines for Professional Conduct," available at: http://www.aps.org/policy/statements/02_2.cfm.

69 Office of Science and Technology Policy, Memorandum on Scientific Integrity, Washington, D.C., December 2010.

70 National Research Council, *"On Being a Scientist—Responsible Conduct in Research,"* (National Academy Press, Washington, D.C., 1995).

71 America COMPETES Reauthorization Act, 111th Congress, H.R. 5116, Public Law 111–358, January 4, 2011, Section 103.

13. Revision Log

Rev. No.	Effective Date	ECR No.	Pages Affected	Brief Description of Revision
AA	10/1/12	n/a	All	Initial release

Appendix A: Acronyms

ACS	access control system
AI	authorizing individual
ALARA	as low as reasonably achievable
AMC	amplitude modulator chassis
ARC	advanced radiographic capability
ARIANE	active readout in a neutron environment
AWG	arbitrary waveform generator
BLIP	Beamline and Laser Integrated Performance
BUTrY	beryllium/uranium/tritium/yield
CCB	change control board
CCD	charge-coupled device
CCRS	chamber center reference system
CCXI	charge coupled x-ray imager
CMT	Campaign Management Tool
CPP	continuous phase plate
CR	Compton radiography
	contact radiography
CSF	cavity spatial filter
DD	direct drive
DDS	disposable debris shield
DIM	diagnostic instrument manipulator
DISC	DIM-insertable streak camera
DIXI	dilation imager for x-rays at ignition
DOE	Department of Energy
DRC	Directorate Review Committee
DT	deuterium–tritium
EDS	energy dispersive spectroscopy
EFC	Experimental Facilities Committee
EHXI	equatorial hard x-ray imager
EMP	electromagnetic pulse
EOS	equation of state
ES&H	environment, safety and health
FABS	full aperture backscatter station
FFLEX	filter fluorescer
FLIP	Facility and Laser Integrated Planning
FMEA	failure modes and effects analysis
FOA	final optics assembly
FWHM	full-width at half maximum
GA	General Atomics
GDS	grating debris shield
GRH	gamma reaction history
GXD	gated x-ray detector
HED	high-energy-density

HEDSS	High-energy-density stockpile science
HEMPI	high energy multipinhole imager
hGXD	hardened gated x-ray diagnostic
hGXI	hardened gated x-ray imager
HMMA	Hazardous Materials Management Area
ICCS	integrated computer control system
ICF	inertial confinement fusion
ID	indirect drive
IET	Integrated Experimental Team
ILS	injection laser system
IQ	installation qualification
ISMS	Integrated Safety Management System
ISP	input sensor package
IWS	integration work sheet
LC	Livermore Computing
LE	lead engineer
LEH	laser entrance hole
LLNL	Lawrence Livermore National Laboratory
LLNS	Lawrence Livermore National Security
LN	liquid nitrogen
LO	lead operator
LoCoS	Location Component and State
LOTO	lockout/tagout
LPOM	Laser Performance Operations Model
LRU	line-replaceable unit
LSWG	Laser Safety Working Group
LTAB	Laser and Target Area Building
MA	main amplifier
MCP	microchannel plate
MOR	master oscillator room
MRS	magnetic recoil spectrometer
NAD	neutron activation detector
NB	near backscatter
NEL	NIF Early Light
NEPA	National Environmental Policy Act
NIF	National Ignition Facility
NIF&PS	National Ignition Facility & Photon Science
NIS	neutron imager system
NITOF	neutron imager time-of-flight
NNSA	National Nuclear Security Administration
NOL	NIF Optics Loop
NOM	NIF Operations Manager
NTOF	neutron time-of-flight
OAB	Optics Assembly Building

