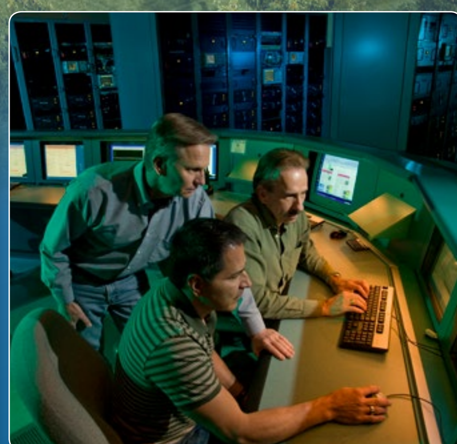
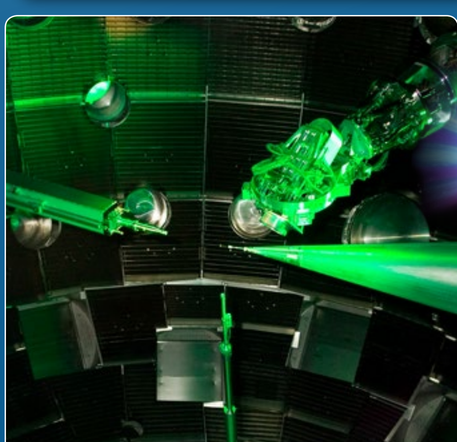
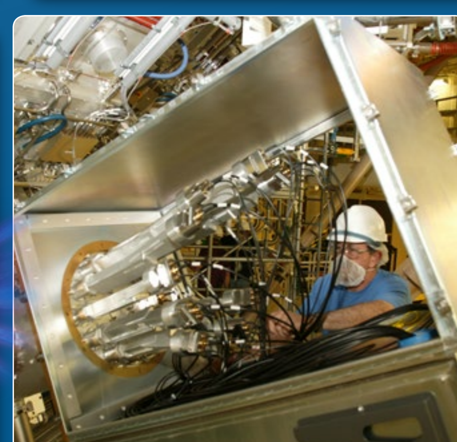
NIF&PS

National Ignition Facility

User Guide 2016







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Auspices Statement

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1. National Ignition Facility Overview

1.1. National Ignition Facility Missions and Users

The National Ignition Facility (NIF) is an operational multi-megajoule laser facility at Lawrence Livermore National Laboratory (LLNL) in Livermore, CA. In March 2009, the construction of NIF was completed and it entered into full operations. 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 (DOD) and other federal offices and agencies. NIF is 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 information to support 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. National Ignition Facility History

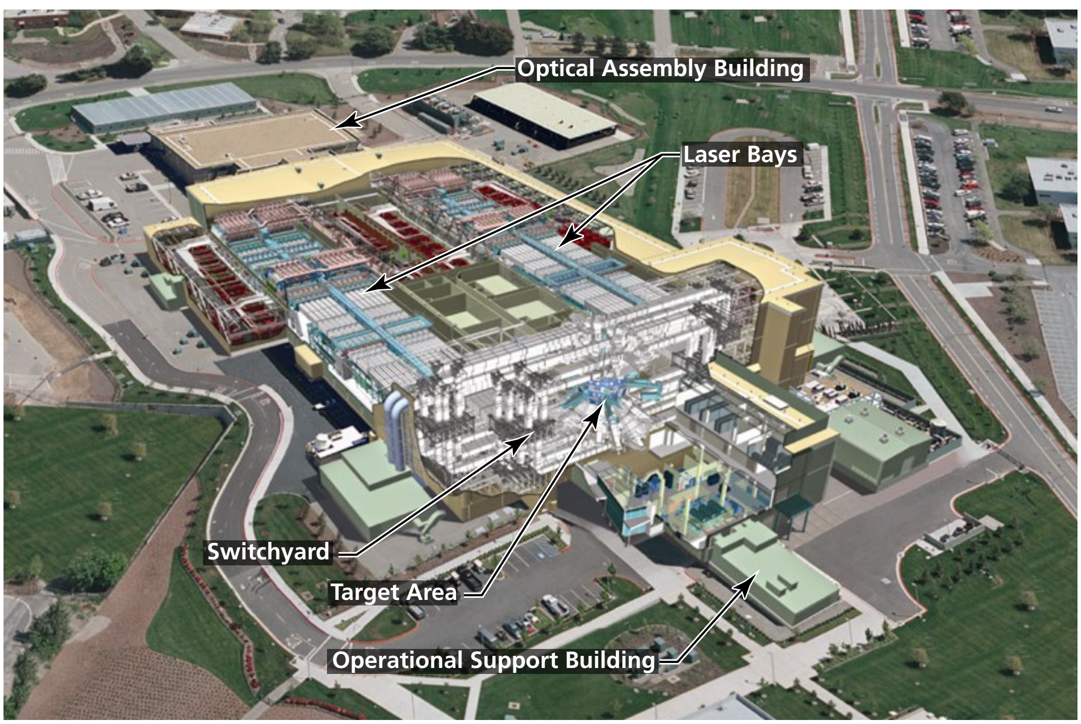

Figure 1-1. National Ignition Facility (NIF) aerial view, showing the two laser bays, switchyard, target chamber area, Operational Support Building, and Optics Assembly Building.

The formal commencement of NIF was the signature of NIF "Key Decision Zero" by 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 the NIF groundbreaking ceremony 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. In April 2003, the full 192-beam beam path was completed in both laser bays. In May 2003, NIF produced 10.4 kJ of ultraviolet laser light in a single laser beam line 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 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 established facility infrastructure. By the completion of construction in March 2009, over 6000 LRUs had been installed in 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.

Experiments in 2011 and 2012 continued to explore ignition physics. Several scheduled maintenance periods 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, which were set during NIF planning in the late 1990s.

Since 2012, NIF has continued to evolve as a user facility. A gathering in the summer of 2013 of national experts in the areas of facility management and high-energy-density experiments launched a 120-day study to improve operations, efficiency, and user experience at NIF. Since then, the number of target shots has increased. One hundred seventy-nine target shots were completed in FY2012 (October 2012 to September 2013), 209 in 2013, and 191 in 2014. The facility performed 356 target shots in FY2015, a >50% increase in the number of target shots from the previous year. The facility shot rate is expected to continue to increase in FY2016 and beyond. The increase has mainly been accomplished by improving operational efficiency during and between shot sequences, performing similarly configured experiments in sequence to minimize transition time and streamlining the experimental request and review process (see Section 3.2 for more information on the experimental process).

2. Governance, Roles, and Metrics

2.1. Governance Plan

The organization for NIF Governance is outlined in Figure 2-1. The governance process allocates time to four major mission areas: Stockpile Stewardship Program (SSP): Inertial Confinement Fusion (ICF), SSP: High Energy Density (HED), Discovery Science (DS), and National Security Applications (NSA). After the governance process allocates time and produces a detailed schedule, the execution of experiments and the production of data is the responsibility of facility operations and a program's integrated experimental team.

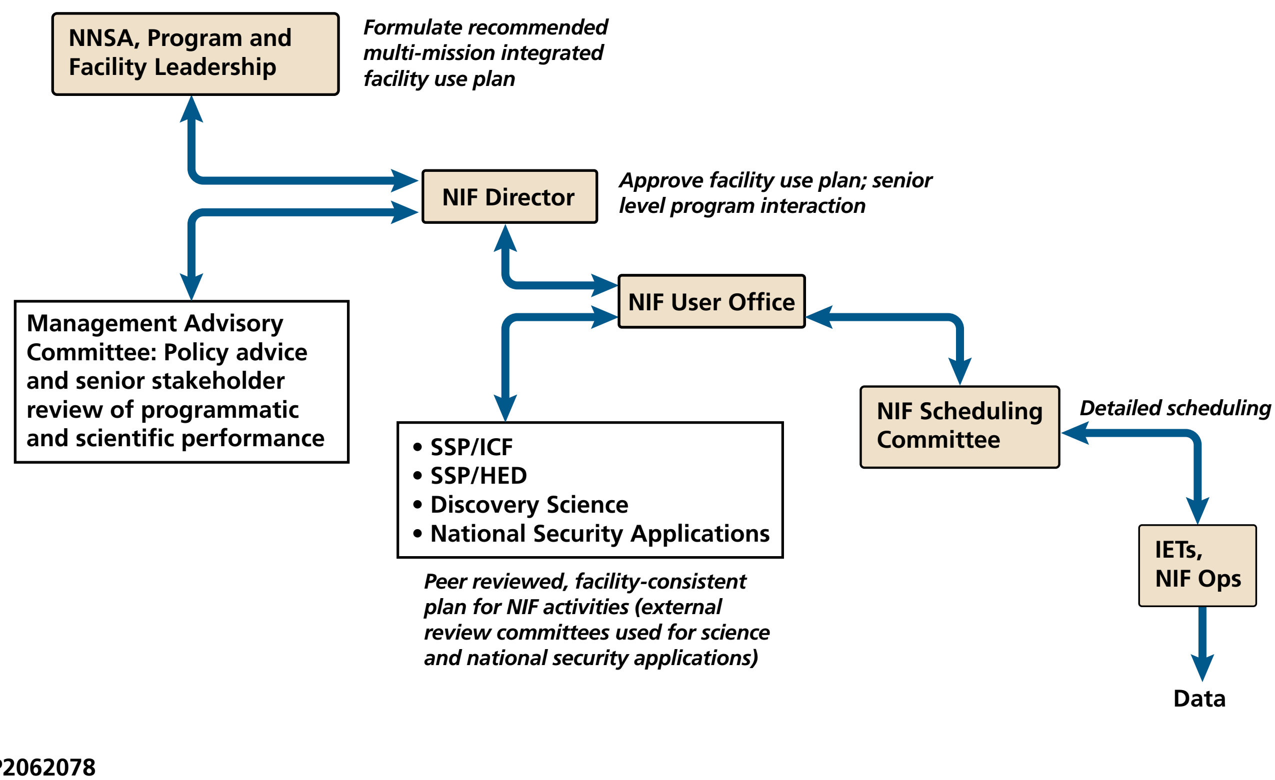

Figure 2-1. The figure shows the key participants as well as the flow of requirements and information underlying the NIF governance process. The governance process collates stakeholder and sponsor priorities, current and future facility capabilities, and user input to allocate facility access each fiscal year for users in various mission areas.

2.2. Time Allocation and Experiment Scheduling

The process for allocation of NIF facility time is summarized in the *NIF Governance Plan* (see Section 2.1). Laser time is allocated in four major program areas:

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

The experimental definition and scheduling process is initiated when the User Office provides the four programs and the facility with blocks of time throughout a given six-month period consistent with their allocations. The blocks are then filled with experiments and submitted to the NIF Scheduling Committee (NSC). The NSC integrates the schedule and prepares it for review by impacted facility stakeholders and approval by the Facility Advisory and Scheduling Committee (FASC). Changes to the schedule, once adopted as a baseline, are managed through schedule change requests (SCRs) to the NSC. The NIF User Office can advise on how to formulate and propose an SCR.

The approved NIF schedule is accessible to all users at **https://lasers.llnl.gov/for-users/nif-calendar.** A more detailed schedule is available inside LLNL's network domain and requires a password for access. Information on accessing the latter schedule is available from the NIF User Office.

2.3. Key Individuals, Committees, and Programs

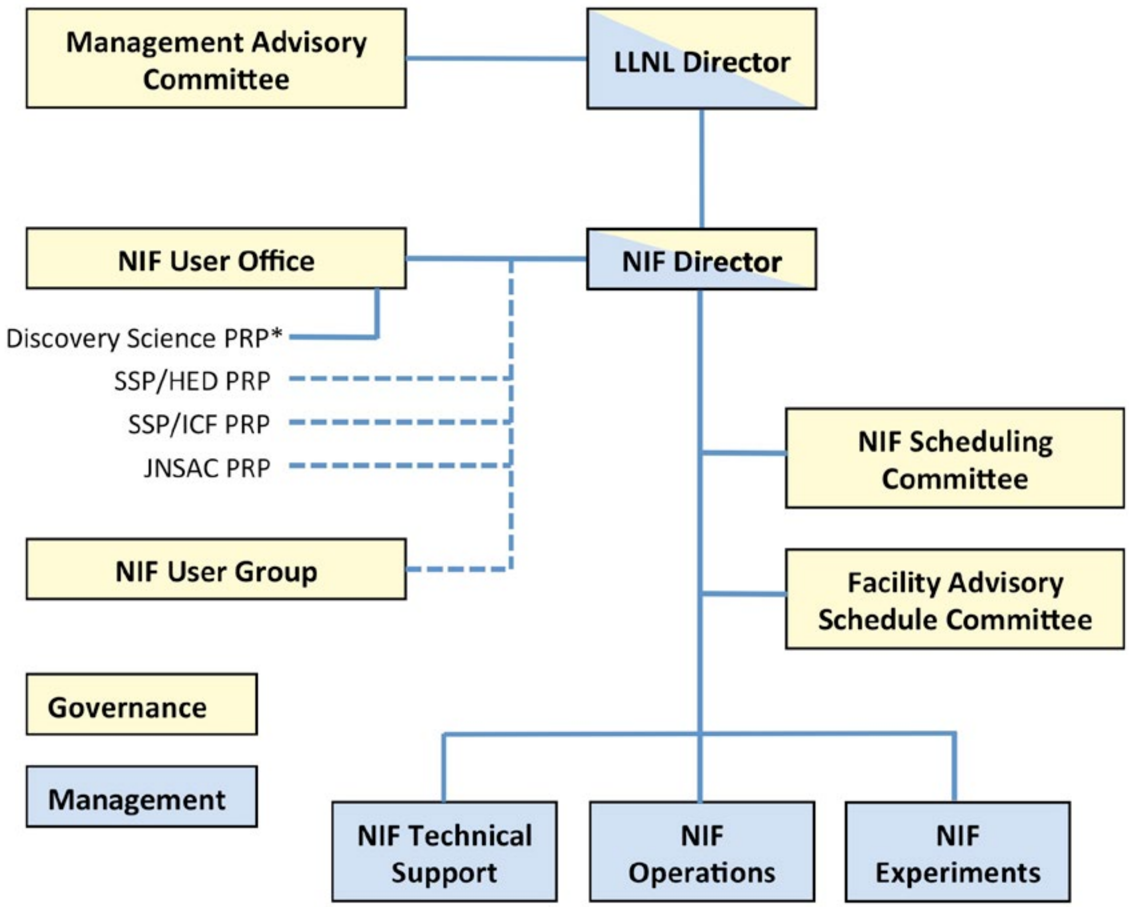

Figure 2-2. NIF governance and management elements. PRP stands for peer review panel.

Figure 2-2 shows the governance and management elements involved in developing and executing the integrated NIF Facility Use Plan. A high-level schedule and a plan for the implementation of target shots, laser-science shots, and new capabilities comprise the integrated, multi-mission Facility Use Plan; it is delivered by the LLNL Director to NNSA each fiscal year. Blue boxes in Figure 2-2 indicate management elements associated with NIF. The User Interface box represents the program areas: ICF, HEDSS, DS, and national security other than SSP. The roles of the individuals and committees illustrated in the figure are as follows.

LLNL Director
Provides management oversight of NIF and ensures appropriate integration of major mission activities consistent with the Laboratory and sponsor strategic direction, user facility best practices, and the Lawrence Livermore National Security contract. The LLNL Director oversees evaluation of the performance of NIF as a user facility, including evaluation of the NIF Director. The LLNL Director concurs on the NIF annual Facility Use Plan before it is released to the user community.

NIF Director
The NIF Director leads and manages NIF as a user facility, implements governance and other management processes needed to support the NIF user community, safely and securely operates the facility, executes experiments, and develops and implements strategies for the evolution of NIF and its capabilities. The NIF Director also ensures that the facility and diagnostic, laser, target, optics, and other technologies are optimized and available to users consistent with available resources and priorities.

NIF Management Advisory Committee (MAC)
MAC is appointed and chartered by the LLNL Director and reports to the LLNL Director. It includes the NIF Director (ex officio), senior representatives familiar with NIF missions, and user community stakeholders. MAC provides input to the LLNL and NIF Directors on facility use and strategic direction, and will advise on the appropriately balanced utilization of the facility among missions. It will evaluate the membership and general effectiveness of the Peer Review Panels (PRPs), review the performance of the NIF Director and the performance of the facility on an ongoing basis, and report to the LLNL Director on its status.

FASC
FASC recommends to the NIF Director system time allocations, promotes an effective user community, and reviews the facility's overall effectiveness for users. This committee meets twice a year to recommend and approve the baseline schedule for NIF. It includes a representative from each of the NIF programs as well as other stakeholders.

NIF Operations Manager (NOM)
The NOM has overall responsibility for activities and operations in the NIF facility buildings (581/582, 682, 683, and 684). This includes being responsible for facility safety and security, managing NIF site access, and being the authorizing individual for facility and experimental operations. The NOM has the responsibility to implement and maintain the Facility Safety Basis for B581, including shot yield management and control and hazardous materials management and control.

NIF User Office Director
The User Office Director develops and maintains facility policies regarding governance, data handling, and other user concerns; oversees administrative support of NIF users; and serves as the primary point of contact with the NIF user community. The User Office Director is responsible for ensuring that campaign leaders provide evaluations of facility performance, that the NIF User Office provides facility feedback to campaign leaders, and that the User Office provides a summary of user feedback to NNSA.

NIF User Group
The NIF User Group is a self-organized group that represents the user community to the NIF Director and other individuals/organizations as appropriate. The NIF User Group has a charter (see Appendix B) and is directed by an executive board that is elected by the community. The members of the executive board serve three-year terms on average. This board is composed of a mix of academic and national laboratory representation.

PRPs
PRPs for HEDSS, ICF, NSA, and DS review proposed experiments from a scientific and programmatic perspective as described below. All PRPs consist of NIF facility representatives

and subject matter experts (SMEs) drawn from both the program in question and the broader technical community and appointed by the NIF Director. They function as follows:

- HEDSS, ICF, and NSA PRPs will evaluate proposals based on the proposal team's likelihood of achieving the defined scientific, technical, and programmatic objectives.
- The NSA PRP provides recommendations to the Joint National Security Applications Council (JNSAC) and the sponsors of individual proposals.
- The DS PRP will evaluate proposals based on scientific merit.
- PRPs may meet jointly as needed.

PRP recommendations are provided to the NIF Director and program leadership and are used by the NIF Director in developing a recommended multi-mission Facility Use Plan.

NSC

NSC develops and maintains the NIF schedule following the guidelines of the approved NIF Facility Use Plan. The NSC plans an optimized use of the facility by grouping shots with like diagnostic configurations. It manages changes to the NIF schedule through the SCR process and produces the baseline detailed shot schedule for two quarters of the fiscal year a minimum of six months ahead of the start of that period. The NSC baseline schedule is reviewed and approved by the FASC before being forwarded to the NIF Director for acceptance and implementation.

NIF Technical Support, NIF Operations, and NIF Experiments

The NIF Technical Support, NIF Operations, and NIF Experiments groups are the management elements that maintain NIF as a world-class HED research facility, operate the facility in support of all missions, and support the NIF Director in formulating and executing the NIF multi-mission Facility Use Plan. These groups also support PRPs in reviewing user proposals from the facility perspective.

2.4. Experimental Execution Roles and Responsibilities

This section describes the roles and responsibilities of key individuals involved in the experimental execution process discussed in Section 3.2.

Program	Point of Contact for Experimental Development and Progress Monitoring
SSP (ICF and HEDSS)	Campaign Manager
National Security Applications	Sponsoring Program Manager
DS	Principal Investigator

Program Leader

The Program Leader decides on the scientific path to meet program objectives and delegates responsibility to Campaign Responsible Individuals (RIs) when a program has many independent technical work streams. He/she is the principal point of contact for sponsoring agencies and provides high-level leadership during the proposal and prioritization processes within a program area.