OQ	operational qualification
OSB	Operational Support Building
OSP	operational safety plan
PA	power amplifier
PABTS	preamplifier beam transport system
PAM	preamplifier module
PDS	precision diagnostic system
PEPC	plasma-electrode Pockels cell
PHXI	polar high energy x-ray imager
PI	principal investigator
PPE	personal protective equipment
PQ	performance qualification
PS	polarization smoothing
PTOF	particle time-of-flight
RAGS	radiochemistry analysis of gaseous samples
RI	responsible individual
RMS	requirements management system
ROD-BT	rad-optic diagnostic bang time
RS	responsible scientist
S&PRB	Safety and Performance Review Board
SAVI	shot analysis, visualization, and infrastructure
SBD	safety basis document
SBS	stimulated Brillouin scattering
SD	shot director
SIS	safety interlock system
SOP	streaked optical pyrometer
SPA	Safe Plan of Action
SPBT	south pole bang time
SPIDER	streaked polar instrumentation for diagnosing energetic radiation
SRC	solid radiochemical collector
SSD	smoothing by spectral dispersion
SSP	Stockpile Stewardship Program
SXI	static x-ray imager
TaLIS	Target and Laser Interaction Sphere
TARPOS	target positioner
TAS	target alignment sensor
TAV	target area vacuum
TCC	target chamber center
TCSS	target chamber service system
THD	tritium, hydrogen, deuterium
TMP	thermal mechanical package
TPS	tritium processing system
TRC	Technical Review Committee
TSF	transport special filter
VBL	Virtual Beam Line
VISAR	velocity interferometer system for any reflector

VSP	Visiting Scientist Program
WAP	work authorization point
WFL	wedged focus lens
WRF	wedged range filter
XRF	x-ray fluorescence

Appendix B: Data Policies (Draft)

Policy on Data and Dissemination of Results for NIF Fundamental Science Experiments

I. Purpose of Policy

The NIF is a NNSA facility dedicated to support of DOE national security, energy, and fundamental science missions. NIF facility time will be allocated to fundamental science experiments based on a peer-review process similar to that used at DOE Office of Science user facilities. These experiments, involving U.S. and international researchers from academia, industry, national laboratories, and other institutions, will generate data of broad scientific interest. This data will be in a variety of forms, including information regarding the NIF, scientific data in the process of interpretation, and analyzed data ready for publication.

The purpose of this policy is twofold:

1. To ensure that NIF fundamental science data is made available in an appropriate manner to researchers involved in particular experiments, the broader scientific community, and the general public; and
2. To define data-handling responsibilities for the NIF facility and parties with access to NIF fundamental science data.

It is the policy of the NIF to encourage free and open exchange of fundamental science data. The NIF will abide by generally accepted guidelines for scientific conduct, including the right of individual scientists to publish their data results and analysis.[68,69,70,71]

The NIF Director, assisted by the NIF User Office, is responsible for implementing this policy.

II. Definitions

This policy will distinguish between facility-related data (“NIF facility data”) and data related to and from experiments (“NIF experimental data”). Appendix C contains a detailed definition of NIF facility data and NIF experimental data. All data is the property of the NNSA and is managed by this policy.

III. Policies and Roles

Principal Investigator (PI) responsibilities: The PI is the individual responsible for managing all aspects of data analysis for a given experiment, from provision of raw data to team members through final publication and data archiving. The PI will be assisted in this effort by NIF staff, particularly the NIF liaison scientist assigned to the experiment.

All fundamental science data will be assumed to be non-proprietary.

Collaboration definition and collaborator responsibilities: Immediately following approval of his/her proposed experiment, the PI shall provide the NIF User Office a list of individuals involved in the experiment and related activities. The individuals on this list, which is maintained by the PI on an ongoing basis, will be referred to as the “Collaboration” in the remainder of this document. The PI should work with the liaison scientist to determine NIF staff required for experimental execution to be included in the Collaboration.

Each Collaboration should develop a plan for managing membership, authorship of publications, designation of invited speakers, and related issues. The NIF User Office is available to assist in this effort.

Each member of the Collaboration will be expected to sign a user agreement or other appropriate LLNL documentation that will include an agreement to abide by this policy.

It is expected that the PI and members of the Collaboration will work together effectively as a team using the procedures typically followed in scientific collaborations.

Data ownership and access: All data from NIF fundamental science experiments is owned by the PI and the Collaboration. Members of the Collaboration shall have access to all NIF facility data and NIF experimental data associated with their experiment. The PI should work with the liaison scientist to ensure all members of the Collaboration have appropriate access to raw and analyzed data and, when applicable, NIF analysis capabilities. Each Collaboration will be expected to define a plan for management of their NIF experimental data within the Collaboration.

NIF facility data from each experiment will be immediately available to all NIF users.

Period of exclusive use: Members of the Collaboration have exclusive use of NIF experimental data for up to 18 months following the data production date. The period of exclusive use may be reduced when appropriate and will not apply to published data. On occasion, the period of exclusive use may be extended for certain data sets if deemed necessary to ensure the integrity of the data analysis and publication process.