Campaign Responsible Individual (RI)

The Campaign RI is either the Principal Investigator (PI) or Liaison Scientist. He/she 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 PI; 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 DS and NSA experiments, the RI will also serve as the NIF Liaison Scientist, the primary interface for researchers external to NIF.

Principal Investigator
For DS experiments, the individual initiating the experimental proposal is the PI. The PI is responsible for overall formulation of the campaign and the shot plan. The PI will work with Shot RIs on his/her team, Project Engineers, and the Liaison Scientist to develop campaign plans and monitor the progress of the overall experimental program. The PI will also work with NIF management and Shot RIs to ensure appropriate staffing for the experimental campaign.

Collaborator
Collaborators are individuals identified by the PI (DS) or Campaign RI (NSA) who are associated with a particular project and who may participate in reviews or presentations, but do not have shot setup responsibilities. Collaborators may be directly involved in post-shot data analysis at the PI's or Campaign RI's discretion.

Shot RI
The Shot RI sets up the experiment(s) in the Campaign Management Tool (CMT), satisfies all required expert-group assessments and reviews as part of the experimental lifecycle, and executes the shots. The RI is the individual principally responsible for post-shot data analysis. It is possible that the Shot RI will also be the PI or Campaign RI, although in practice, for a campaign with a significant number of shots, the level of involvement for each role leads to these naturally being different individuals.

Project Engineers
Project Engineers help provide the necessary technical definition of shots for scheduling and target fabrication purposes. They are the principal channels for data in the shot planner and are responsible for keeping scheduled experiments on track through various readiness gates.

Liaison Scientist
For DS experiments where the PI is an external user and no LLNL scientist is available to act for the campaign, the DS Program Leader may assign an LLNL Liaison Scientist to act on behalf of the PI for the experimental planning and scheduling of the experiment.

2.5. Performance Metrics

Progress is continuously monitored on NIF in the areas of efficient utilization of the facility, quality data return on every shot, ease of implementation for Shot RIs, and overall campaign flow for PIs and Campaign RIs. This is accomplished through the collection of performance metrics specific to both the experimental shot cycle and the facility operation in general. Studying trends in the metrics helps NIF staff ensure that the facility can support an ever-growing pool of international users with ever more opportunities for unique science experiments. On an annual basis, the NIF Director will assess facility performance using published metrics. This evaluation will be made available to the user community.

2.5.1. Accumulation, Analysis, and Reporting of Performance Metrics

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

- Compliance with environment, safety, and health regulations.
- Facility availability for experiments, calculated using data collected during facility operations.
- Experimental effectiveness as measured by completion of user campaigns and feedback from lead investigators.
- User feedback regarding the proposal solicitation and review processes and experiment execution.
- Degree of recognition obtained, including papers published, talks given, and number of meetings and workshops

with NIF and NIF attendees, including those in both technical and leadership roles; degree of student and postdoctoral involvement.

As part of the process of evaluation of NIF as a user facility, NNSA will perform periodic external reviews of the operation of NIF as a user facility, in a manner similar to that of the reviews performed of DOE Office of Science user facilities, usually on a three-year cycle.

2.5.2. Customer Feedback

An electronic customer feedback survey is launched following each NIF target shot. These surveys are used to provide user feedback to NNSA, LLNL management, and NIF management to determine how best to enhance and expand user facility services. In addition to the survey, other mechanisms for information gathering include:

- A monthly User Forum
- The annual NIF User Group meeting
- User Feedback Tool
- PRPs
- Program Management

2.5.3. 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.

2.6. National Ignition Facility User Group

The NIF User Group provides an organized framework and independent vehicle for interaction between the scientists who use NIF and NIF management. The NIF User Group advises the NIF Director on matters of concern to users, as well as providing a channel of communication through which NIF users can interact with funding agencies and the public. The group represents the interests of the NIF users to NIF management to facilitate the availability and effective use of NIF for the broader research community.

The NIF User Group Executive Committee is a formal organizational unit whose members are elected by the members of the NIF User Group. They typically meet several times each year and communicate the needs and desires of users regarding NIF operating policies, use of NIF, user support, and other relevant issues of concern to those engaged in non-programmatic research at the facility.

A representative of the NIF User Group Executive Committee is invited to attend selected NIF management meetings where operational issues impacting users are discussed to ensure evaluation of user interests and the most efficient and optimal utilization of the facility.

All scientists interested in using NIF are welcome to join via the **User Group website**. Annual **NIF User Group meetings** are held to which all members are invited.

3. Experimental Design and Execution

3.1. Experimental Process Overview

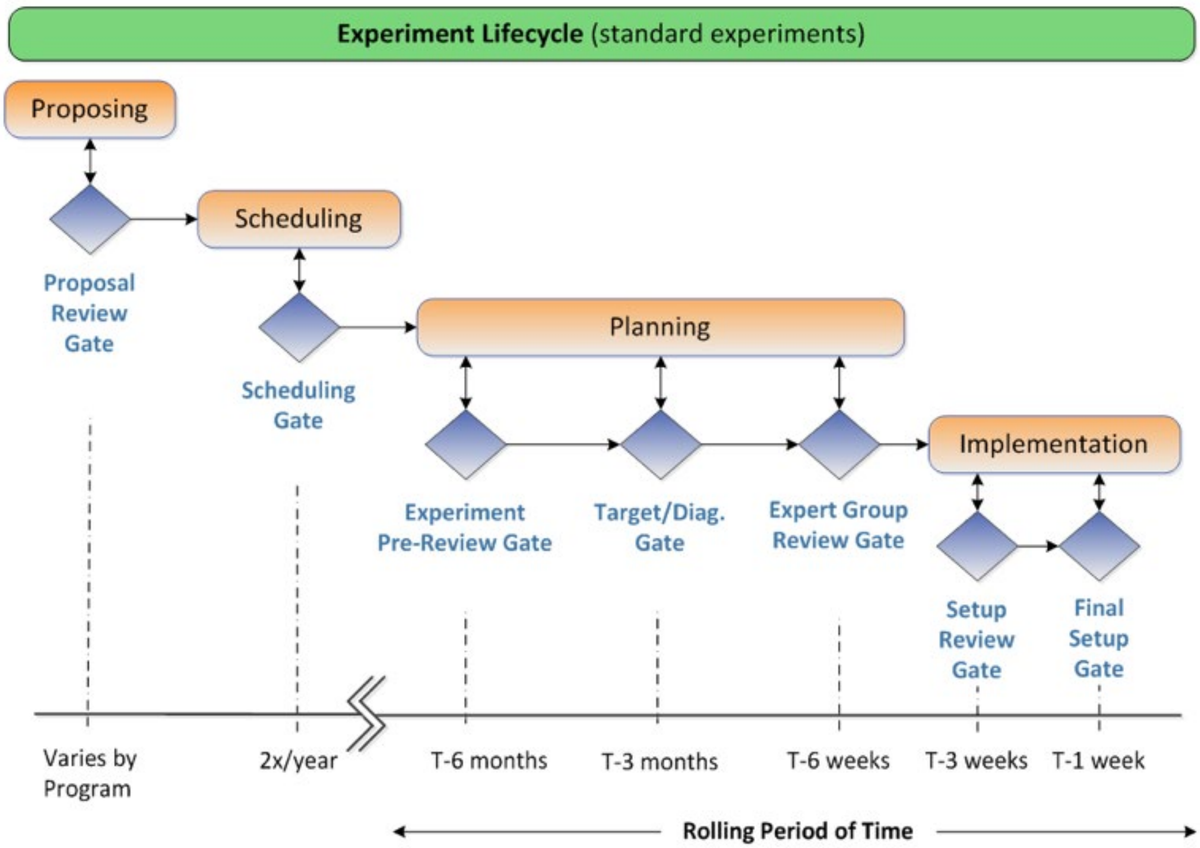

Figure 3-1. NIF's experimental process.

Below is a brief summary of key milestones in the NIF experiment process (see Figure 3-1) for proposing, scheduling, planning, and setting up an experiment in the context of communicating with NIF on a timeframe to support successful execution of the experiment.

Proposal Phase

A call for proposals is announced at least one time per year for each program. (See Section 3.1.1. for more on proposals.) The call includes facility time allocations in units of shot days, as well as a timeline that indicates salient dates such as proposal submission dates. All submitted proposals are reviewed for scientific merit and program impact by panels of internal and external experts. There is also a high-level proposal review for facility readiness and capability by NIF staff. The chair of the review committee summarizes the recommendations for each proposal in a report and sends the report to the NIF Director. The principal investigator receives a written notification from the NIF Director of the proposal evaluation and decision.

Scheduling Phase

All accepted proposals require a set of essential data that defines the experiment to be submitted through the NIF user portal (see Section 3.1.3. for more on the essential data). A program liaison is made available for those Principal Investigators (PIs) needing assistance. The experiment definitions allow for the programs to work in conjunction with the facility to schedule experiments consistent with constraints and capabilities. Batch scheduling of experiments occurs twice a year. (See Section 3.1.2. for more on scheduling.)

Planning Phase

Scheduled experiments are defined by the Shot Responsible Individual (RI) and planned such that they meet physics goals while not compromising on facility safety. This is the longest phase of the experiment process, as it starts no later than six months before and ends six weeks prior to the scheduled shot date. The Shot RI collaborates with Target Fabrication on a target design that will allow the experiment goals to be achieved (see Section 7.2.). The Shot RI consults with the Diagnostics engineering team to communicate any special hardware needed in the Diagnostic Instrument Manipulator (DIM) and to negotiate participation of fixed diagnostics. The Shot RI specifies laser performance and pulse shaping, which may drive pre-experiment calibration activities or performance tests. At various points in the planning phase, expert group members review the details of the experiment definition to ensure that the experiment falls within the safety envelope. Iterations on experiment design are common during this phase.

Implementation Phase

The Shot RI finalizes all setup parameters in the Shot Setup tool. All experiments go through the Setup Review three weeks before the shot date to ensure readiness and begin preparation for execution. Once the setup is final, the experiment is approved by the NIF Operations Manager (NOM). The day of the shot, the Shot RI provides a pre-shot briefing to the Shot Director and NIF Operations staff. Operations personnel follow the appropriate procedures leading to execution of the shot. Within hours after the experiment, the Shot RI completes an online brief operational report and shot survey.

3.1.1. Proposals

The NIF User Office will assist in the formulation of discovery science proposals, including estimation of required resources. In addition to basic background information to be provided via a web-based form (**https://nifpub.secure.force.com**), 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 conducting the proposed work with NIF.
- **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 require a submitted written scientific justification describing the specifics of the proposed experiment.

3.1.2. Experimental and Facility Requirement Planning

The first step in the execution of a planned NIF experiment (following the awarding of time to successful proposals) is submission of the initial experiment definition at the Scheduling gate via the NIF User Portal. The definition includes details of essential data needed for scheduling of experiments. The different categories of attributes are described below:

1. **Experiment Name:** The identifier for the experiment used for planning is defined here. The identifier is a concatenation of abbreviations for the program, campaign name, sub-campaign name, and the platform name. See Section

3.1.3 for a more detailed description of this identifier.

2. **Experiment Scheduling:** Shot allocation quarter and a scheduled no-later-than date are entered here. Also, if the newly-defined experiment must be scheduled after any predecessor experiment, the predecessor is called out here.
3. **Diagnostic Request:** Diagnostic instruments that are inserted into the target chamber via a DIM are listed here; for each DIM-diagnostic, priority and type should be indicated per Table 3-1. This is a first attempt at describing the DIM diagnostic configuration; following facility reviews and negotiation, the final set of participating DIM diagnostics will be determined at a later date. Of course, anything the PI or RI determines as primary to their physics goals will be treated as such.

   Any new diagnostic instrument needed for the experiment is specified here as well. Any known required calibration or commissioning activities should also be listed, as this helps the facility to plan ahead and work with the RI to ensure that analyzable physics data is obtained.

Table 3-1. 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)

4. **Laser Setup:** The fundamental laser parameters that provide a rough sketch of the laser drive envelope are entered in this section of the definition. The parameters include laser energy, laser power, total number of beams, and backlighter beams. It is understood that detailed laser parameters will be clarified and finalized at a later time.
5. **Target and Target Handling Summary:** If the target will be fabricated by LLNL, the complexity of the target is specified per Table 3-2. If a similar target has been fabricated before, that must be indicated along with the differences between the previous target and the new request. If the target will be fabricated at another institution, this fact should be stated here instead as an additional comment. Note that the target will still need to be metrologized at NIF and potentially undergo expert group reviews (see Section 3.3).

Table 3-2. Target complexity levels.

Level	Complexity Description
1	Minor modification or existing target type
2	Moderate to Major modification to existing target type
3	New target design

The essential requirements for target handing are also entered in this section of the definition. The target positioner, target gas fill, target temperature, and shot type are all listed. A more detailed description of target handling capabilities can be found in Section 5.4. A description of the various shot types is shown in Table 3-3.

Table 3-3. Shot type definitions.

Shot Type	Definition
Warm Simple	* Room Temperature target * Meets simple target alignment (≥30 μm)and up to 2 DIMS (no NIS diagnostic)
Warm Complex	* Room temperature target * Meets precision target alignment (20 μm), requires 3 DIMS, *or* requires NIS diagnostic
Cold	Cryogenic target
Layered	Layered target

3.1.3. Experiment Naming

When an experiment is originally defined, several attributes are defined that identify the experiment throughout its lifecycle. These attributes follow a standard convention that allows both the program and the facility to efficiently prepare, execute and status the specific experiment, as well as allowing for the collection of experiments on NIF. These key attributes include:

Program

Identifies the program that is responsible for the experiment. Current programs are listed below. New Programs are created by the NIF Director.

- I — Inertial Confinement Fusion (ICF) Program. Prior to FY13, experiments within this program were identified as "NIC."
- H — High-Energy-Density (HED) Program
- D — Discovery Science (DS) Program. Prior to FY16 these were identified as "Fundamental Science."
- N — National Security Applications (NSA)
- Fa — Includes shots conducted by the facility to support laser optimization, diagnostic calibration, new capability commissioning, etc.

Campaign

Each program defines a series of shots with a unifying purpose, such as understanding an aspect of physics or supporting a given sponsor. These are typically mid-term to long-term in nature. New campaigns are established annually by the leaders of the programs. Examples include HED's Radiation Transport campaign or NSA's Department of Defense (DOD) campaign. New campaigns require Program Manager approval.

Sub-campaign

Each program further defines focus areas within their campaigns to help manage the work. Examples include the Pleiades and Opacity experiments within the HED Radiation Transport campaign and Source Development and Sample Exposure within the NSA DOD Campaign. Sub-campaigns tend to be mid- to short-term in nature. New sub-campaigns require Program Manager approval.

Platform

A platform names a collection of diagnostics and target types. New platform names may be added with NIF User Office manager concurrence. To avoid an explosion of platform names, users are requested to consult the User Office when requesting a new platform name.

"FLIP_Id"

When an experiment is defined, it is given a unique "FLIP_Id" for identification throughout the lifecycle. The name is derived from abbreviation of the attributes above with an Optional Parameter to help in experiment description. Often the optional parameter is the sub-campaign. All FLIP_Ids end with an alias that consists of a three-letter sequence that facilitates auto-incrementing: "AAA," "BBB," "CCC," etc. The alias allows for multiple experiments to be planned having the same campaign, sub-campaign, and platform identifiers. There is currently a 28-character limit on the FLIP_Id.

For example, consider the experiment sponsored by the HED program to develop a capsule backlighter platform for the Radiation

Transport campaign. The optional parameter was defined by concatenating abbreviations for the Opacity sub-campaign and the capsule backlighter. Table 3-4 shows the FLIP_Id for this example and how it was constructed.

Table 3-4. Illustration of the parameters comprising the FLIP_Id.

Program	Campaign	Platform	Operational param.	Alias	FLIP_Id
H	RadT	BL	OpacCap	AAA	H_RadT_BL_OpacCap_aaa

3.2. Experimental Review Process

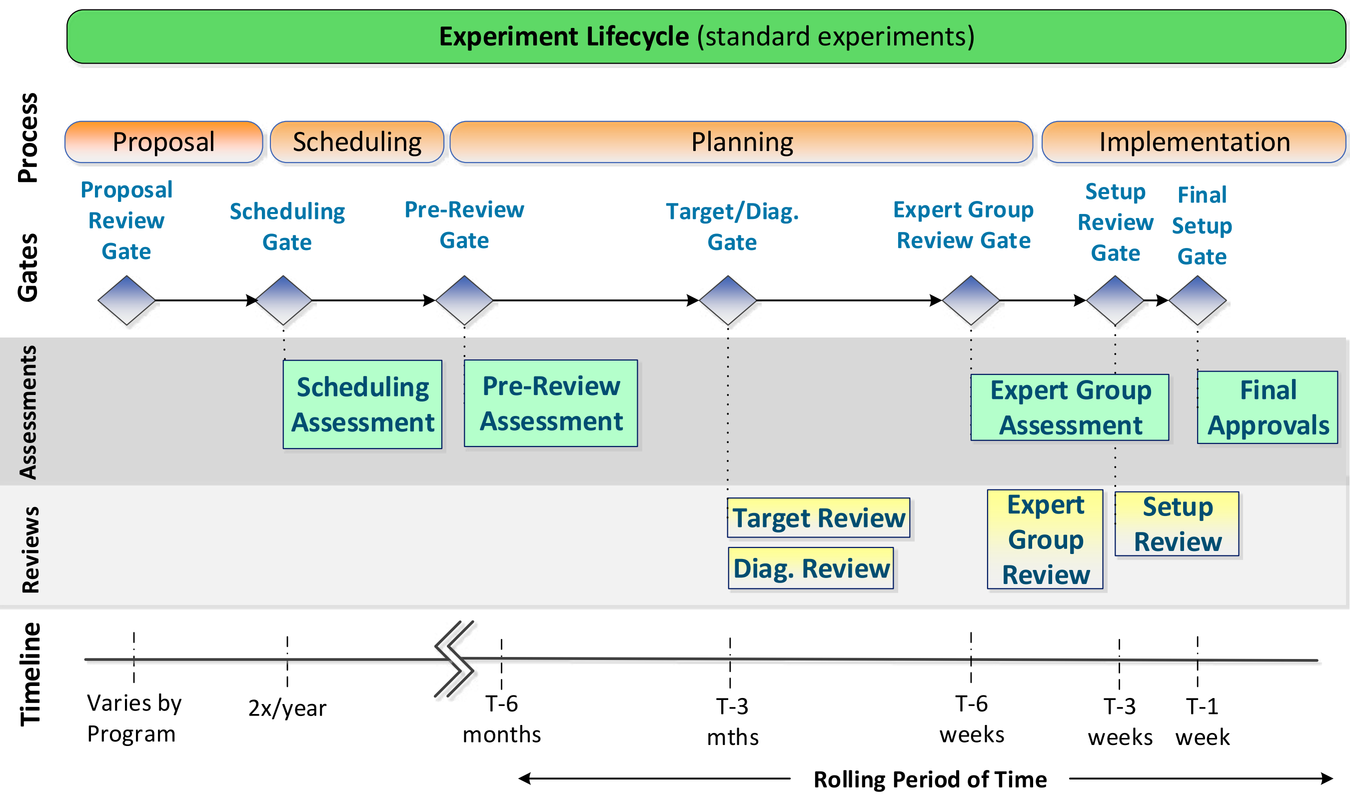

Figure 3-2. NIF's experiment review process.

Gates, assessments, and reviews define the overall structure of the experimental process. Gates are those fixed points in time in the process where the Shot RI provides information about the experiment to support subsequent work and facility feedback. An assessment is defined here to be stakeholder evaluation of current experimental definition in order to gauge readiness to proceed and identify issues that place the shot schedule at risk. The assessment is done offline without Shot RI presence. A review, however, does involve the presence of the Shot RI. It is a forum that involves a presentation by the Shot RI to stakeholders in order to facilitate discussion and allow for issue closure.

The green boxes of Figure 3-2 illustrates four assessments that occur for every experiment. The yellow boxes depicts four typical reviews. All reviews except the setup review are called on an as-needed basis. The total set of assessments and reviews is not limited to what is shown in the figure; it will vary with the complexity of the experiment. In general, the number of reviews depends on the degree of difference between the planned experiment and previously shot experiments. Note that program reviews for scientific merit are conducted outside of the process shown in the figure.

Scheduling Assessment

The scheduling assessment considers all experiments within the six-month scheduling period. Submission of the initial definition for each experiment, as described in Section 3.1.2, is required to allow for a draft schedule to be constructed by the programs. During the assessment, the timeframe of experiments on the schedule is reviewed, diagnostic and target capabilities are verified, long-lead items are identified, and optics impacts are assessed. This assessment usually leads to a negotiation between program representatives and facility stakeholders to balance capabilities, physics requirements, and schedule. The result of the assessment is stakeholder agreement with a baseline schedule.

Pre-Review Assessment

The pre-review assessment occurs for every experiment on a rolling six-month-to-shot basis. It requires the Shot RI to verify and add experimental data that is in the Shot Planner tool with the help of the project engineer. If the experiment is unique relative to the NIF experiment base, an experiment template is requested to be filled in and submitted as a supplement to the Shot Planner data (see Section 3.2.1). During the assessment, stakeholders evaluate experimental complexity, identify new requirements, and flag issues that affect multiple stakeholders. The result of the pre-review is feedback to the Shot RI on aspects of their experiment plan that require attention or negotiation with facility stakeholders. Any reviews assigned during the assessment are also conveyed to the Shot RI.

Target Review

The target fabrication team follows an engineering design process involving a conceptual design review six months from scheduled shot date and a final design review three months before shot date. At six months, a target request in the PORT tool needs to be created. The target request must include a set of PowerPoint charts that conceptually captures the target configuration. The notification for the target request is included with the notification of the Pre-Review assessment. Interaction between target engineering, Shot RI, alignment team, metrology group, and target operations occurs periodically between six and three months, and the final design review represents the culmination of all of the engagement. The review includes representation from all of the aforementioned stakeholders and requires a target drawing and documents for aligning and charactering the target. The result is an agreed-upon target design to begin fabrication.

Diagnostic Review

The diagnostic review occurs three months from the scheduled shot date and requires a list of diagnostics and their assigned priorities to be defined in the Campaign Management Tool (CMT). If all selections are available in CMT, the review becomes an assessment, and no further action is needed by the Shot RI. However, if any diagnostic configurations are not currently selectable in CMT, the RI must attend the review to define those configurations. The result of the review is agreement on diagnostic participation and an initiation of the request process for small new capabilities associated with the diagnostic snout.

Expert Group Assessment

The expert group assessment completes the planning process for new experiments and

initiates evaluation of the setup for repeat experiments. An administrative coordinator for the Expert Groups will send the RI a viewgraph template that must be filled out describing the salient aspects of the proposed experiment.
For this assessment, the Shot RI must have a complete laser setup in CMT, a target design, and a list of diagnostics, materials, and target metrology requirements. During the assessment, stakeholders evaluate shot plans relative to the NIF experience base. A review may result to resolve issues (see Section 3.3). The output from this assessment is either concurrence that the planned experiment is safe and executable or a report to the NOM with identified risks that he/she may or may not choose to accept.

Expert Group Reviews

An expert group review may be called as a result of the expert group assessment so that stakeholders may discuss raised issues with the Shot RI. Typically, issues may arise from expert group assessment of the risk to optics from backscattered laser light, the risk to the facility from target debris and shrapnel, the impact of a requested pulse shape on the laser system, or any other issue relating to matters outside the experience base of safe operations. A presentation is expected from the Shot RI to help facilitate the discussion.

Setup Review

The setup review requires a completed shot setup in CMT, staffing plans, and a rules-of-engagement document. Experimental setup is reviewed for completeness and unresolved stakeholder issues are discussed. The result is a list of outstanding issues.

Final Approvals Assessment

The final approvals assessment requires a complete shot setup with all supporting documentation and closure on setup review action items. During this assessment, stakeholders evaluate that experiment settings are safe for the facility. The result is shot setup approval.

3.2.1. Experiment Template for Reviews

The NIF experiment template is requested as needed, depending on the degree of variation of the planned experiment from those previously executed. When required, the request for the template is made either at the Pre-Review or Expert Group assessment gate based on how early preparatory work must commence. The template requests the following information:

1. **Experiment Summary:** This page includes summaries of the experiment purpose and goals as well as a brief bulleted summary of what is new.
2. **Experimental configuration:** A schematic drawing of the target is provided, including any shields, backlighter targets, or pinholes.
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). This is only a sketch of the required laser power; the detailed laser parameters will be clarified and finalized at a later time.
4. **Diagnostic requirements:** Diagnostics requested for the experiment should be listed; for each diagnostic, priority and type (see Table 3-1) should be indicated. As with laser requirements, this is a first attempt at describing the diagnostic configuration. Diagnostic lines of sight and critical dimensions are also indicated. Facility configuration(s) suitable for this experiment should also be provided.
5. **Target requirements:** If the target will be fabricated by LLNL, a conceptual 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 potentially undergo expert group reviews. (See Section 3.3).

6. **Additional information:** If a new platform or configuration is being fielded, then additional information is needed three months from shot date:
   a. Experimental configuration (beams + target).
   b. Interference checks for unconverted light for the target.
   c. Beam and shroud interference checks for snouts if needed.
   d. Target drawing.
   e. List of target materials and mass.

3.3. Expert Groups and Facility Stakeholders

NIF has a number of expert groups and facility stakeholders that are consulted throughout the shot preparation and execution process. Stakeholders formally review experiments in advance of the setup review. Formal approval by any stakeholder is captured and documented online with the Approval Manager tool. For issues related to experiment execution that arise in real time and cannot be resolved within a specific review, a management review board (MRB) is convened.

Alignment

The alignment group provides the technical expertise to support the fabrication and metrology of a target or diagnostic for alignment. The group provides tools, procedures, and processes to support the development of the alignment plan and reviews all supporting documentation. Alignment group members typically need to work with the Target and Laser Interaction Sphere (TaLIS) as the alignment plan is being drafted.

Beamline and Laser Integrated Performance (BLIP)

BLIP is responsible for reviewing the experiment in the context of laser performance and safety. BLIP maintains the Laser Performance Operations Model (LPOM) that predicts and optimizes system performance for each experiment's requested laser pulse. The BLIP team is also available as a resource to help define the laser requirements and evaluate whether expected performance will meet the shot goals. This group coordinates with the NIF Optics Loop (NOL) as needed.

Classification

Targets and experiments are assessed to ensure that no classified data can be acquired without proper controls and procedures in place.

Cleanliness and Materials

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 performed to ensure compliance with NIF cleanliness protocols. The chairman of the Cleanliness Steering Committee must authorize any new equipment before it can be installed on NIF.

Diagnostics

Representative stakeholders from the Diagnostics organization provide various types of review throughout the experimental process. New diagnostic instruments and DIM-based snouts are long-lead items (greater than six months) that are passed through a series of design reviews before construction begins. Reviewers are assessing all aspects associated with the instrument, including safety, size, weight, compatibility specifications, and system requirements. Diagnostics members are also available to offer guidance and review of requests for small hardware modifications (no later than three months from shot date). Guidance on the use of existing diagnostics (e.g., availability of common consumable parts) in a given experiment is also provided.

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 generates the final optics exchange plan, inspection plan, and blocker plan for review during the shot approval process. In addition, NOL supports the decision-making required for day-to-day operation of the NIF optics loop.

Radiological Operations

The Radiological Operations group provides guidance and resolution on Environment, Safety & Health issues related to radiological safety. The working group assists in the characterization and understanding of hazards and advises whether the issue falls within safety and environmental limitations. The group recommends controls or alternative approaches in order to reach a consensus consistent with NIF policy.

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 the NIF target chamber and participates in target area design reviews. The TaLIS model-based expert analysis is a critical aspect of shot planning.

Target Operations

The Target Operations group installs the target and supports gas and cryogenic operations as required for experiments. This group provides guidance and develops procedures and processes to support requested target setups.

Targets

The target engineering organization follows a design review process for all targets built at LLNL/General Atomics. A target engineer works with the appropriate stakeholders to uncover any physics, safety, and cleanliness issues. In particular, TaLIS is consulted early in the process to verify that there are no concerns pertaining to debris and shrapnel and configuration. Targets supplied by the experimentalist are also evaluated to ensure that they meet certain fundamental design and materials requirements. See Chapter 7 for more information.

3.4. Experiment Planning Checklist

Below is a checklist of the major steps to assist the experimentalist in planning and carrying out an experiment.

Scheduling

Shot RI receives notification of experiment to be scheduled in the six-month block

- ○ Complete experiment definition *(work with liaison to define and enter data required for scheduling)*

Shot RI receives notification of schedule date or issues

- ○ Implementation/Strategy discussions needed? If yes, proceed with indented section below. *(will be identified by NIF User office or Program to address plan vs. facility schedule inconsistencies)*
    - ○ Diagnostic engineering discussion
    - ○ Long-lead target discussion
    - ○ Strategy discussion

Planning

Shot RI receives notification to review and update Shot Planner definition prior to T-6 month pre-review

- ○ Update experiment definition
- ○ Upload supporting viewgraphs for new campaign or by request *(this "6-pager" may be replaced by a table with similar shot + differences)*
- ○ Request target
- ○ New target design request? If yes, proceed with indented section below.
    - ○ Define target requirements
    - ○ Define alignment strategy
    - ○ Define metrology requirements
    - ○ **Target design and metrology review**
- ○ New target operations request? (e.g. gas handling, fill pressure) If yes, proceed with the indented section below.
    - ○ Define new target operations requirements
- ○ Identify diagnostic participation in the Setup tool.
- ○ New Diagnostic Request? If yes, proceed with indented section below.
    - ○ Request new diagnostic configuration
    - ○ Define diagnostic requirements
    - ○ **Diagnostic design review**
- ○ New Materials? If yes, proceed with indented section below.
    - ○ Define new materials requirements

Implementation

- ○ Complete laser setup in CMT and submit to LPOM *(identify date final pulse will be ready if proxy is submitted)*
- ○ Expert group review needed? If yes, proceed with indented section below.
  (Shot RI will be notified around T-6 weeks if the review is needed.)
    - ○ Update supporting viewgraphs
    - ○ **Expert group review**
- ○ Complete final laser setup
- ○ Complete target setup
    - ○ Review target RVP
- ○ Complete setup of participating diagnostics
    - ○ Review diagnostic RVP
- ○ Define shot staffing plan
- ○ Define shot beam, target, and diagnostic rules of engagement
- ○ **Experiment setup review**
- ○ Punch-list actions

3.5. Experimental Platforms

NIF experiments are typically executed via experimental "platforms." A NIF experimental platform typically consists of an integrated laser set up, target design, data analysis plan, classification level, and diagnostic configuration capable of providing well-characterized pressure, temperature, radiation or implosion-trajectory conditions.

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. 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 an experiment looking at the formation of Herbig–Haro 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 when possible. 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 facility stakeholders.

For more information on the platforms, see the Users section of the NIF website (**https://lasers.llnl.gov/for-users/experimental-capabilities**).

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 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 a unique experimental platform 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. Users are allocated blocks of time following a successful proposal, so it is up to the user to measure complexity in their setup against the number of shots they can accomplish.

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4. Laser System

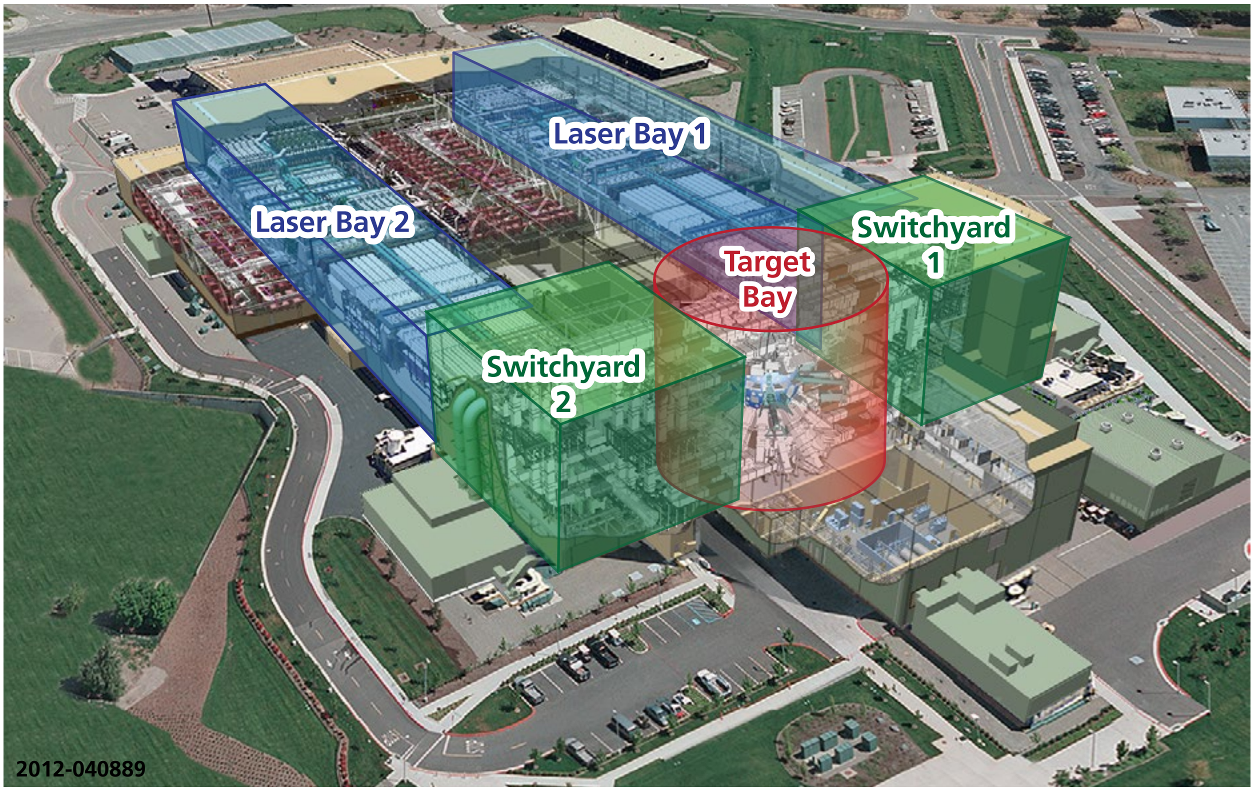

Figure 4-1. High-level architectural components of the NIF laser system.

This section provides an overview of the laser performance and pulse shaping capabilities for experiments on the NIF laser. For more information on laser performance, see *The National Ignition Facility Laser Performance Status*[1] by Haynam et al. The following subsections provide a brief description of the laser configuration, peak power and energy operating limits, pulse shaping capabilities, focal spot conditioning options, and laser diagnostics.

4.1. Laser Configuration

The NIF 192-beam neodymium glass laser is capable of delivering up to 1.8 MJ of total energy and up to 500 TW of peak power at the third harmonic (351 nm, commonly referred to as "3ω") of the fundamental 1.053 nm Nd:YLF frequency ("1ω"). Since its completion in 2009, the delivered energy and peak power have steadily increased to the peak values mentioned above.

Figure 4-1 identifies the major elements of NIF's 192-beam architecture. Figure 4-2 shows the schematic of the 192 laser beamline layout. The 1ω section of the laser is arrayed in two laser bays (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. The 96 beams in each laser bay are further grouped in 12 bundles (2 clusters of 6 bundles each), each bundle consisting of 8 beams. Each bundle consists of an array of flash-lamp-pumped Nd:glass amplifier slabs, where the injected ~1 J of 1ω energy is amplified to over 20 kJ per beam.

[1] C.A. Haynam et al., "National Ignition Facility Laser Performance Status," *Appl. Opt.* **46,** 3276 (2007).

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.

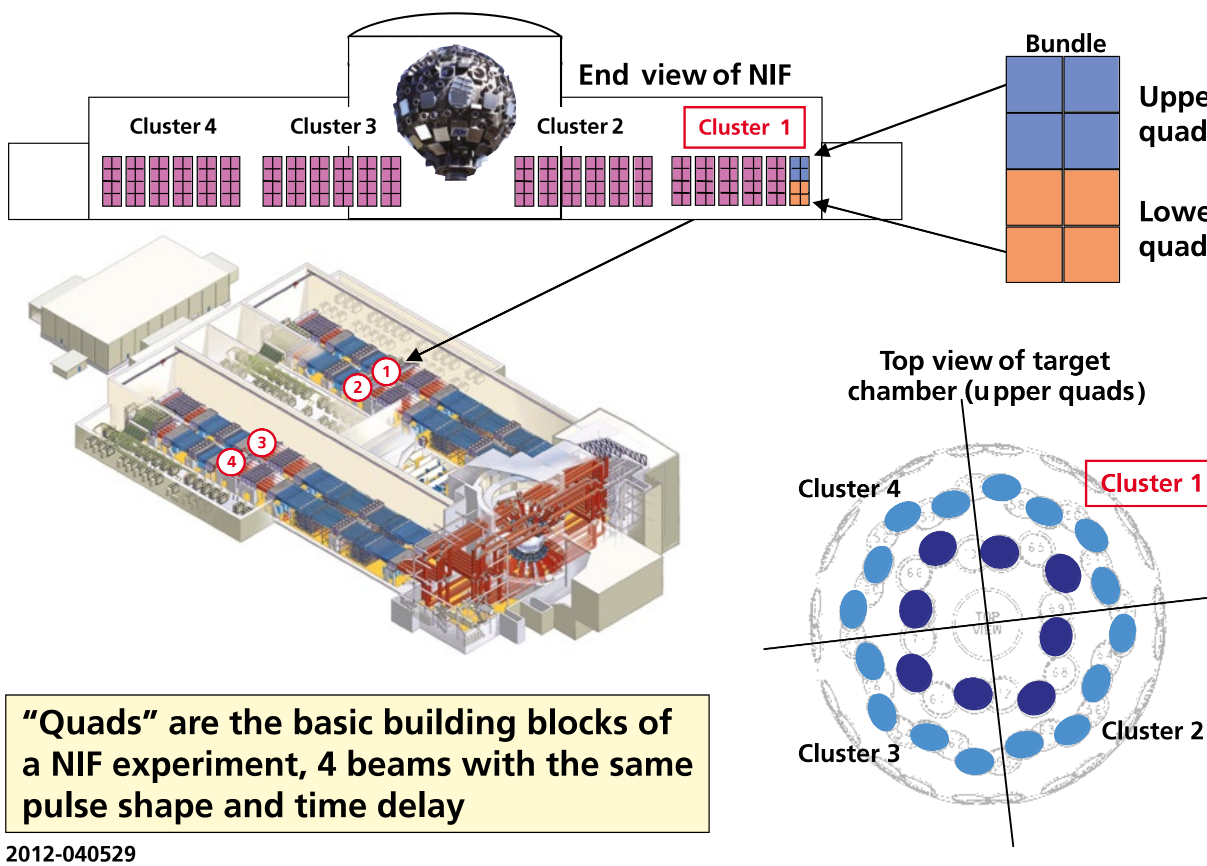

Figure 4-2. NIF is organized into clusters, bundles, and quads of beams.