Following the period of exclusive use, NIF experimental data will be available to the broader scientific community and general public upon request to the PI. For NIF experimental data, the period of exclusive use will apply only to particular information central to analysis and interpretation of experiments.

All requests for changes to the period of exclusive use should be directed to the NIF User Office.

Use of NIF experimental data by researchers external to the Collaboration: The PI may provide access to NIF experimental data from their experiment to individuals outside the Collaboration, and may delegate this authority to others in the collaboration. Any use of this data should be done using accepted guidelines of scientific conduct. Individuals outside the Collaboration receiving unpublished NIF data will need to acknowledge their intention to follow this policy and follow the LLNL review and release process for papers or presentations including NIF unpublished data.

Individuals external to the Collaboration requesting access to published NIF experimental data should contact the first author of the associated publication.

Period of exclusive use of data for developers of new diagnostics: Exclusive use of data for up to one year will be granted to developers of new NIF diagnostics to allow time for presentation and publication of results related to the development, construction, and performance of the instrument.

Disseminating results: The PI should develop a plan for presentation of the research at conferences and meetings and publication of results. The PI is responsible for ensuring that the author list for each presentation/publication is correct and that members of the Collaboration are informed of all planned presentations and publications. The PI should submit copies of all presentations and articles involving NIF facility and experimental data to the NIF User Office.

Review and release of NIF facility and experimental data: All NIF facility and experimental data published or presented outside of LLNL via presentations, conference talks, or other methods must first be approved via the NIF review and release process.

Public communication and press guidelines: The PI's home institution has the right to issue the first public communication regarding NIF results. Other members of the Collaboration may simultaneously release public information as well.
In the event the PI's home institution does not choose to issue public communications, NIF or other members of the Collaboration may choose to do so.

All press communications involving NIF data should be discussed with Collaboration members and the NIF User Office prior to release. All press releases including reference to NIF data should include an appropriate acknowledgement statement and the name of an LLNL media contact.

Theses: NIF facility and experimental data may be used in student theses prepared as a requirement for the granting of an advanced degree from a participating institution.

Conflict resolution: Conflicts that cannot be resolved by the PI may be referred to the NIF Director for resolution via the NIF User Office. The NIF Director will have final authority in all matters covered in this document.

Acknowledgements: All presentations or publications involving NIF data should include an acknowledgement[69]:

NIF facility and experimental data shown or discussed reflects work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

IV. Change Control

Proposed changes to this policy should be submitted to the NIF Director or the NIF User Office. The NIF Director is responsible for approving changes to this policy. A record of changes shall be appended to future versions of this document. NNSA and the NIF user community will be consulted regarding any significant changes to this policy.

Policy on Data and Dissemination of Results for NIF National Security Experiments

See the NIF User Office for a copy of this policy.

Appendix C: Definition of NIF Facility Data and NIF Experimental Data

1. *NIF facility data:* NIF data consists of facility information regarding NIF capabilities, facility configuration, laser and optics performance, and facility operations relevant to user experiments, including:
    - a NIF laser, diagnostics, optics, data acquisition, data analysis, and other system capabilities.
    - b NIF facility configuration, including that of laser, target diagnostics, optics, hazardous materials handling, and other subsystems as appropriate.
    - c General information supplied to all users regarding conduct of experiments at NIF and roles and responsibilities of NIF staff and the user community.
2. *NIF experimental data:* NIF experimental data includes NIF target shot information relevant to analysis of data from NIF experiments, including:
    - a Shot-specific setup information for laser, target diagnostics, target, optics, hazardous materials, and other subsystems, including pre-shot target characterization information.
    - b All raw data obtained from laser, target diagnostic, target, optics, hazardous materials handling, and other subsystems.
    - c All processed data produced by the NIF data analysis system, including calibration data and analysis software.
    - d Interim data analysis products produced by scientists in the course of analysis of NIF data.
    - e NIF analyzed data suitable for publication. This is generally the most accurate value of a particular measurement from a particular diagnostic that can be generated by applying the latest calibration parameters and analysis algorithms developed by diagnostic specialists.
    - f NIF data published in peer-reviewed journals.
3. *Information not covered under this policy:* NIF facility data and NIF experimental data do not include:
    - a All information regarding management of NNSA and other user programs at the NIF, including details of NIF operational budgets.
    - b All information from pre- and post-experiment radiation hydrodynamic simulation of NIF experiments by LLNL or other staff, except as appearing in presentations or publications involving comparison of data with experiments.
    - c Private, individual-specific analysis not required for analysis, presentation, or publications involving NIF data.