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 (Figure 4-3). 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 4-1.

Table 4-1. 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

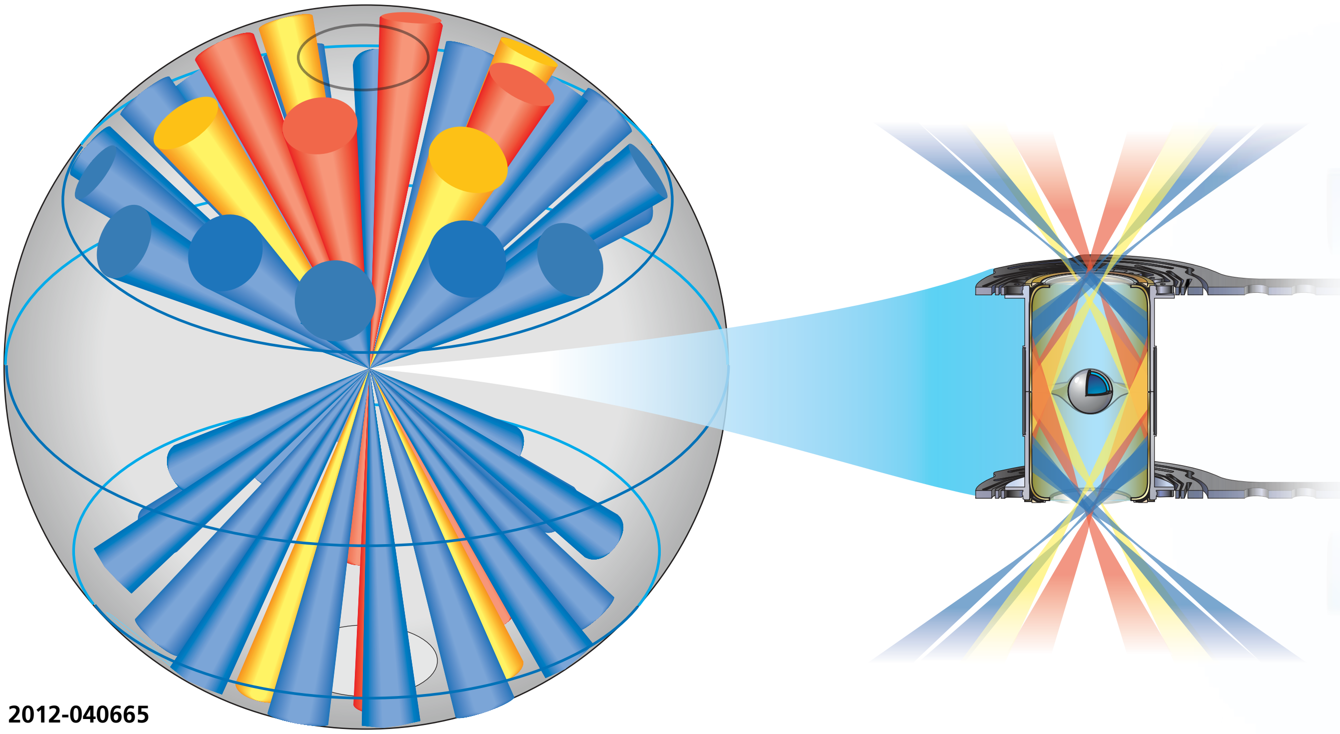

Figure 4-3. NIF beams are arranged to support vertically mounted, indirect drive hohlraums/targets. The four cones of beams at 23.5°, 30°, 44.5°, and 50° polar angles as shown as red, yellow, and blue (for 44.5 and 50°) respectively.

Once the beams in a quad enter the target chamber, they pass through the final optics assembly (FOA) where the 1ω light is frequency tripled to its third harmonic, 3ω. Figure 4-4 shows a schematic of the FOA optical layout. The frequency converted 3ω beam, nominally 37 cm square, is focused onto the target with a 7.7 m focus lens that is wedged slightly to separate the best focus 0.351 µm laser light from the residual 1.053 and 0.532 µm unconverted light. The effective aperture is 1250 cm^2. A quad of beams has 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 is 7.9.

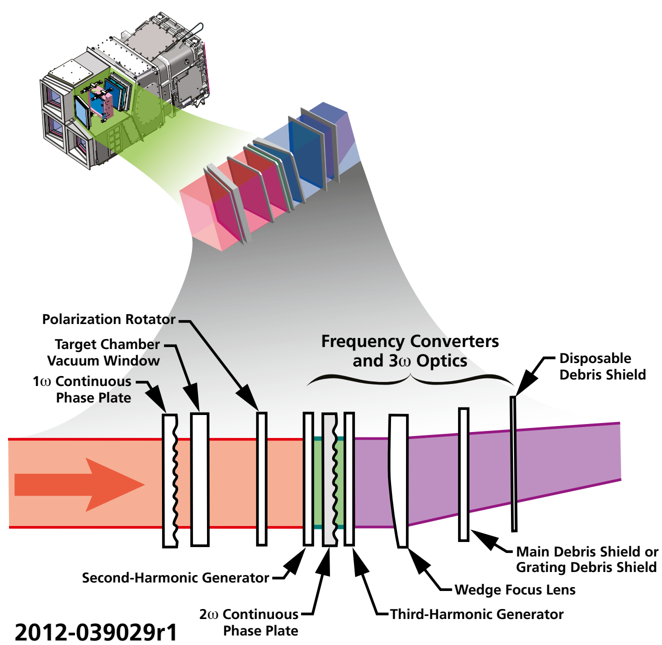

Figure 4-4. Schematic layout of NIF's final optics assembly for a single beamline. The mechanical system mounts to the NIF target chamber and contains the final set of optics for four NIF beamlines (one quad).

Individual beams are pointed near chamber center by tilting the LM5 and LM8 turning mirrors. The currently permitted range of pointing for each beam is nominally ±30 mm up/down and ±5 mm left/right in beam coordinates and ±30 mm in Z (along the beam direction) about the target chamber center (TCC). There are beam-specific limits imposed to manage near-opposed light and final turning mirror aperture issues. These limits are managed with a pointing range check in the Campaign Management Tool (CMT).

4.2. 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 for safe laser operation 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, 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 4.10.

Figure 4-5 shows the sustainable operational energy and power limitations overlaid on delivered pulse energy and corresponding power. Operating in the power/energy space defined by the grey circle shown in the figure minimizes the damage risk to the laser.

For any given experiment, the user-requested energies and pulse shapes are submitted to the Laser Performance Operations Model (LPOM) to assess their feasibility. LPOM simulates the beam fluence and intensity of each participating beam at all relevant points in the laser and checks the results for compliance with NIF's equipment protection limits. If any limit checks fail, NIF's expert groups are available to work with the experimenter to modify the pulse shape or energy requests to protect the laser while continuing to meet experimental needs.

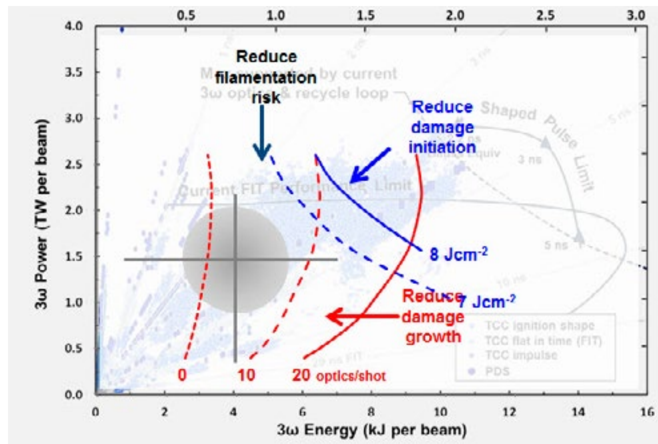

Figure 4-5. NIF's energy and power operational range. NIF laser performance limits are driven by optics damage and non-linear effects.

4.3. Laser Wavelength

NIF's front end consists of three individually tunable oscillators that are mapped to different cones. Inner 23.5° quads receive one wavelength, the 30° quads receive the second wavelength, and all outer cone (44.5° and 50°) quads receive the third wavelength. The installation of the three oscillators and the specific mapping of their wavelengths to the inner and outer cones is driven by the need to control and mitigate the laser plasma instabilities in the ignition hohlraums.[2]

[2] 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**.

Table 4-2. Current wavelength tuning ranges for the three oscillators on NIF.

Cone angle for the quads	Lower limit for wave-length tuning	Upper limit for wavelength tuning
Inner 23.5º and 156.5º	1052.85 nm	1053.41 nm
Inner 30º and 150º	1052.85 nm	1053.41 nm
Outer 44.5º, 50º, 130º, and 135.5º	1052.43 nm	1052.9 nm

The user requests a $\Delta\lambda$ wavelength separation between the inner and outer cones of beams that is required to meet the physics goals of the experiment. The potential backscatter risk due to laser–plasma interactions is reviewed by the backscatter working group, and if the request is safe for the facility, it is accepted for the shot. The absolute wavelengths consistent with the approved $\Delta\lambda$ are then determined by the facility in order to minimize the overall number of changes and impact to the schedule. These final wavelengths are then configured in the shot setup (i.e., in CMT) by the user.

4.4. Pulse Shape, Timing, and Prepulse

4.4.1. Pulse Shaping

The pulse shape and timing are common for all four beams within a single quad. Each quad may be independently configured for timing and pulse shape. NIF has the capability to produce a wide variety of precision pulse shapes. The flexibility of the pulse shaping is limited between the two quads within a single bundle due to amplifier configuration and residual gain issues.

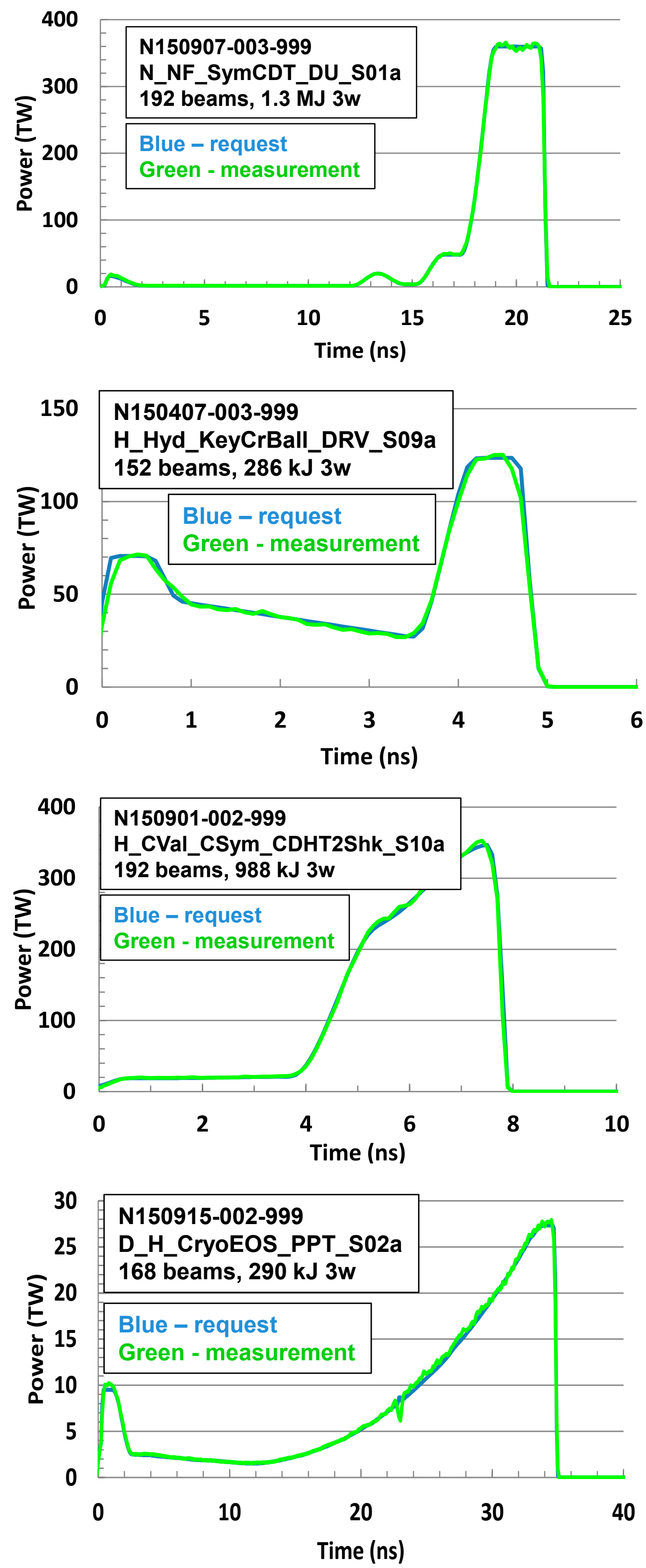

Figure 4-6. Some recent examples of pulse shapes delivered on target on NIF. In the bottom image, a longer than 30 ns pulse at the target chamber center (TCC) is generated by concatenating two under-30 ns pulses from different quads.

In order to request a pulse shape, the user enters the desired pulse shape and energy at the target through the shot setup. This request is then transformed to a Master Oscillator Room (MOR) pulse shape request through the LPOM setup calculations, which take into account the pulse shape distortions due to the main laser gain saturation and also due to the frequency conversion. The requested MOR pulse shape is then created using an arbitrary waveform generator (AWG). The maximum pulse width for any quad is currently limited to 30 ns due to the current MOR pulse-shaping hardware and the regenerative amplifier round-trip time. Figure 4-6 shows some recent examples of the sorts of pulses that can be generated on NIF. In addition to shaped pulses, NIF also can generate 88 ps full width at half-maximum (FWHM) Gaussian pulses (called “impulses”) used for point x-ray sources.

4.4.2. Pulse Synchronization and Delays

The four beams within each quad are synchronized to arrive simultaneously at TCC. 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_0 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.

The arrival times of pulses at the TCC on NIF can be independently adjusted on a per-quad basis. The desired pulse delays are requested by the user through the shot setup in CMT. For delays that contain the start and stop of the pulse within a 0–35 ns absolute time window, the NIF system can handle the timing changes automatically. Timing changes that result in the end of the pulse occurring after a 35 ns window require a delay fiber to be installed in the respective quad(s) to achieve the requested delay. The maximum allowable time delay could be up to 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.

Two quads within a common bundle must have a relative delay that is less than ~80 ns due to mechanical and electrical constraints in the Plasma Electrode Pockels Cell (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.

4.4.3. Prepulse

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 10^8 W/cm^2 of 1.05 µm light approximately 3–5 ns before the nominal start of the laser pulse shape.

4.5. Frequency Conversion and Unconverted Light Management

Primary operating wavelength for the target shots on NIF is the third harmonic of the 1053 nm fundamental wavelength at 351 nm. Efficient conversion of the amplified 1ω light to its third harmonic is accomplished by a pair of non-linear potassium dihydrogen phosphate (KDP) and potassium di-deuterium phosphate (DKDP) crystals installed in the beamline FOAs (Figure 4-4). First crystal combines two 1ω photons into a second harmonic photon at 527 nm (second harmonic generator or SHG) and the second crystal combines a 1ω photon and a 2ω photon into a 3ω photon at 351 nm (third harmonic generator or THG). The crystal thicknesses and cut angles are chosen to optimize the peak power conversion efficiency. However, since the conversion efficiency varies with intensity and experiments often require shaped pulses (such as those shown in Figure 4-6), there is a considerable amount of unconverted light remaining on NIF beamlines, particularly for shaped pulses. Most of the unconverted light is in 1ω.

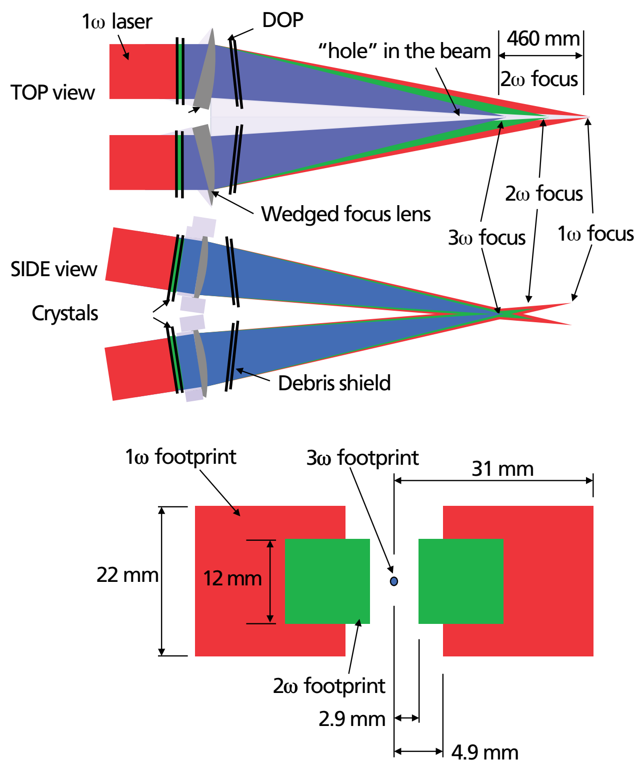

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Figure 4-7. Distribution of the unconverted 1ω and 2ω light at the 3ω focal plane from the NIF beams within a quad. The footprints from the two other beams in the quad overlap these.

The frequency conversion at the NIF FOAs results in all three harmonics (1ω, 2ω, and 3ω) entering the target chamber. The final focusing lens for each beam is wedged slightly to separate the three harmonics at TCC. Figure 4-7 shows the pattern of 1ω, 2ω, and 3ω light from a single quad when looking in the 3ω focal plane. The chromatic dispersion of the focus lens combined with the wedge angle of the lens gives a separation of ~2.9 mm between the closest 2ω beam edge from the 3ω aim-point and ~4.8 mm between the closest 1ω edge and the 3ω aim-point. The overlap becomes more complicated when multiple beams are focused to a given point. Figure 4-8 shows an example of the distribution of 1ω footprints from 96 NIF beams (upper hemisphere beams, for example) pointed and focused at TCC.

If this unconverted light is propagated past focus, it hits beam dumps at the far wall. Mitigation strategies to deal with the effects of the unconverted light are discussed in Section 5.6.1 and 5.6.2.

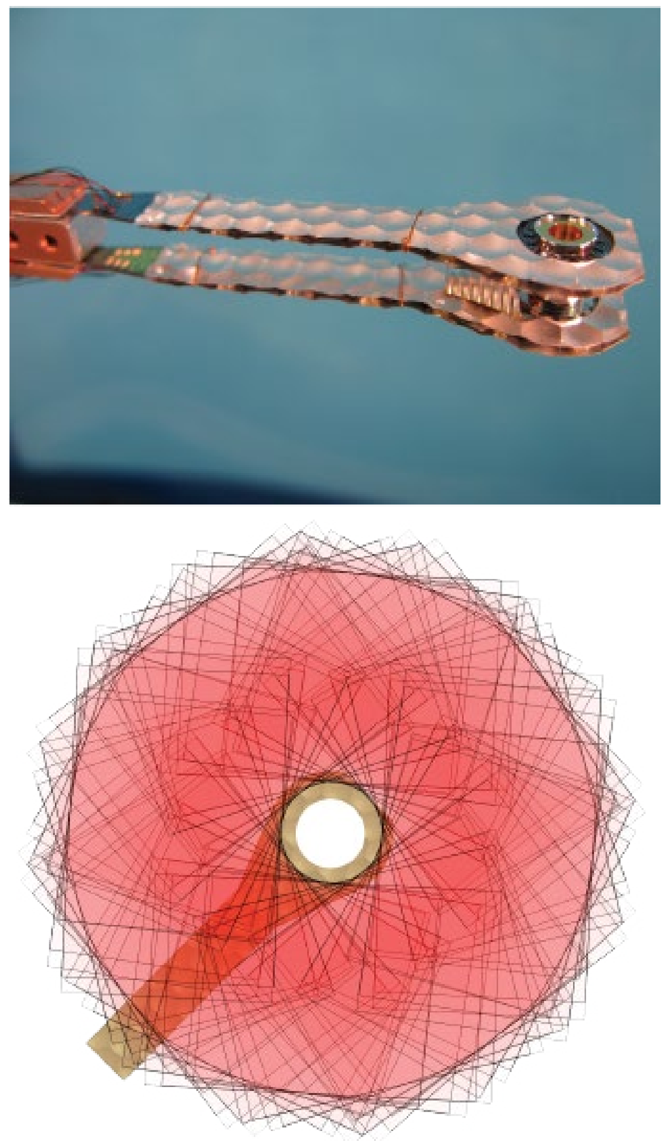

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Figure 4-8. (top) Cryogenic target with dimpled 1ω light shield. (bottom) Schematic display of the 1ω and 2ω unconverted light footprints from the 96 beams from one NIF hemisphere (upper or lower) in the plane of the unconverted light shield.

4.6. Focal Spot Conditioning

Large aperture, high power beams such as on NIF generally produce non-diffraction limited irradiance profiles at focus because of optical aberrations on the beams caused by the large number of optical surfaces. NIF beams produce about 150 μm spots (containing 50% of the beam energy) (see Figure 4-9). To limit the peak intensity and to lower the backscatter risk from targets, the focal spot is typically conditioned using continuous phase plates, smoothing by spectral dispersion and polarization smoothing.

4.6.1. Continuous Phase Plates

A continuous phase plate (CPP) is an optic that is presently located in the NIF final optics assemblies (FOA) between the SHG and the THG crystals. CPPs consist of deterministically imposed surface variations that add phase aberrations to the laser beams propagating through them. A typical CPP surface profile is shown in Figure 4-10. The effect of these phase aberrations is to broaden the focal spot profile in a controlled manner.

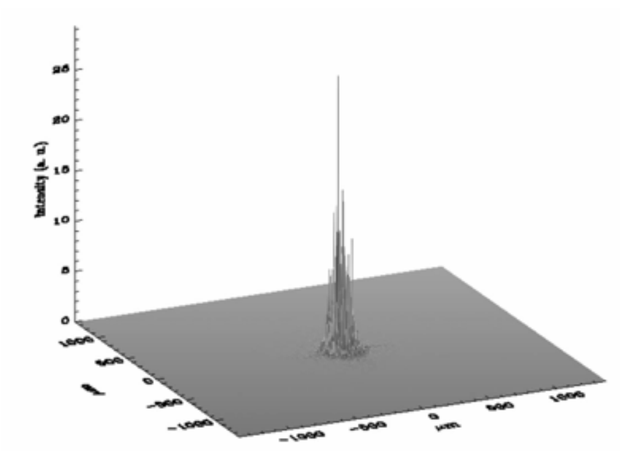

Figure 4-9. Typical focal spot of the NIF beam without a phase plate.

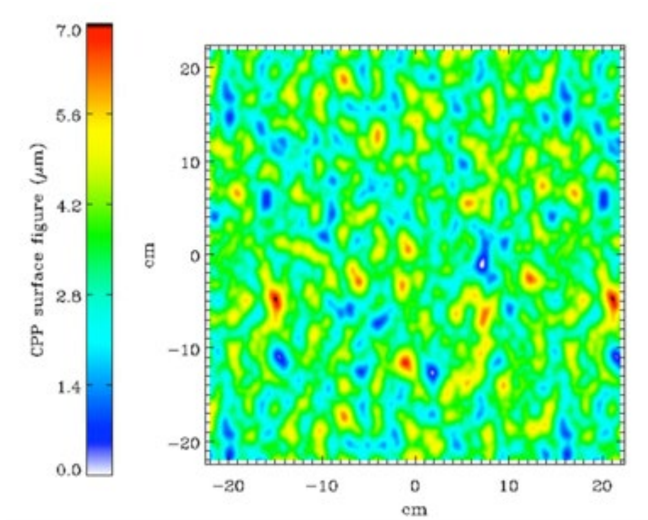

Figure 4-10. Example of the surface profile of a typical continuous phase plate (CPP).

Different CPP phase profiles can be applied to produce different sized focal spots. Table 4-3 below lists currently available CPP designs for use on NIF and the present default installation on the NIF beamlines. Figure 4-11 shows the expected focal spot sizes for the four currently installed CPP designs on NIF. The user can request removal of the CPPs from selected beamlines for a given experiment and can also request replacement of the default CPPs with the 400 μm designs in selected beamlines.

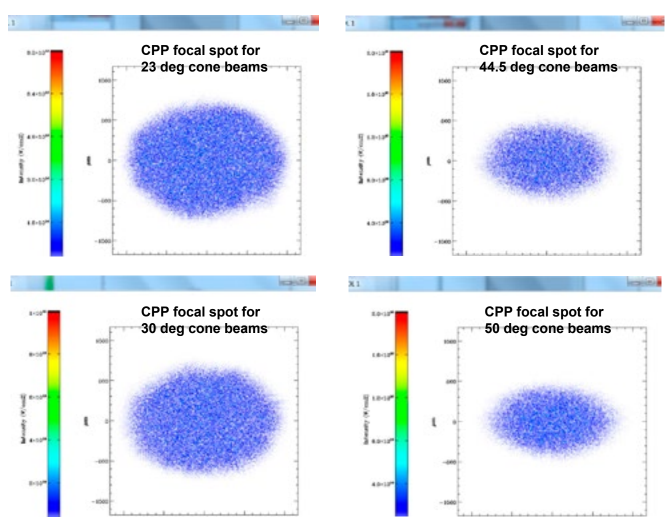

Figure 4-11. Focal spots for the default CPPs currently installed on NIF beamlines.

Table 4-3. Currently available CPPs for use on NIF.

Drawing Tab	CPP name in CMT	Current seating on NIF	Qty	Major axis diameter FWHM (a) (mm)	Minor axis diameter FWHM (b) (mm)	Ellipticity b/a
-16	Rev3 Inner Cone 2W CPP	Installed on 23° beams	32	1764	1262	0.72
-12	1.0 Rev1a Inner Cone 2W CPP	Installed on 30° beams	32	1648	1180	0.72
-17	Rev3 Outer Cone 2W Cpp	Installed on 44.5° beams	64	1270	734	0.58
-08	1.0 Rev1 Outer Cone 2W CPP	Installed on 50° beams	64	1186	686	0.58
-18	400µm_Round_2w	available for installation at user request	8	400	400	1.00

If a user requires CPP designs (focal spots) other than those listed in Table 4-3, adequate time and resources need to be allocated for the design, fabrication, installation and commissioning of the new CPPs on NIF beamlines. Users are encouraged to work with the NIF final optics team to realize this.

4.6.2. Smoothing by Spectral Dispersion

As shown in Figure 4-11, focal spots produced by the CPPs still contain speckle with peaks ~10 times the average. Such high intensity speckles can increase the risk of laser–plasma instabilities. Further conditioning of the focal spot is achieved by causing the speckle pattern to change in time and time averaging of the varying speckle pattern to reduce the high intensity speckles. This is schematically illustrated in Figure 4-12. The time averaging is realized by the hydrodynamic or plasma processes in the target environment. The time variation of the focal plane speckle is achieved by a process known as smoothing by spectral dispersion (SSD). In SSD, a small amount of frequency modulated (FM) bandwidth is added to the laser, and this is angularly dispersed using a diffraction grating in the front end. The angularly dispersed frequencies lead to a spatial offsetting of the focal spot produced by the CPP. The time averaging of this dispersed spot then leads to a reduction of the focal plane contrast—often referred to as speckle averaging. On NIF, the FM bandwidth is applied using a 17 GHz frequency modulator in the MOR region. The minimum SSD bandwidth is restricted to 45 GHz at 1ω. If higher SSD bandwidths than 90 GHz are needed for a given experiment, this should be negotiated with the NIF operations team and expert groups.

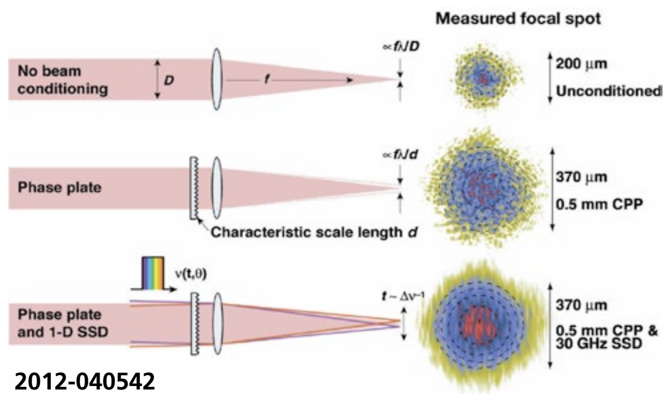

Figure 4-12. Schematic illustration of how CPPs and 1-D smoothing by spectral dispersion achieve focal spot conditioning.

4.6.3. Polarization Smoothing

Since orthogonal polarizations do not interfere with each other, two orthogonally polarized, uncorrelated speckle patterns can be overlapped in the target region to achieve a reduction in the speckle contrast. This mechanism is known as polarization smoothing (PS). The advantage of PS is that it does not require any time averaging as is needed for SSD smoothing. The limitation of PS is that the maximum contrast reduction is $1/\sqrt{2}$ because of only two available orthogonal polarizations. In spite of this limitation, many plasma instabilities have shown that PS has significant benefits due to the time-instantaneous nature of speckle smoothing.

PS on NIF is implemented on a quad basis in the 1ω section of the FOA. Polarizations on two beams in a quad are rotated by 90⁰ using full-aperture KDP or DKDP half-wave plates in the 1ω section of the FOA. See Appendix C for a polarization seating chart.

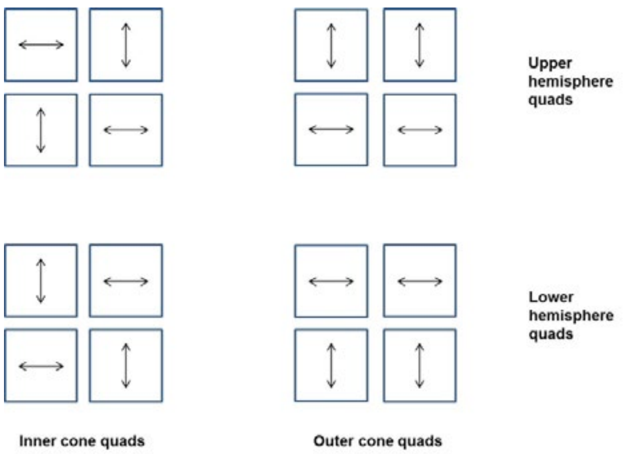

Figure 4-13. Schematic of the distribution of the 3w polarization within various NIF quads.

4.7. 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 ≈20 ns total duration 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%.

For each quad on NIF, we have one power sensor in the input sensor diagnostic package (ISP), two 1ω power sensors at the output sensor package (OSP) and one 3ω power sensor in the 3ω drive diagnostic package. Thus we get a direct measurement of the 3ω power vs time on a quarter of the NIF beams. 3ω power for other beams in a quad is derived using the 1ω power sensor data (from ISP or OSP) and flowing this forward to the 3ω power using LPOM calculations. The flow-forward power is then normalized to the measured 3ω energy. This data is then used to deduce 3ω power accuracy and power balance.

4.8. Laser Performance Operations Model

The Laser Performance Operations Model (LPOM) is an integrated computational system designed to accomplish multiple NIF operations functions.

1. LPOM automates the calculation of the laser setup required to achieve experimental goals. LPOM is built around a physical optics propagation code, the Virtual Beamline (VBL). VBL code, using a detailed NIF laser model, does a back solve to come up with a required pulse shape needed to deliver the requested 3ω pulse shape by the user. This is an essential step that enables NIF to deliver high precision pulse shapes for experiments (such as those shown in Figure 4-6). A shot setup for a 192 beam NIF experiment can be completed in approximately 20 minutes.
2. The LPOM suite of codes completes a laser post shot data analysis to assess the delivered energy, power, etc. to the expected values. Additionally, near-field contrasts, power accuracy and power balance are calculated. Deviations between the measured and the expected quantities are used to update the laser models to improve future performance. Periodic adjustments of the code's energetics parameters have allowed LPOM to predict total energies within 2–3%, and provide beam-to-beam energy balance better than 5% for full system

shots with energies and powers as high as 1.8 MJ and 500 terawatts (TW).

3. LPOM also manages the equipment protection on the NIF laser. It uses the data gathered from the Final Optics Damage Inspection (FODI) measurements to determine where to place the Programmable Spatial Shaper (PSS) blockers to block the damage sites from further growth. For a given laser setup the LPOM package uses the built-in rules to assess the risk of damage to optics throughout the laser chain (front end, Injection Laser System (ILS), the main amplifier, and the final optics).
4. LPOM can also be used in a stand-alone mode to conduct exploratory studies to enable new, safer laser configurations and design new experimental operational platforms.

Together with the optics loop tools, LPOM is a valuable asset for designing NIF experiments.

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 recalibrate its models 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.

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.

4.9. Optics Recycling Strategy

The NIF laser is routinely operated at or slightly above the damage threshold limits in order to extract the maximum performance. This operating mode often results in damage to the FOA optics, which are exposed to the highest powers and fluences. We manage and mitigate the optical damage in multiple steps. The FOA optics on all 192 beams are inspected after high fluence shots using FODI. If a damage site is detected on an optical component, it is logged and included in the performance model for the laser. It is also monitored with subsequent FODI inspections for growth. The growth of a damage site is arrested by blocking a small amount of the beam (~2 cm diameter disc) centered on the damage site location using the PSS on NIF. The number of such blocked sites is limited to such that the energy loss is less than 5% per beam. Periodically, we exchange the damaged FOA components (crystals, WFLs, and grating debris shields) with fresh ones. The optical damage sites are mitigated[3] in an offline facility and the mitigated optics are placed back into service (recycled) by installing them on NIF beamlines. We also continue to develop processes that produce more damage-resistant optics so they can be in the beamline for a larger number of shots.

A damage risk assessment is calculated for each proposed experiment on NIF. The sequencing of experiments is arranged such that the damage to the optics and growth rate of damaged sites from the shots is optimally matched to the damage mitigation and refurbishment rate. Current mitigation and recycling facility capacity is able to support over 400 experiments per year on NIF.

[3] M.L. Spaeth et al., “Optics Recycle Loop Strategy for NIF Operations Above UV Laser-Induced Damage Threshold,” *Fusion Science & Technology* **69** (2016).

4.10. Advanced Radiographic Capability

In the first quarter of FY2016, the NIF facility commissioned the Advanced Radiographic Capability (ARC) short-pulse laser system. ARC high-energy backlighting capability is required for the Stockpile Stewardship Program (SSP)-High-Energy-Density (HED) and SSP-Inertial Confinement Fusion (ICF) programs. Two beams in a single NIF quad (Q35T) are converted into four ARC "beamlets"; the infrastructure to convert the other two beams in the quad to four more beamlets is partially installed in the NIF target bay. A layout of the ARC system is shown in Figure 4-14. Conversion of NIF beamlines to high-intensity, picosecond operation requires three top-level changes to the existing NIF beam lines:

- Addition of the High Contrast ARC Front End (HCAFE), which provides dual regenerative amplifiers for split beam injection.
- Improved amplifier isolation for backscatter protection.
- Pulse compression in the NIF Target Bay and final focusing optics.

The HCAFE uses short pulse optical parametric amplifier technology[4] to meet the high temporal contrast requirement of 80 dB for $t < -200$ ps before the main pulse (70 dB at TCC). The dual amplifiers on the ARC Dual Regen Table and split beam injection produce two beamlets that can be independently timed (0–20 ns currently) and pointed (0–1 mm currently) to a target. Pointing between the B353 and B354 pair of beamlets is currently ± 50 mm. The short-pulse output of the compressor is diagnosed using the ARC Diagnostic Table (ADT) during system shots. The ADT is capable of measuring key short-pulse laser performance metrics (near-field and far-field intensity patterns, pre-pulse levels, spectrum and energy in the compressed pulse, etc.) on system shots. The measured focal spot performance goal for a 1.5 kJ beamlet with 30 ps FWHM Gaussian pulse is 50% of the energy with $\geq 10^{17}$ W/cm^2 irradiance and contained in 150 µm spot size.

Currently, ARC is commissioned at 30 ps pulses and 1 kJ per beamlet. As ARC optics are upgraded and laser performance optimized, the maximum energy will increase to 1.5 kJ at 30 ps pulse length. As new user requirements are developed for future missions, ARC will be commissioned at different operational parameters (pulse length, beamlet timing and pointing, etc.).

[4] C. Dorrer et al., "High-contrast optical-parametric amplifier as a front end of high-power laser systems," *Optics Letters* **32** (15), 2143 (2007).

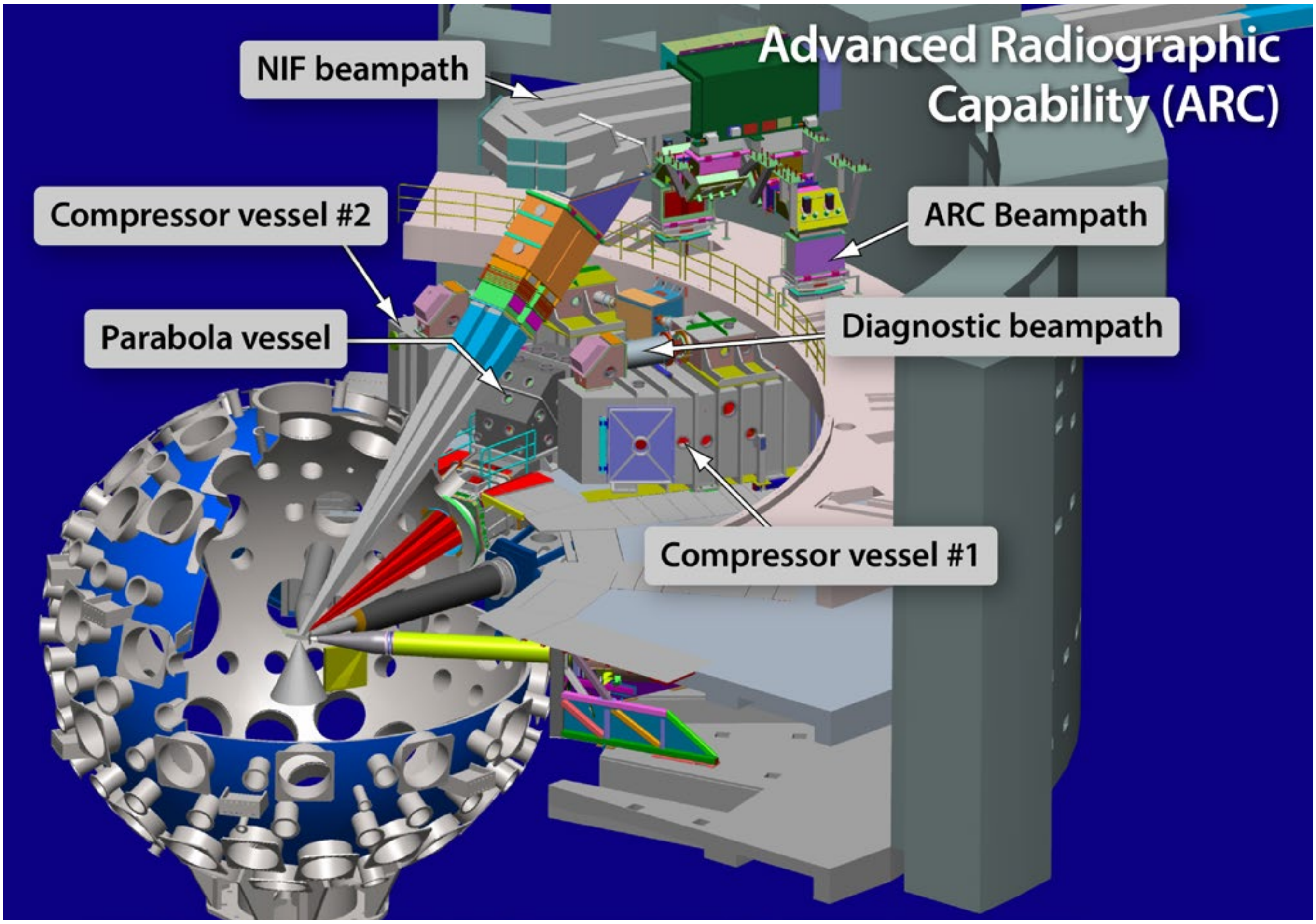

Figure 4-14. Advanced Radiographic Capability (ARC) system in the NIF Target bay. The ARC beamlets (shown in red) enter the chamber from ports near the chamber's equator.