Appendix D: Experimental Platforms

Below is a listing of NIF experimental platforms. For the most current platform list, see the Users section of the lasers website: https://lasers.llnl.gov/for_users/experimental_capabilities/index.php
Capsule Implosion and Inertial Fusion Platforms

Name	Purpose	Principal Diagnostics
DT Implosion	High performance ICF implosion with 50/50 DT fuel mix.	hGXI, NIS, NTOF
Symmetry Capsule (SymCap)	Drive energetics and hohlraum symmetry (polar and azimuthal) and DD yield, ion temperature	GXD and HGXI with pinholes, Dante, FABS/NBI, NTOF, WRF, SPBT, SPIDER, SXI
Convergent Ablator (ConA)	Backlit trajectory of symmetry capsule and measure velocity and in-flight density profile	GXD or DISC with slit, NTOF, WRF
Convergent Ablator (ConA) THD[1] Implsoion	Backlit trajectory of THD ablator, velocity and in-flight density profile	hGXI or DISC with slit
Convergent Ablator (2D Radiography)	Backlit trajectory of symmetry capsule and measure velocity and in-flight density profile (2D image)	hGXD with pinholes
Exploding Pusher (Direct Drive)	Low density, low convergence implosion for neutron production. Used to calibrate nuclear diagnostics.	NTOF, NAD, MRS
Exploding Pusher (Indirect Drive)	Low density, low convergence implosion for neutron production. Used to calibrate nuclear diagnostics through uniform low ρr shell	NTOF, NADs
Mix Capsule	Backlit symmetry capsule to check hydrodynamic instability growth	GXD with pinhole
NTOF and GRH Timing	Timing of nuclear diagnostics with hard x-ray source	NTOF, GRH
1D Convergent Hydrodynamics	Various platforms to study 1D hydrodynamics of capsule implosions (versions of reemission ball, shock timing, and symmetry capsule)	See reemission ball, shock timing, and symmetry capsule
Reemission Ball	Measure symmetry of drive in the initial portion of ICF implosion in polar and azimuthal directions	GXD with pinholes, soft filter
Shock Timing	Measures strength and timing of shocks in ICF implosions	VISAR
Shock Timing	Measures strength and timing of final (4th) shock in ICF implosions	VISAR/SOP
THD Compton Radiography	Used for high energy x-ray backlighting of ICF implosions to measure cold fuel symmetry and uniformity	hGXD
THD2 Implosion	High performance ICF implosion using mix of deuterium, tritium, and hydrogen for dudded yield. Typically measure capsule performance and implosion symmetry.	hGXI, NTOF
THDREI	Backlight DT fuel trajectory and in-flight thickness	DISC
X-ray Diagnostic Flatfield Testing	Characterize flatfield behavior of gated x-ray detectors	GXD, hGXI
X-ray Diagnostic Timing	Characterize timing of x-ray gated and streaked detectors	GXD, hGXI, DISC