5. Target Area

This section provides a description of the target area, with information on port allocation, target handling, and target and beam alignment capability.

5.1. Target Chamber Layout

The NIF target chamber is located in a cylindrical section of the Laser and Target Area Building (LTAB). The target area is approximately 100 feet in diameter and 100 feet high. Two views of the target area are shown in Figures 5-1 and 5-2.

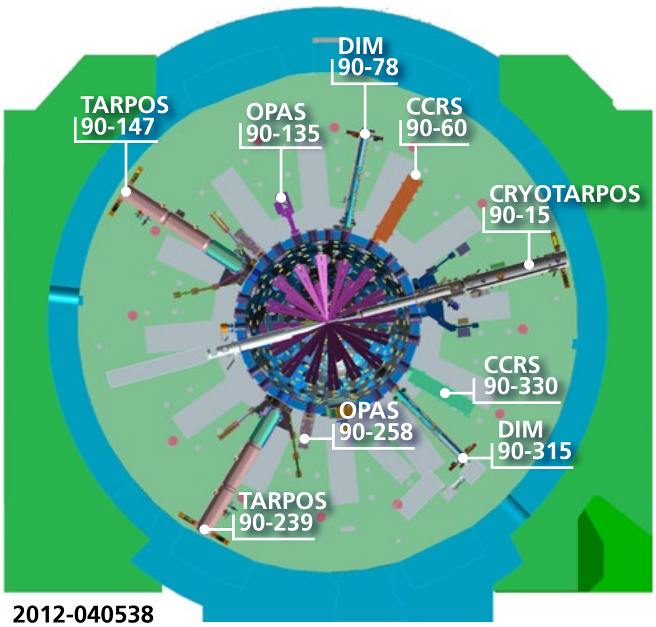

Figure 5-1. Top view of the target area at waist level.

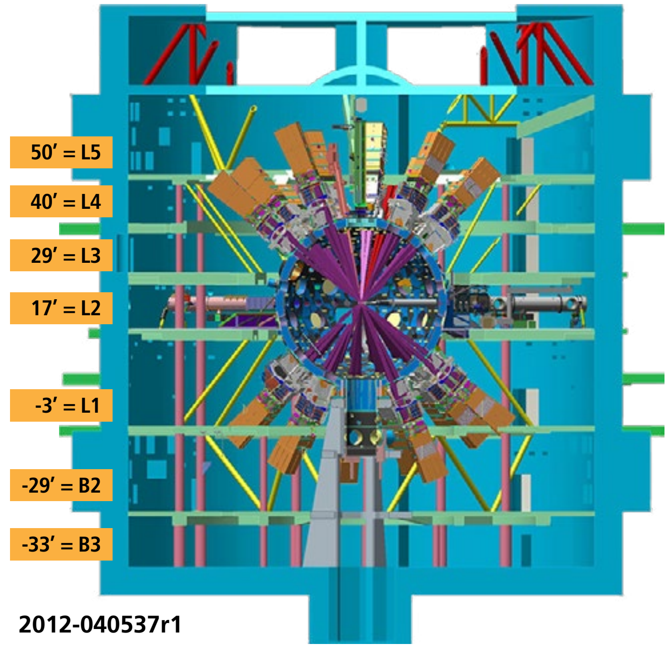

Figure 5-2. Elevated view of the target area.

5.2. 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 5-3). 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 are available for a future symmetric direct drive NIF configuration. A complete listing of the beam ports is provided in Table 4-1.

There are diagnostic ports from 18 cm to 53 cm in diameter distributed around the target chamber. These ports are shown on Figure 5-3. 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 5-1.

There are also access ports and ports designated for the alignment systems, including the target positioner (TARPOS). These are described in Section 5.4.

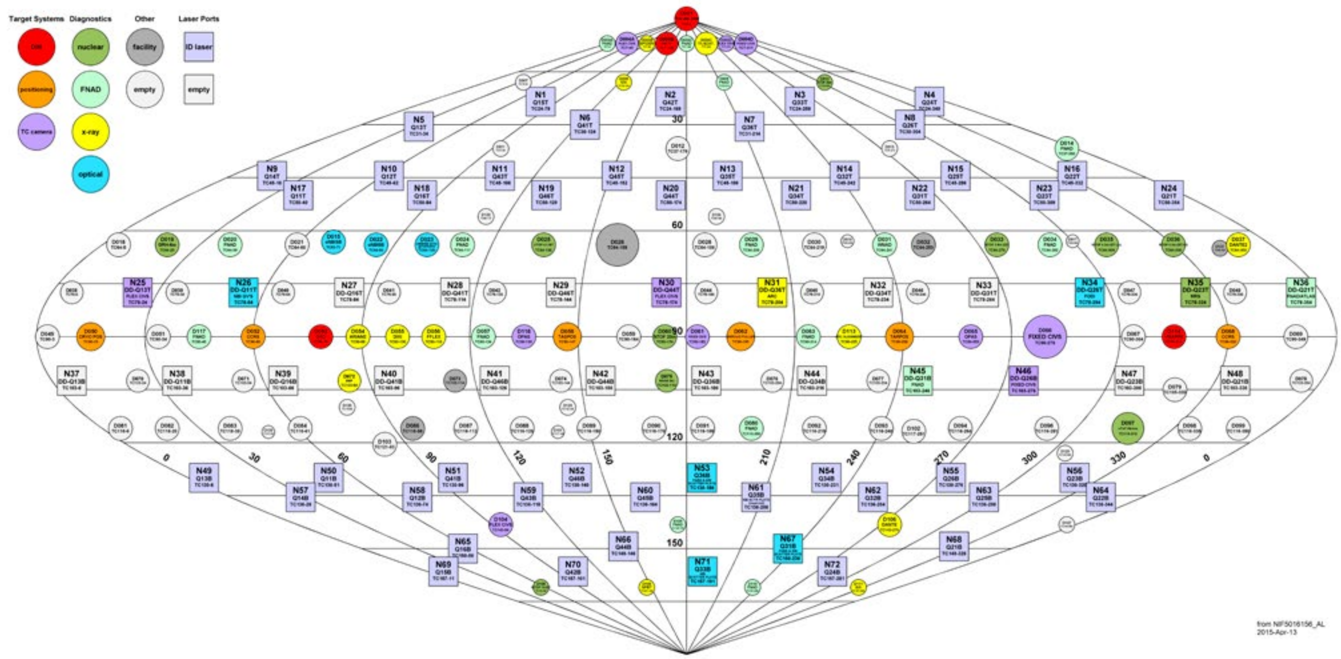

Figure 5-3. View of the NIF target chamber, showing the location of quads and major diagnostics. Diagnostic placement may vary depending on the experimental campaign.

Table 5-1. 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)	0 pt	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

Port	Θ	Φ	Size (mm)	0 pt	Θ	Φ	Size (mm)
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
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-	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

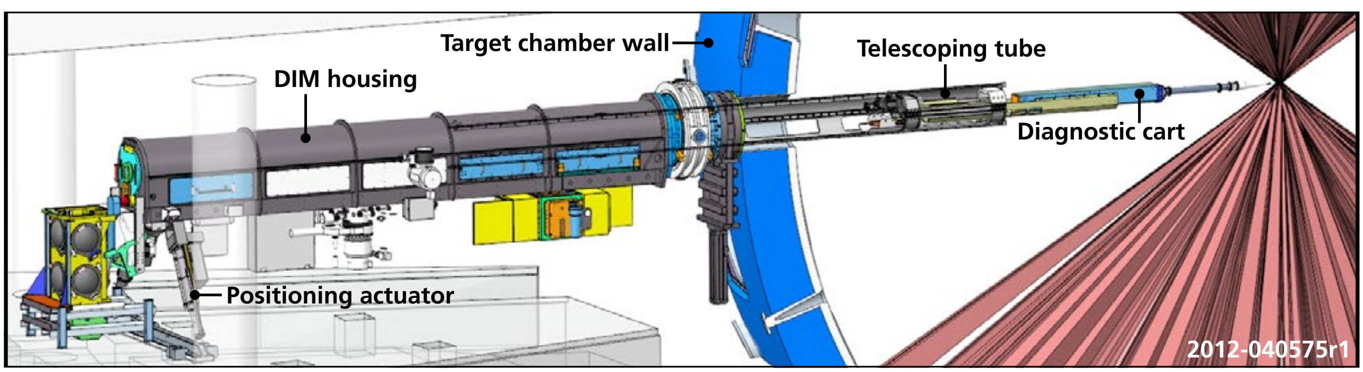

Figure 5-4. Diagnostic Instrument Manipulator (DIM), showing the housing, extension tube, and diagnostic in an extended mode.

5.3. Diagnostic Instrument Manipulator

A Diagnostic Instrument Manipulator (DIM) is provided on a few 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 diagnostics for different experiments.

For more information on DIM and designing diagnostics for DIM, see Section 6.3.

5.4. Target Handling Capabilities

5.4.1. Target Positioners

NIF is equipped with two target positioners (TARPOS), located at 90-239 and 90-015, which are capable of holding cryogenic and non-cryogenic ("warm") targets, including gas targets. The TARPOS at 90-015 is designed to handle layered targets, including those containing tritium. It is commonly referred to as "cryoTARPOS," though both TARPOS can field cryogenic (but not layered) targets.

The cryoTARPOS has an in situ, three-axis x-ray viewing system and can handle large quantities of tritium for producing cryogenic layers of tritium–hydrogen–deuterium (THD) gas mixtures (see Section 5.4.3).

Both TARPOS provide for positioning a target within ±5 cm of TCC. Translation in the vertical direction by ±5 cm is achieved by a combination of rotation about the gimbal and an opposite bend ("nod") approximately 2 m from chamber center (see Figure 5-5). These same motions allow for up to a 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.

TARPOS also provides for ±14° rotation about the axis of the positioner itself; the limit is due to internal cabling. Each is outfitted with a cable harness that includes wires for temperature control of a cryogenic target system[5], gas fill lines, fiber optics (90-239 only), and other power cables.

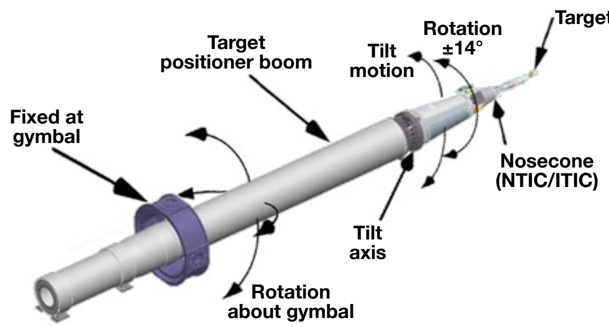

Table 5-5. Diagram of the target positioner, showing the degrees of freedom for positioning a target.

5.4.2. Positioner Interfaces

Targets are mounted on both target positioners to the normally installed Target Insertion Cryostat (TIC). The TIC provides the structural interface to the positioning systems, and also contains the on-board cryostat that is cooled by a high-pressure He compressor and on-board expander system (as well as associated instrumentation and heaters).

Three types of mounts are provided to interface targets to the positioner. Cold targets (and some warm targets) are mounted to the copper cold rod on the TIC via a target gripper base (Type 1, Figure 5-6). Most warm targets are connected to the TIC by a universal Kinematic Mount (KM) base (Type 2, Figure 5-6). Both of these mounts can interface with the TIC gas system lines (described below) to allow for target gas fills. A third type of mount is only used for mounting TARDIS (target diffraction in situ) targets (Type 3, Figure 5-6). Interface Control Drawings (ICD) AAA12-112562 (TARPOS) and AAA14-114368 (cryoTARPOS) describe the interfaces.

[5] 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*.

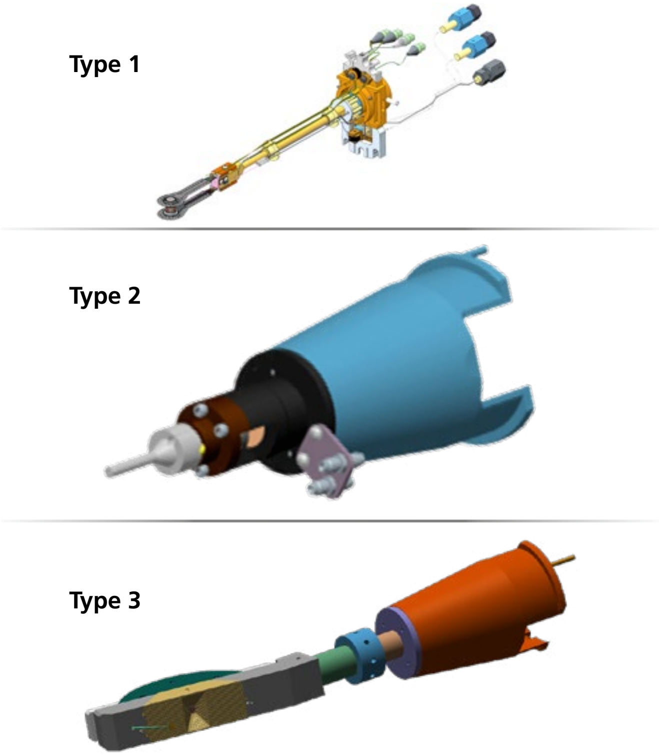

Figure 5-6. Three types of target mounts. Type 1: Target Inserter Cryostat and gripper-based target on the cryogenic target positioner (cryoTARPOS). Type 2: Kinematic Mount base. Type 3: Target diffraction in situ (TARDIS) assembly and mount.

5.4.3. Tritium Handling

NIF is capable of fielding tritium-containing targets on both cryoTARPOS and TARPOS. 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 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 THD) in small pressure vessels known as reservoirs. These reservoirs are 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 bases 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 specifications provided by experimenters. These mixes must meet both tritium facility and NIF limits and be compatible with NIF system capabilities.

For both cryoTARPOS and TARPOS, the mix and pedigree of fusionable-gas fills (including T, D, and ^{3}He) and the target design are controlled to manage the potential neutron yields for a given shot and help determine 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 (if possible).

5.4.4. Gas Fill

Both TARPOS and cryoTARPOS are provided with three gas systems that enable in situ target filling with various combinations of cryogenic and condensable gases. Each positioner contains five gas lines that run from the target interface through the positioner boom to the wall-mounted target gas manifolds (TGMs) in the target bay. One line is a high-pressure line, normally used to fill cryogenic capsules. Two additional lines are typically used to fill hohlraums with low-pressure cryogenic gases. The final two lines are normally used to fill warm targets with low-pressure condensable gases. Lines are typically 0.030” internal diameter stainless steel, ending in VCR fittings near the target interface.

Three nearly identical TGMs are provided for each positioner (Figure 5-7). These provide the remotely operated valving, sensors, and vacuum resources necessary to pump/purge the targets and associated gas lines and fill them with the proscribed gas fill at the requested pressure.

With the exception of ^{4}He, gases are filled from individual shot bottles that are filled on site with the requested gas mixtures. Shot bottles may be used for one to several shots, depending on the gas type, requested shot pressure, and bottle size. The target operations group manages the gas bottle preparation and operations. Custom gas mixtures are characterized on-site by mass spectrometry. Certifications for all gases used are available through the Location, Component, and State (LoCoS) system.

A number of different gases and gas mixtures and various pressures have been shot to date. Tools to assist in calculating cryogenic gas properties are available; a target gas density calculator can be requested from the NIF User Office, or see the Target Operations group for assistance.

Commonly used gas fills (the combinations of gas mix, fill pressure, and temperature) are listed in Appendix D. (A current version may be obtained from the Target Operations group). These are considered standard, and may be routinely specified by experimenters. Other combinations are possible, but may require significant advance planning and effort (or may not be possible due to physical or equipment limitations). Contact the Target Operations group very early in the planning process to help ensure that your request can be accommodated.

Figure 5-7. Cryogenic System Operator installing a shot gas bottle on a target gas manifold.

5.4.5. Target and Diagnostic Manipulator

Beginning in late FY2016, a third positioner will be available at target chamber location 90-348. This new system is referred to as the Target and Diagnostic Manipulator (TANDM) and will be able to be used as both a target positioner and a diagnostic positioner (see Section 5.3). The 90-348 TANDM will be able to field the same capabilities as the other DIMs, with the same cable plant and data acquisition capability as DIM 90-78. TANDM will be able to field warm gas-filled targets. The expectation is that the TANDM will be able to transition from diagnostic positioner to target positioner in less than four hours.

5.5. Target Area Alignment

Target and beam alignment are done using the chamber center reference system (CCRS), the target alignment sensor (TAS), and TARPOS, positioned around the target chamber as illustrated in Figure 5-1. Details on the individual components and procedures are available elsewhere, but a summary is provided here.

Target Chamber Center (TCC) is defined by the intersection of two orthogonal optical axes, called the chamber center reference system. Each of the CCRS consists of an optical telescope that has a view of the volume ±5 cm relative to TCC. These telescopes are used to position the target alignment sensor at any specific location near TCC to within about 10 µm.

TAS consists of a frame with four optical views of TCC from the top, bottom, and two sides. 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 5-8).

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

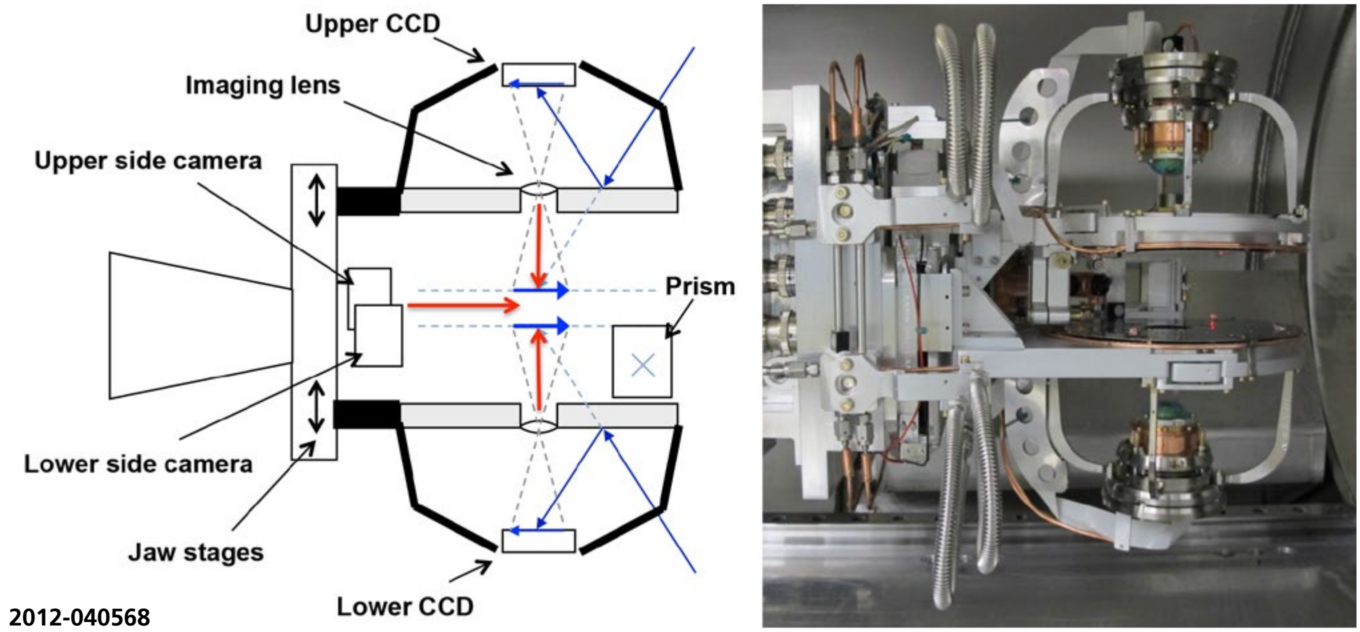

Figure 5-8. Diagram of the Target Alignment Center, showing the three directions for viewing the target (red arrows) and the mirrors for equivalent plane beam alignment.

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 consistent with alignment using the TAS.

NIF target alignment is described further in *An overview of target and diagnostic alignment at the National Ignition Facility*[6] and *Beam and target alignment at the National Ignition Facility using the Target Alignment Sensor (TAS)*.[7]

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

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

5.6. Beams to Target

5.6.1. Unconverted Light

The conversion of the 1ω (1.05 μm) light at NIF into 2ω and 3ω (0.53 and 0.35 μm) light is described in Section 4.5. The effect on the laser system and target chamber of the residual 1ω and 2ω light following frequency conversion must be taken into account in experiment design. 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 TCC, 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. The unconverted light that propagates past the target strikes beam-dumps consisting of stainless steel louvered panels that are designed to capture this light and prevent any ablated material from being ejected into the chamber.

Unconverted light incident on target needs to be taken into account and managed with the target design.

5.6.2. Counterpropagating Light

The NIF target chamber is set up to avoid direct propagation of the 1ω laser past TCC 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.

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 depending on the orientation of the target. 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, the 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 on both 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 Velocity Interferometer System for Any Reflector (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 small radius of curvature in one dimension, and larger conical shape in the other.

5.7. 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*[8] or *NIF Fiducial System Architecture*.[9]

5.8. 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 target chamber. Whenever an 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*[10] and *Debris and Shrapnel Mitigation Procedure for NIF Experiments*.[11]

5.9. Cleanliness and Materials

All components for user-supplied hardware that will be exposed to the NIF target-chamber vacuum will have to meet NIF cleanliness and vacuum compatibility. The materials and cleanliness of equipment or experimental assemblies, including target assemblies, that will be attached to or inserted into 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 anti-reflective coatings used on lenses and other transmission optics. *All materials and assemblies that are proposed for use on or in NIF must be reviewed and approved before they may be used. Prior to installation they must also be cleaned by NIF-approved cleaning vendors using special processes that ensure compliance with NIF cleanliness requirements.*

Materials review and approval and relevant cleaning processes are communicated in a formal written NIF Materials Assessment issued on behalf of the NIF Cleanliness Steering Committee by its chairman, the Group Leader of NIF Operational Cleanliness. NIF Operational Cleanliness personnel conduct evaluations of materials and cleaning that are required as a part of the materials review and approval process and also provide oversight of clean rooms, cleaning vendors, and facilities in which clean assembly of equipment is performed to assure compliance with NIF cleanliness protocols. The Group Leader of NIF Operational Cleanliness is responsible for materials reviews and generally writes and issues the NIF Materials Assessments. In this capacity, the Group Leader for NIF Operational Cleanliness works directly with the responsible individuals (RIs) for systems and assemblies proposed for

[8] *Component Specifications for Fiducial Generation and Distribution Subsystem*, NIF-5002565.

[9] *NIF Fiducial System Architecture*, NIF-5003450.

[10] *Debris and Shrapnel Risk Management Plan*, NIF-TBD.

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

use on NIF to assure the completeness of the Materials Assessments and to arrange for any testing that may be required. The evaluation of complex assemblies can often require many weeks or months, so RIs are urged to begin the materials review early in the design process. The chairman is also a member of the Target and Laser Interaction Sphere (TaLIS, Section 3.3) Committee and in this capacity approves all target assemblies for materials and cleanliness. These approvals will not be granted unless a relevant NIF Materials Assessment has been completed and issued. For further information and to initiate a NIF Materials Assessment contact the current Group Leader for NIF Operational Cleanliness, William H. Gourdin, or the NIF User Office.

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6. Target Diagnostics

6.1. Overview

Large laser and pulsed power facilities at national labs such as LLNL have afforded the scientific community significant experience with measuring high-energy-density plasmas and with developing routine, reliable, and accurate diagnostic suites. NIF's diagnostic development benefits from those decades of experience and from the involvement of organizations such as the University of Rochester's Laboratory for Laser Energetics, Massachusetts Institute of Technology, General Atomics, National Security Technologies, and the UK and France's atomic energy agencies.

NIF is equipped with an array of nuclear, optical, and x-ray diagnostics that together provide over 400 channels for experimental data. New instruments are added regularly (see **https://lasers.llnl.gov/for-users/experimental-capabilities/diagnostics**). Optical diagnostics measure the backscattered 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 gamma radiation and measure physical properties such as neutron yield, ion temperature, bang time, core temperature, and reaction history.

NIF diagnostics are either deployed to a fixed location in the target chamber/bay or fielded on a Diagnostic Instrument Manipulator (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 (TCC). DIMs can fit in a number of designated target chamber ports, but three are currently mounted in two locations: one in the target chamber north pole (0-0) and two on its equatorial plane (90-78 and 90-315); see Section 5.3. DIMs also provide a standard set of utilities, cables, and controls to support operation of all DIM-based diagnostic instruments.

Facility-provided diagnostics data locations are listed in Table 6-1. Table 6-2 lists key DIM snouts and appendages that can be used in conjunction with a DIM-based detector. Figure 5-3 shows the location of the DIMs, target positioners, and major fixed diagnostics. Appendix E 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 any of the DIMs. If an instrument at a fixed location requires a pinhole or filter on a DIM, this is noted.

Table 6-1. Instruments for which automated data reduction is available.

Location	Diagnostic	Diagnostic Description	Facility-Provided Automated Data Analysis Outputs
90-315	VISAR	Velocimetry Interferometer System for Any Reflector: Streak image for reflections from shock waves and surfaces	Streak image that is cross timed and corrected for background, flat field, saturated pixel, and warp.

Location	Diagnostic	Diagnostic Description	Facility-Provided Automated Data Analysis Outputs
Q31B, Q36B, Q33B	FABS/NBI	Full Aperture Backscatter and Near Backscatter Imager: spectrometers, static, and streak image detectors for energy balance and backscattered energy	Estimated backscattered energy to each cone.
7-90	SPIDER	Streaked Polar X-Ray Imager: for measuring x-ray burn history	Cross-timed x-ray bang time and burn width. Corrected and cross-timed streak image.
90-100	DIXI	Dilation X-Ray Imager: for high temporal resolution imaging of implosion shape and time history	Camera image corrected for warp, saturated pixel, flat field, and background. Image plate data is fade corrected.
90-78, 0-0, 90-315	GXD, HGXD	Gated X-Ray and Hardened Gated X-Ray Detectors for imaging of implosion shape and time history	Timing of gated pulses. Image plate data is fade corrected. Film data is linearized.
0-0, 90-78, 90-315	DISC	DIM Insertable Streak Camera: for measuring implosion velocity on backlit shots	Streak image that is cross timed and corrected for background, flat field, saturated pixel, and warp.
18-123, 161-326	SXI	Static X-Ray Imager: for imaging radiation drive through laser entrance hole	Corrected reoriented camera image (and estimate of laser entrance hole (LEH) size using camera image). Image plate data is fade corrected and reoriented (and used to estimate LEH size).
90-110	FFLEX	Filter Fluorescer: hard x-ray detector for measuring electron preheat	Hot electron temperatures.

Location	Diagnostic	Diagnostic Description	Facility-Provided Automated Data Analysis Outputs
64-350, 143-274	DANTE	Soft x-ray detector for hohlraum drive and temperature	Voltage traces at each x-ray energy cross timed and corrected for scope, attenuation, and cabling. Filter response for each x-ray energy channel. Estimated x-ray temperature profile over time.
161-146	SPBT	South Pole Bang Time: x-ray detector	Integrated energy under bang.
64-20	GRH	Gamma Reaction History: nuclear burn history and fuel density	Gamma bang time and burn width. Scope traces cross timed and corrected for scope, attenuation, Mach–Zhender system, and gamma detector.
90-315	NIS	Neutron Imaging System	Camera image corrected for warp, saturated pixel, flat field, background, and microchannel plate (MCP) gain. Fiducial time.
161-56, 116-316, 90-174, 64-136, 64-309	NTOF	Neutron Time of Flight: for measuring prompt and downscattered neutrons at several locations around the target	Yield and ion temperature of DT or DD peak. Downscattered ratio of 10–12 MeV yield to 13–15 MeV yield.

6.2. New or Modified Target Diagnostics or Components

Before a new or modified piece of equipment can be deployed at NIF, it must undergo a formal process, including one or more reviews. The review scope is adjusted according to the complexity and risk associated with the product. Reviews may include NIF representatives from the steering committee, operations, Target and Laser Interaction Sphere (TaLIS), shot setup/Campaign Management Tool (CMT), diagnostics, mechanical engineering, assembly, cleanliness, snouts, instrument mounting, and others, depending on the instrument's complexity and intended use.

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

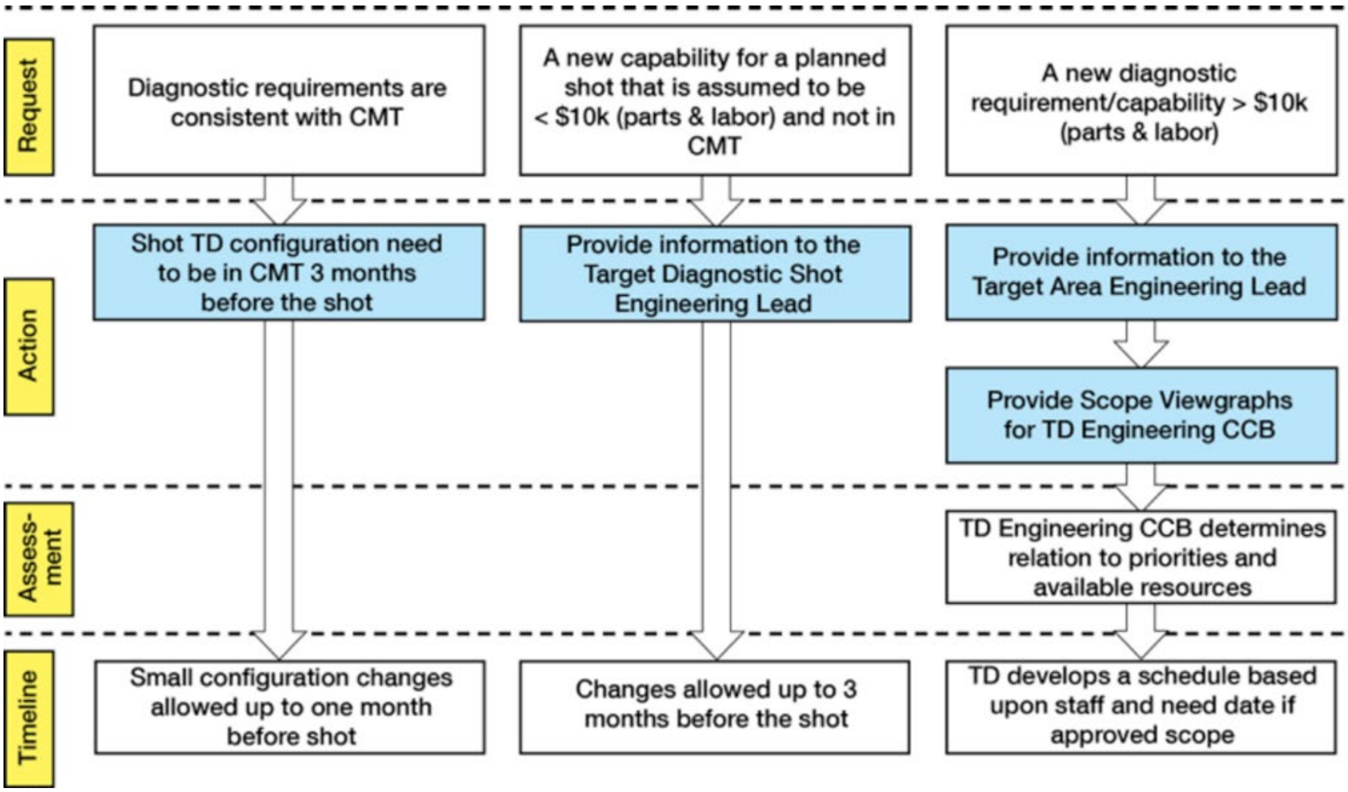

Figure 6-1. The process flow for designing, building, and installing a new diagnostic at NIF. CCB is change control board, TD is target diagnostics, and CMT is campaign management tools.

6.2.1. Simple Configuration Changes

For minor configuration changes, such as switching to a different filter, pinhole collimator, or snout type using in-stock materials, the Shot Responsible Individual (RI) should contact the Target Diagnostic Shot (TDS) Engineering Lead. Requests are reviewed at the twice-weekly three-month pre-shot review meeting. The CMT target diagnostic configuration (see Section 8.1, User Tools) is completed three months before the experiment, but small changes are allowed up to one month before the experiment for existing items in CMT.

6.2.2. Small Hardware Modifications

Small hardware modifications to existing diagnostics are those that cost less than $10,000 in materials and labor, such as a new holder or filter configuration or a new snout tube or cap. For such modifications, the Shot RI contacts the TDS Engineering Lead, preferably six and no less than three months before the shot date with the change request. If it is determined that the request cannot be completed within the budget or timeframe guidelines, it will be considered a new capability request.

6.2.3. New Capabilities

The Shot RI must contact the Target Area Engineering Lead to request the development of capabilities that cannot be achieved through small hardware modifications and/or that will cost over $10,000. Examples might include a new VISAR filter wheel, new streak camera sweep speed options, or spectrometer crystal changes. Requests must be made at least six months in advance of shot date, and more for complex projects.

Primary steps in the process include:

- The Shot RI and TD representative prepare a written set of requirements, including clearly defined performance criteria and

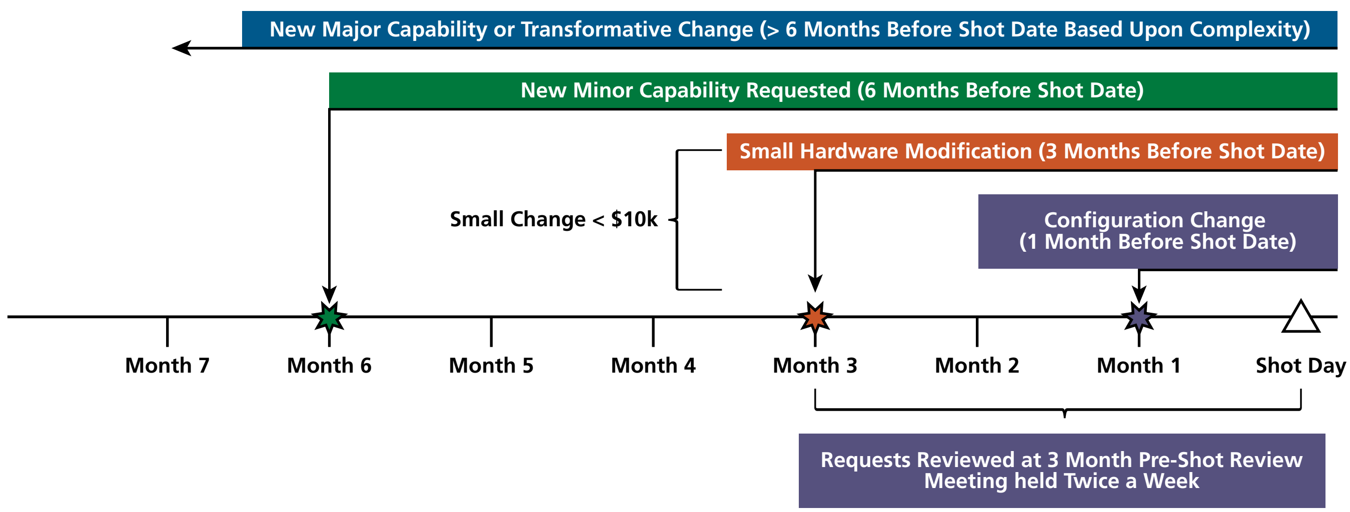

Figure 6-2. Timelines for diagnostic development, existing diagnostic modifications, and minor configuration changes.

requirement verification methods.

- The Target Diagnostics Engineering Change Control Board (CCB) reviews the requirements and ensures that they fit within budget, scope, and staffing.
- Once the scope is approved, Target Diagnostics develops a schedule for construction, testing, and installation based upon staffing and scheduling and complexity of the project. This may include prototype construction and testing, to confirm that the instrument will meet specifications.
- The instrument is built, offline tested, installed, and commissioned.
- The diagnostic is added to CMT and is available for shot integration.

For more information on designing diagnostics for NIF, see *Diagnostic Design Guidance for the National Ignition Facility*[12] and *Engineering Design Reviews*.[13]

[12] *Diagnostic Design Guidance for the National Ignition Facility*, NIF-5041482.

[13] *Engineering Design Reviews*, NIF-5018587.

6.3. Diagnostic Instrument Manipulator-Based Diagnostic Interface

For users designing diagnostic hardware, the NIF facility provides resources to help users to manage interfaces and meet facility requirements.

6.3.1. Diagnostic Instrument Manipulator-Related Design Considerations

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 shall incorporate features to aid alignment in the Target Chamber.
- 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 materials are adequately considered in the design.

6.3.2. Diagnostic Instrument Manipulator Performance Capabilities

For instrument design purposes, standard DIM capabilities include:

- Radial positioning from the wall of the target chamber to TCC to a resolution of ±20 mm.
- Pointing accuracy of ±0.5 mm in both x and y directions (z is along the radial direction of the chamber).
- Accommodation of loads up to 125 kg with a center of gravity no greater than 1.4 m from the cart rear wheels. Carts and diagnostic assemblies can be no larger than 28.5 cm in diameter.[14]
- Accommodation of diagnostic assemblies up to 285 mm in diameter and up to 3 m beyond the front of the diagnostic cart in length. Accommodates loads up to 125 kg with a center of gravity no greater than 1.4 m from the cart rear wheels.[15]
- 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 DIMs and how to design diagnostics to be compatible with operation in DIMs are available in *Diagnostic Design Guidance for the National Ignition Facility.*[16]

[14] MESN02-169 and MESN03-005.

[15] AAA12-104230.

[16] NIF-5041482.

6.4. User-Supplied Diagnostics

Because NIF is a major user facility, any new diagnostics must be interfaced to the facility and must be controlled and operated by the facility. The NIF facility provides the systems in the target area necessary for executing experiments, including integration, qualification, control, and operation of diagnostics, as well as the target area systems necessary for executing experiments and the requisite offline and online testing and calibration.