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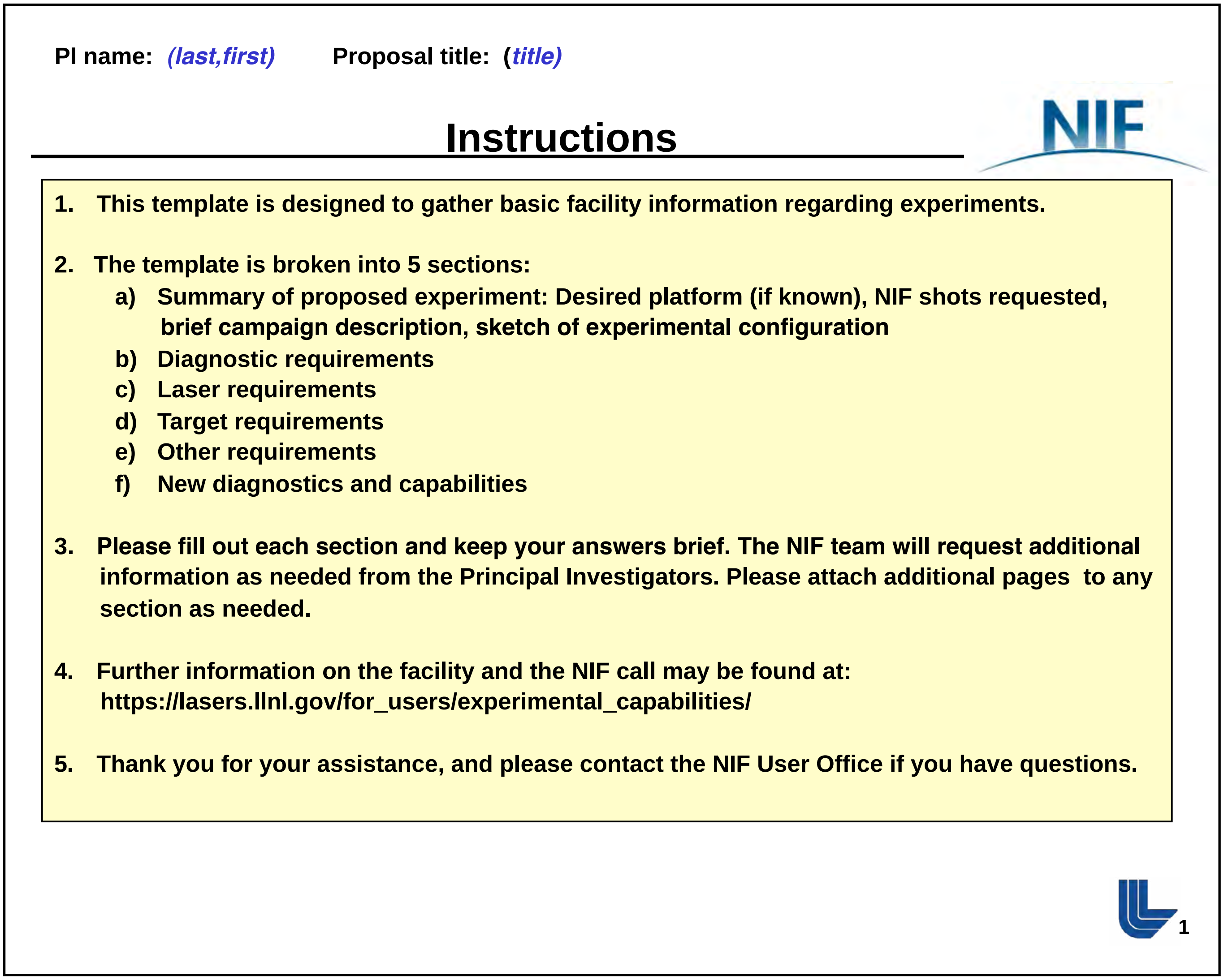
[1] *THD = tritium, hydrogen, and deuterium*

Selected Other Platforms

See the Users section of the lasers website or contact the NIF User Office for a full listing of platforms.

Name	Purpose	Principal Diagnostics
Ablative Rayleigh–Taylor	Measure growth of Rayleigh–Taylor hydrodynamic instabilities in the far nonlinear regime using indirect drive	hGXI/hGXD: measure side-on and face-on evolution of instability growth in rippled foils
Collisionless shock	Examine plasma produced by two separate colliding foil plasmas for evidence of magnetic field generation and collisionless shock formation. Use D3He capsule for proton radiography.	MACS: measure x-ray from one of two planar foils HEIDI: measure time-dependent x-rays from interpenetrating foil plasmas hGXI: measure x-ray from other planar foil Various neutron detectors
Crystal Ball	Study the ablation pressure imparted on a spherical capsule by measuring the shock velocity in a known material, quartz	VISAR, Dante1
Diffraction	Measure crystal and material structure and EOS for ramp-compressed materials (anticipated availability: FY2014)	VISAR: measure shock speed and sample compression TARDIS (target diffraction in situ): measure diffracted x-ray signal from materials
EOS	Explore the nature of solids at above a few Mbar by compressing the material using a ramped laser pulse	VISAR, Dante1 and 2, GXD, SXI, FABS/NBI, FFLEX
Gigabar EOS	Measure EOS of materials at gigabar pressures using implosion geometry	DISC: used to radiograph implosion and infer density profile MACS: x-ray spectrometer used for x-ray Thompson scattering
Material strength drive	Compress a material sample and produce Rayleigh–Taylor instability at the rippled interface between two materials to examine material deformation	VISAR, Dante, x-ray backlighter
Polar Direct Drive	Platforms examining direct drive implosions using NIF beams in an indirect drive geometry	Various
Supernova Hydrodynamics—Rayleigh–Taylor Instability	Measure evolution of Rayleigh–Taylor instability growth in indirectly driven rippled targets	HEIDI: high-energy x-ray imaging Dante1: x-ray drive
Viewfactor	Study the hohlraum drive as seen by the capsule using a large LEH and thin capsule	Dante1 and 2, FABS/NBI, SXI, spectral and time-resolved camera
X-ray Sources	Use gas pipes, coated cavities, and halfraums to generate intense x-ray sources in the ~5 keV region	GXD or hGXI with spectrometer snout, GXD or hGXI with imaging pinholes, FABS/NBI, FFLEX, EXHI, DANTE, EMP, SXI

Appendix E: NIF Facility Proposal Form



PI name: *(last,first)* **Proposal title:** *(title)*

Instructions

1. This template is designed to gather basic facility information regarding experiments.

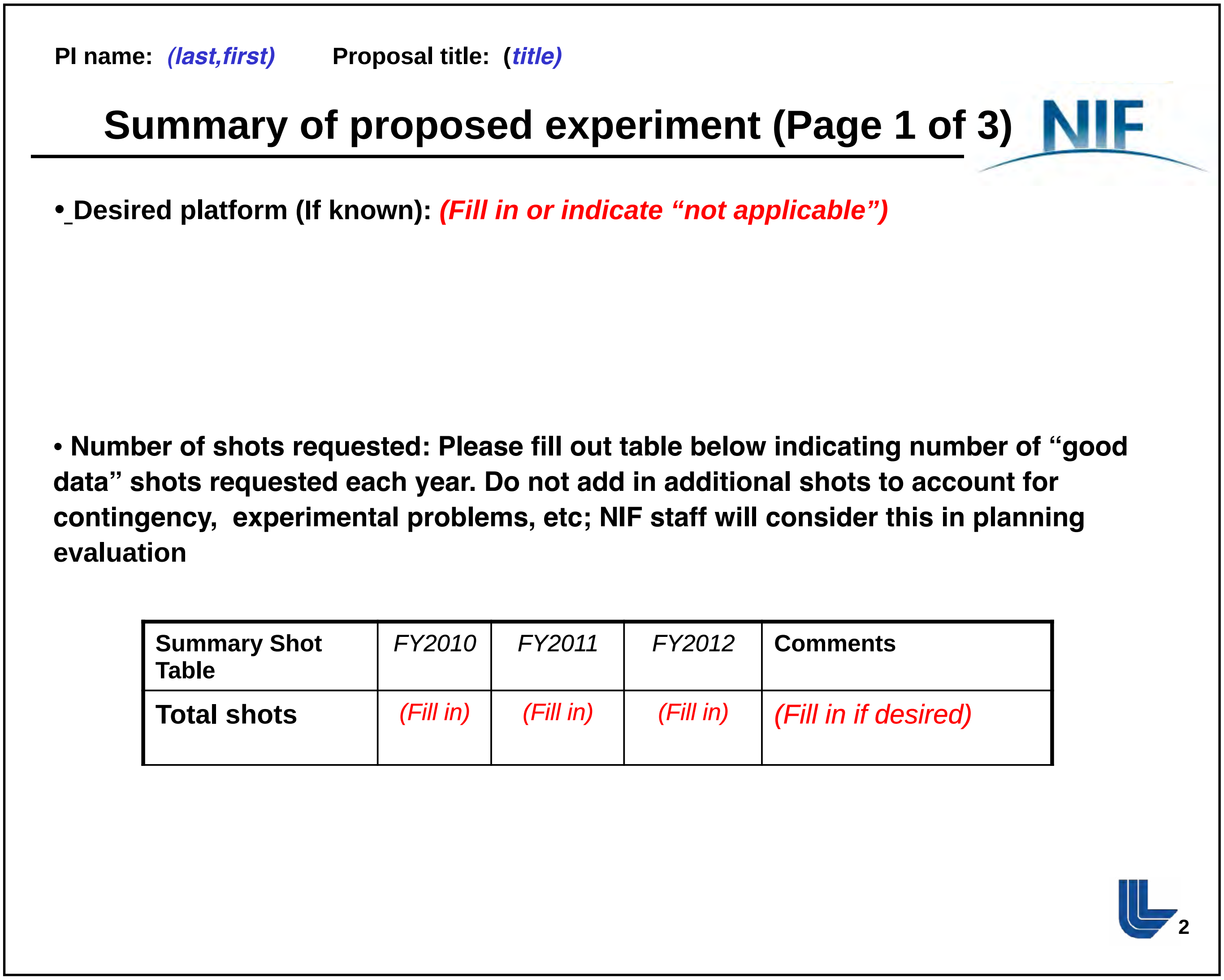
2. The template is broken into 5 sections:
    a) Summary of proposed experiment: Desired platform (if known), NIF shots requested, brief campaign description, sketch of experimental configuration
    b) Diagnostic requirements
    c) Laser requirements
    d) Target requirements
    e) Other requirements
    f) New diagnostics and capabilities

3. Please fill out each section and keep your answers brief. The NIF team will request additional information as needed from the Principal Investigators. Please attach additional pages to any section as needed.

4. Further information on the facility and the NIF call may be found at: https://lasers.llnl.gov/for_users/experimental_capabilities/

5. Thank you for your assistance, and please contact the NIF User Office if you have questions.

1



PI name: *(last,first)* **Proposal title:** *(title)*

Summary of proposed experiment (Page 1 of 3)

- **Desired platform (If known):** ***(Fill in or indicate "not applicable")***

- **Number of shots requested: Please fill out table below indicating number of "good data" shots requested each year. Do not add in additional shots to account for contingency, experimental problems, etc; NIF staff will consider this in planning evaluation**

Summary Shot Table	*FY2010*	*FY2011*	*FY2012*	**Comments**
Total shots	*(Fill in)*	*(Fill in)*	*(Fill in)*	*(Fill in if desired)*

PI name: *(last,first)* **Proposal title:** (*title)*

Summary of proposed experiment (Page 2 of 3)

- **Brief campaign description (include summary of preparatory shots [drive, diagnostic development, other] and actual data acquisition shots):**

PI name: *(last,first)* **Proposal title:** **(***title)*

Summary of proposed experiment (Page 3 of 3)

- **Sketch of experimental configuration: PIs, provide a simple sketch of the experimental configuration below. Include orientation of target, laser and any backlighter beams, diagnostic sightlines, etc. If configuration is identical to an existing platform so indicate. For further information on existing platforms and chamber geometry see the NIF website: https://lasers.llnl.gov/for_users/experimental_capabilities/index.php**

PI name: *(last,first)* **Proposal title:** *(title)*

Diagnostic requirements

- Please refer to the diagnostic list on NIF user website:
  https://lasers.llnl.gov/for_users/experimental_capabilities/diagnostics.php
- List below NIF diagnostics required for your experiment (along with a short summary description of required spatial, temporal, and spectral resolution) *or* describe what you wish to observe, and NIF staff will match to available diagnostics.
- Also indicate below if any additional user-provided diagnostics are required. Provide a short summary of the user provided diagnostic below, including a list of all materials to be introduced into the target chamber.

PI name: *(last,first)* **Proposal title:** (*title)*

Laser requirements (1 of 2)

Laser Parameter	Value
1) Platform to be used	*Specify name or indicate "not applicable"*
2) Number of beams required	*Fill in*
3) 3ω energy desired per beam (Maximum allowed: 3 kJ (2nsec square); for pulses other than 2nsec square provide plot of desired power vs. time on next page. NIF User Office will inform users if energy requirements exceed allowable.)	*Fill in*
4) Peak power per beam (350 TW maximum total peak power for shaped, ignition-like pulses)	*Fill in*
5) Pulse shape (up to 20 neck duration) (Options: Square, impulse (88 psec), or shaped; provide plot of desired power vs. time for shaped pulse on next page)	*Fill in*
6) SSD bandwidth (options—45 to 90 GHz, 45 GHz default)	*45 GHz (modify if desired)*
7) Focal spot size (~250 µm [unconditioned] or ~1 mm [conditioned])	*Indicate 250-µm or 1-mm*
9) Delays between beams (up to 10 nsec—all pulses in a quad must have same delay)	*Specify if desired*
10) Backlighter beam energy, pulse duration	*Specify if desired*
11) Other specifications	*Specify if desired*

6

PI name: *(last,first)* **Proposal title:** (*title)*

Laser requirements (2 of 2)

For shaped pulses, sketch desired power vs. time below:

PI name: *(last,first)* **Proposal title:** (*title)*

Target requirements (1 page per target type)

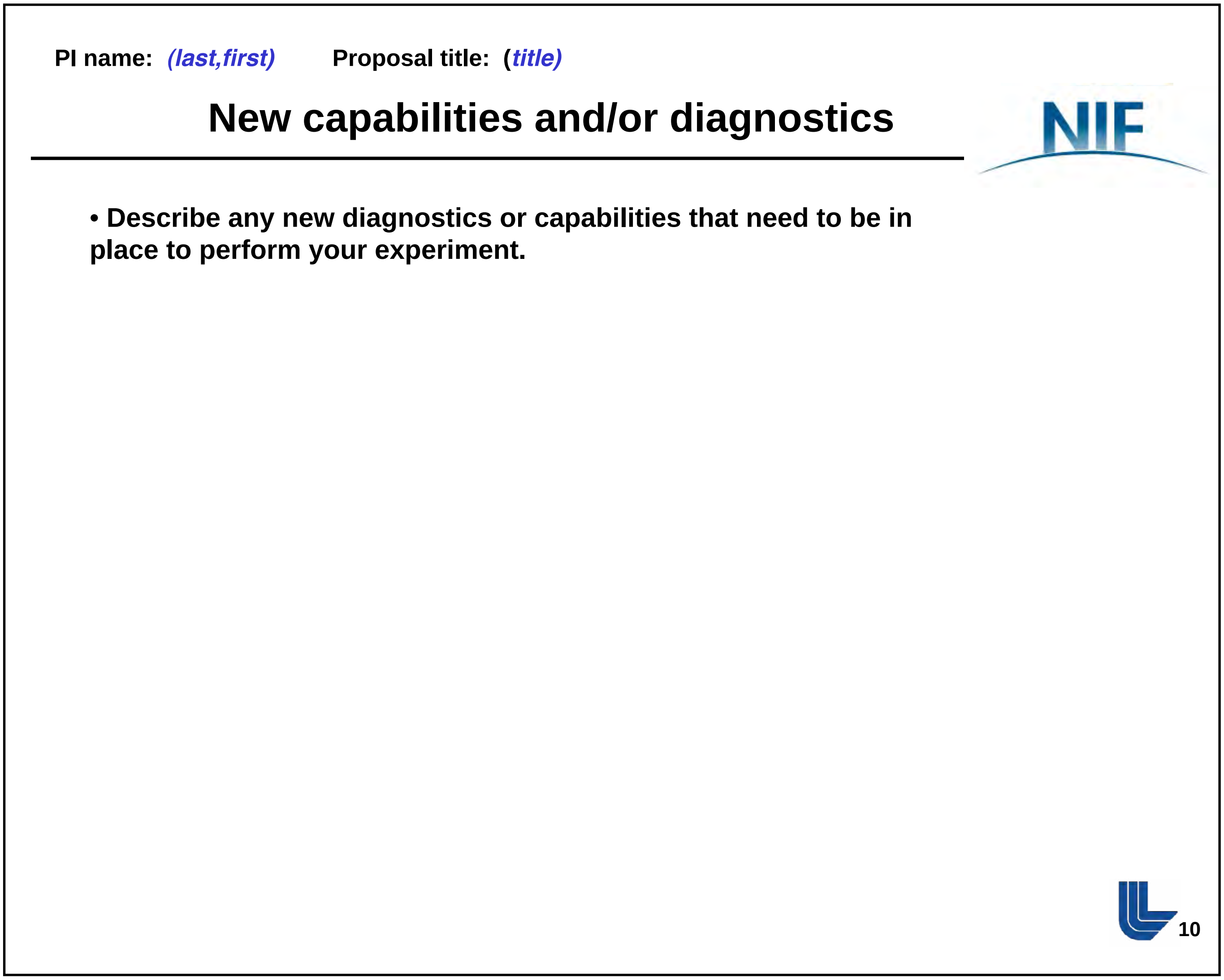
- **List target types required (example: drive measurement; diagnostic test; data acquisition target)**

- **For each target type, provide a sketch of the target below. Include dimensions and a list of *all* materials to be used. Also indicate any critical tolerances required, and indicate components (if any) to be provided by the Principal Investigator.**

PI name: *(last,first)* **Proposal title:** (*title)*

Other requirements

- Indicate other requirements (electrical, vacuum,…) for your proposed experiment. For any items to be introduced into the target chamber not mentioned to this point, please list *all* materials to be used.



PI name: *(last,first)* **Proposal title:** *(title)*

New capabilities and/or diagnostics

- **Describe any new diagnostics or capabilities that need to be in place to perform your experiment.**