Users may supply diagnostics for experimental fielding on experiments, but it is important that these meet NIF and LLNL engineering design standards. NIF Procedure 5.1 defines the diagnostic design review process and the graded approach used to guide the users and to ensure that the diagnostic will be successfully integrated when it is fielded on NIF. The *NIF Engineering Design Review Manual*[17] provides the criteria for reviewing design adequacy. Other procedures have been developed to guide fabrication, material selection, and cleanliness (see Section 5.9 for additional details on these topics). For instance, all materials used in these systems must be listed in MEL99-009 or undergo a 100 hour bake/purge test.

The Work Authorization Process (WAP) (again, using a graded approach) provides a checklist to make sure that the diagnostic can be fielded on a shot. Areas of concern are safety for the people and the facility. Issues include mechanical and electrical aspects such as grounding/shielding, earthquakes, and rigging; human factors for installation/removal, cleanliness, and contamination control; and control and data acquisition system needs for interfacing with the NIF shot cycle software. All of these categories are covered in the WAP checklist.

[17] LLNL-AM-406283, http://www-eng-r.llnl.gov/about/p2_manual.html.

7. Targets

A well-designed and precisely fabricated target is one of the keys to a successful experiment at NIF. While many targets are similar or identical to those previously fielded at NIF, some require the development of new materials, engineering techniques, fabrication and metrology approaches, and fielding strategies. Experimenters should discuss with target designers as early as possible (even before a shot date is determined) the design and type of target, its various components and materials, and its required specifications and tolerances, even if the design is only in the conceptual stage. Early consultation is critical because materials availability and target complexity may impact the fabrication timeline. Experimenters should also stay engaged throughout the target production process.

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 such as beryllium or radioactive elements. When a target requires new materials, target fabrication scientists with expertise in disciplines such as chemistry and materials science begin by developing the essential raw materials. Fabrication engineers then determine whether those materials, some of which may never have been used in targets before, can be shaped, machined, and assembled. If approved, components or an entire target will be assembled and tested. The effort and cost involved in making a new target is estimated by the program and target fabrication through an iterative process.

Targets are made using a number of different resources, depending on the type of target and its components or subassemblies. The majority of targets are made by the LLNL/General Atomics (GA) Target Fabrication team, which has the capabilities and experience to build a wide variety of targets for investigating various areas of science on NIF. Both LLNL and GA have the infrastructure for making and characterizing precision components and assembling them into targets. Other vendors support the fabrication process. It is not necessary to procure targets from the LLNL/GA team; however, any target to be shot at NIF must be assembled with enough precision to be aligned in the target chamber, metrologized at LLNL (see Section 7.2.2), and approved for material compatibility (see Section 5.9) before use in the target chamber vacuum.

Depending on the target type and application, GA or LLNL may perform the various steps involved in making the target, although component assembly and characterization is typically performed on-site at LLNL by a combined team of LLNL, GA, and Schafer Corporation personnel. LLNL is also mainly responsible for the engineering design of targets, including facility interface–driven features, such as alignment fiducials, unconverted light shields, and mass and debris requirements, as well as completion of the final metrology report as part of the requirements verification process (RVP).

This chapter summarizes the process involved in turning a sketch or idea for the target into a real, shootable target at NIF, including the timeframe involved, steps to be addressed, and interfaces to help the user with the process. It also provides a brief overview of the most commonly used target fabrication and metrology capabilities for NIF experiments.

7.1. 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.

7.1.1. Process for LLNL/GA Fabricated Targets

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 generally need four to six months before the experiment for evaluation, planning, and production. In either instance, target fabrication should start with a campaign review for the Campaign and Shot Responsible Individuals (RIs) to lay out long-term target needs for their campaign, at which the Target Fabrication team will provide input on how these needs can be met. A Target Fabrication Change Control Board (CCB) manages changes in target schedule and development.

7.1.1.1. New Target Designs

The general target engineering process for new target designs is as follows.

Target Fabrication reviews physics requirements, design, and schedule
The Shot RI (who is either the Principal Investigator (PI) or the liaison scientist) brings 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. For Inertial Confinement Fusion (ICF), High-Energy-Density (HED), and National Security Applications (NSA) experiments, approval from the appropriate council is typically 12 to 9 months (at a minimum) before an experiment is scheduled for a shot. For Discovery Science (DS) experiments, the approval by the NIF director is typically given 24 to 18 months before the shot. 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 and should call out the use of any hazardous materials. Target Fabrication will provide design feedback, discuss target materials research and development (R&D) needs, and create a time estimate.

Target Fabrication performs engineering analysis and prepares drawings
Once the experiment is scheduled, which happens between 12 and 6 months before the shot date, Target Fabrication assigns a target engineer to work with the Shot RI and prepare a conceptual design and drawings indicating dimensions and tolerances. Focus is put primarily on experiments occurring six months out on a rolling basis. Of course, earlier identification of any target design issues always increases the margin of success.

Experts review and sign off on target design
Target specifications must be agreed to well before the target is built. A target request form (TRF) initiates the fabrication process (see Figure 7-1). Before fabrication formally begins, safety (unconverted light and backscatter), debris (calculation of ejected material), alignment (agreement on needed fiducials, measurement techniques used and verified), self-consistency, special materials, and target mass must be verified. The Shot RI works with representatives from target engineering, the alignment team, the metrology group, and target operations to uncover and resolve any physics, safety, and cleanliness issues early in the process. Any dependencies of the design on target materials R&D should also be identified. Further, the Shot RI, together with NIF, must develop a target alignment plan/strategy. Typically, this process runs continuously from the approval of the experimental proposal, and all issues of the types described above are resolved and any problems mitigated three months before a scheduled shot date.

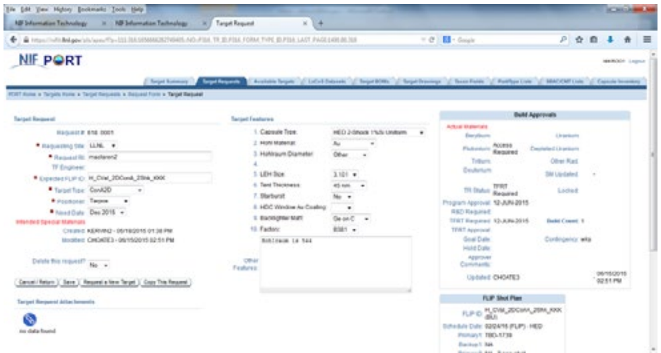

Figure 7-1. The Target Request Form, available via the National Ignition Facility's (NIF's) PORT system.

Target is fabricated and metrologized, electronic RVP generated, and nonconformance issues resolved
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 Management Review Board (MRB) to determine if the target should still be shot, if the specification was reasonable, and whether the experiment can be performed as planned.

Target is accepted and shot
Target delivery to the NIF facility is expected to be no later than two weeks before the scheduled shot date. Shot RI review of the metrology data in the RVP needs to be done at least three weeks before the shot date in order to confirm that all aspects of the target are consistent with what is required to perform the shot.

7.1.1.2. Existing Target Designs

The general target engineering process for existing target designs is as follows.

Target Fabrication reviews physics requirements, design, and schedule
If the target design is identical to previously fabricated targets, the Shot RI (who is either the PI or the liaison scientist) completes the TRF (see Figure 7-1) on the NIF IT/PORT system with help from Target Fabrication. If there are any changes to the target design, it is considered a new target design and follows the process described in Section 7.1.1.1. Since experiments are scheduled on a rolling basis 6 to 12 months in the future, the TRF should be completed no later than 6 months before the scheduled shot date.

Target Request is accepted or rejected
Reasons for rejection/revision might include poor definition or too short of a lead time.

Target is fabricated and metrologized, RVP generated, and nonconformance issues resolved
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 MRB to determine if the target should still be shot, if the specification was reasonable, and whether the experiment can be performed as planned.

Target is shot
Shot RI review of the metrology data in the RVP needs to be done at least three weeks before the shot date in order to confirm that all aspects of the target are consistent with what is required to perform the shot.

7.1.2. Process for 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;
- Undergo a design review by NIF Target Fabrication;
- Pass hazardous materials and Target and Laser Interaction Sphere (TaLIS) reviews;
- Be safe to shoot without damaging the laser;
- Undergo NIF-approved cleaning; and
- Be metrologized at LLNL.

The materials and cleanliness of target assemblies for 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 NIF must be reviewed and approved before they may be used.[18] 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 three to four weeks in advance of the experiment, unless it would not be detrimental to the target or experiment.

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

7.1.3. Process for Livermore Assembly with User-Supplied Components or Sub-Assemblies

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 three months but will vary depending on the target.
- Components arrive at NIF far enough in advance of the shot to allow proper time for assembly. The necessary lead time is usually two months, but will vary depending on the target.
- The assembly must be properly planned with LLNL Target Fabrication.

[18] All materials used in targets are listed in either NIF-0117684, *Cryogenic target materials*, Appendix 11, or NIF-0118227, *High-energy density (HED) and non-ignition target materials*, Appendix 1.

7.2. Capabilities

7.2.1. Fabrication and Assembly

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
- **Capsule fabrication** (see Figure 7-2)**:**
  - 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. For ICF targets, 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.

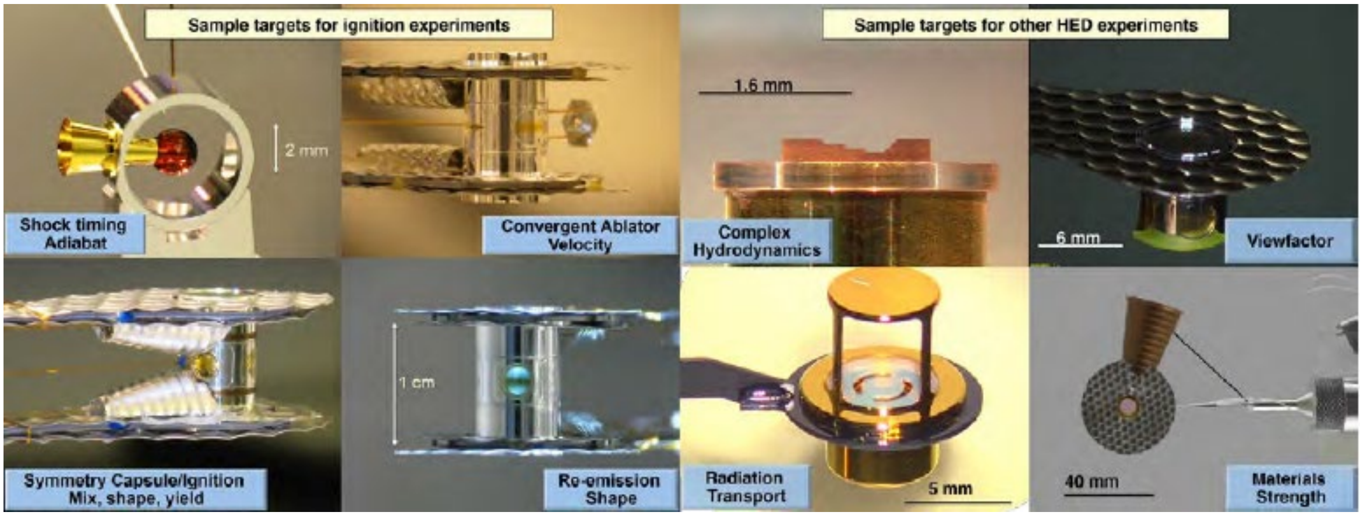

Figure 7-2. Samples of some of the targets fabricated by General Atomics/NIF and fielded at NIF.

- **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 (see Figure 7-3). 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.

Figure 7-3. Cleanroom at LLNL for target assembly and characterization.

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.

For more information on target manufacturing capabilities, visit the GA target catalog: **http://www.ga.com/websites/ga/docs/energy/2016_IFT_Catalog.pdf.**

7.2.2. 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 GA laboratories 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. See Appendix F for a list of LLNL and GA characterization capabilities.

8. Data Handling

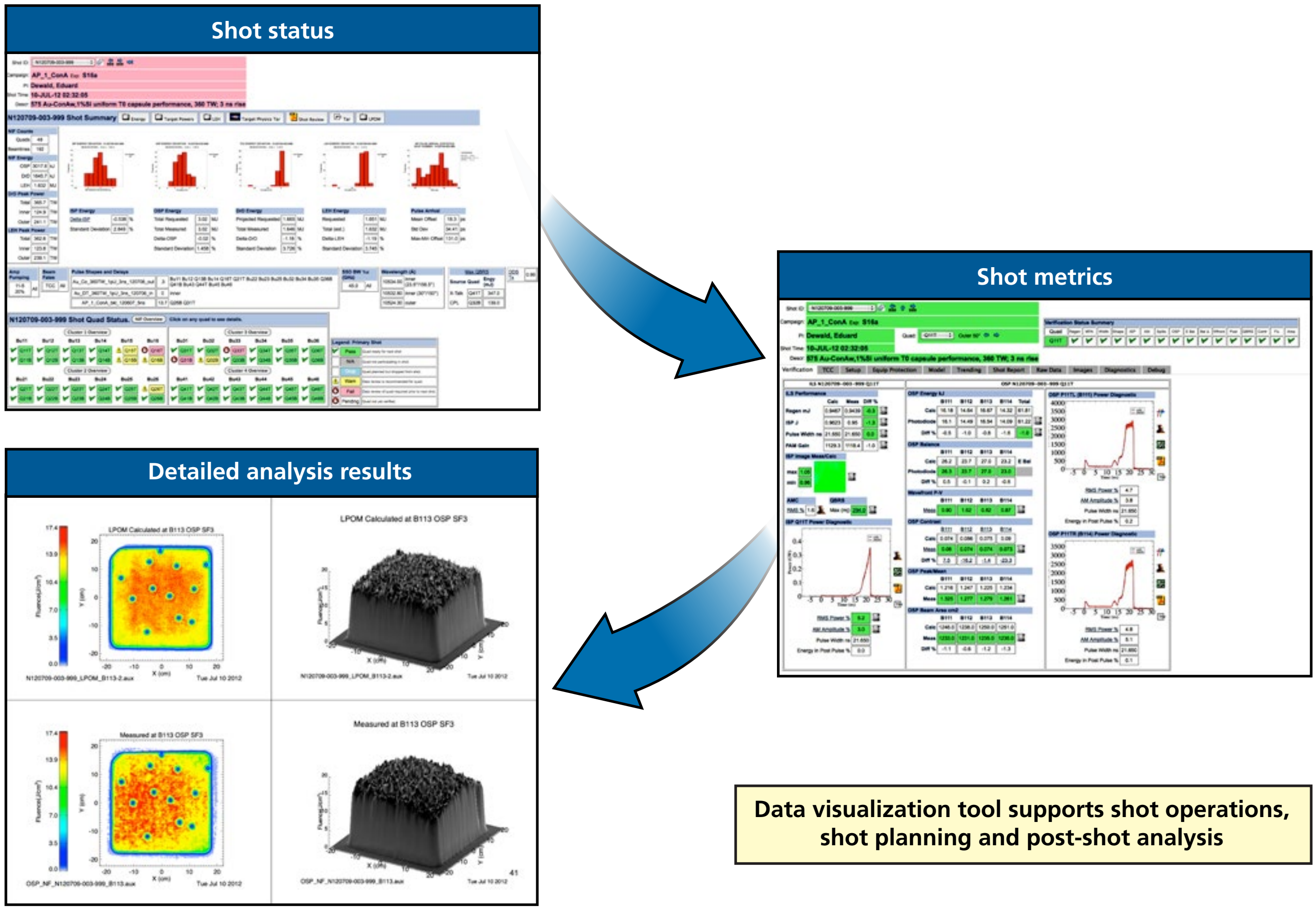

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Figure 8-1. After each shot, users can examine the detailed laser performance for any beamline using a suite of data trending and analysis tools.

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 in 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.[19] 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 the Laser Performance Operations Model (LPOM). To do this, LPOM

[19] 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.

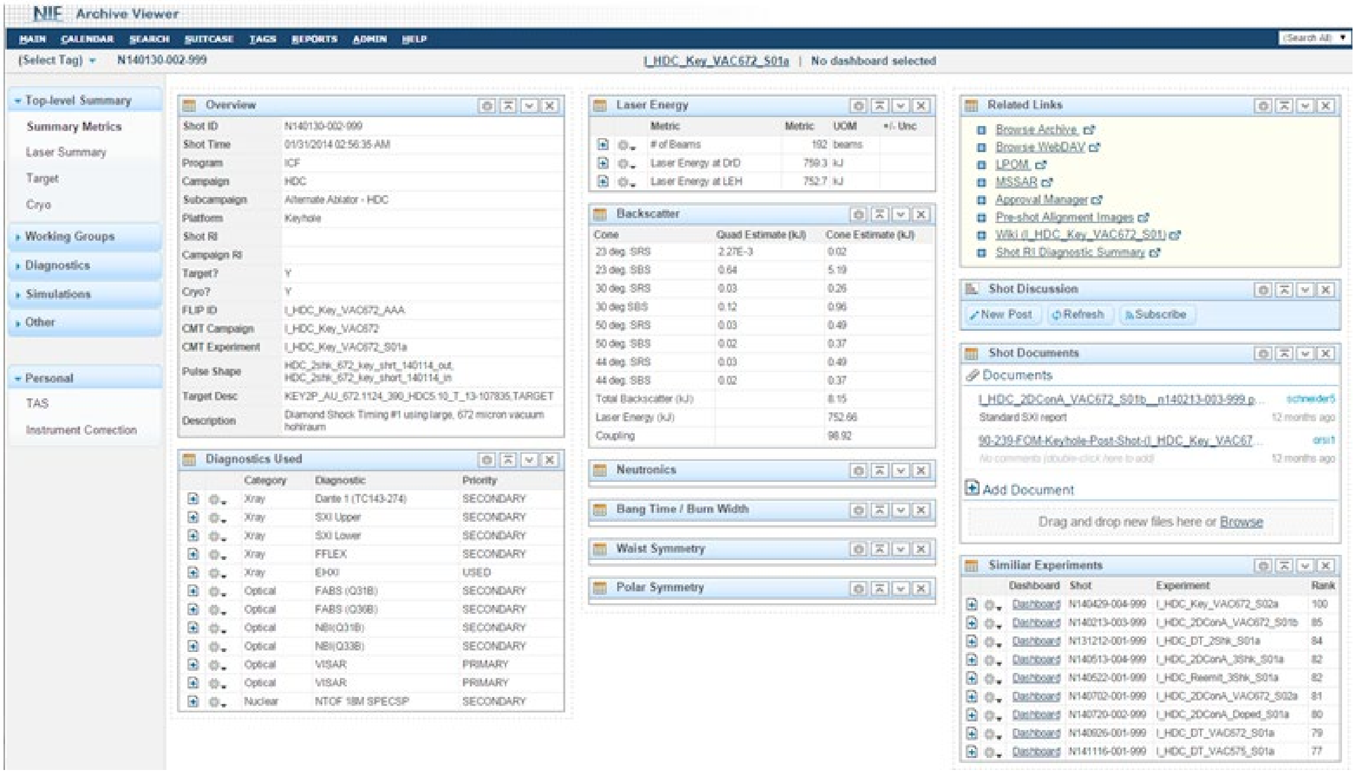

Figure 8-2. The Archive Viewer dashboard provides quick access to high-level shot metrics.

is directly linked to the Integrated Computer Control System (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 graphical user interface (see Figure 8-1), while a subset of the analysis is presented to the shot director through a shot supervisor interface.

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 related 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.

8.1. User Tools

Some of the NIF data management tools are used by both NIF personnel and external collaborators, while others are available only to NIF personnel. Contact the NIF User Office for help in setting up access to the data tools available for your use. Key tools are described briefly below; links to the tools can be found at https://nifit.llnl.gov/.

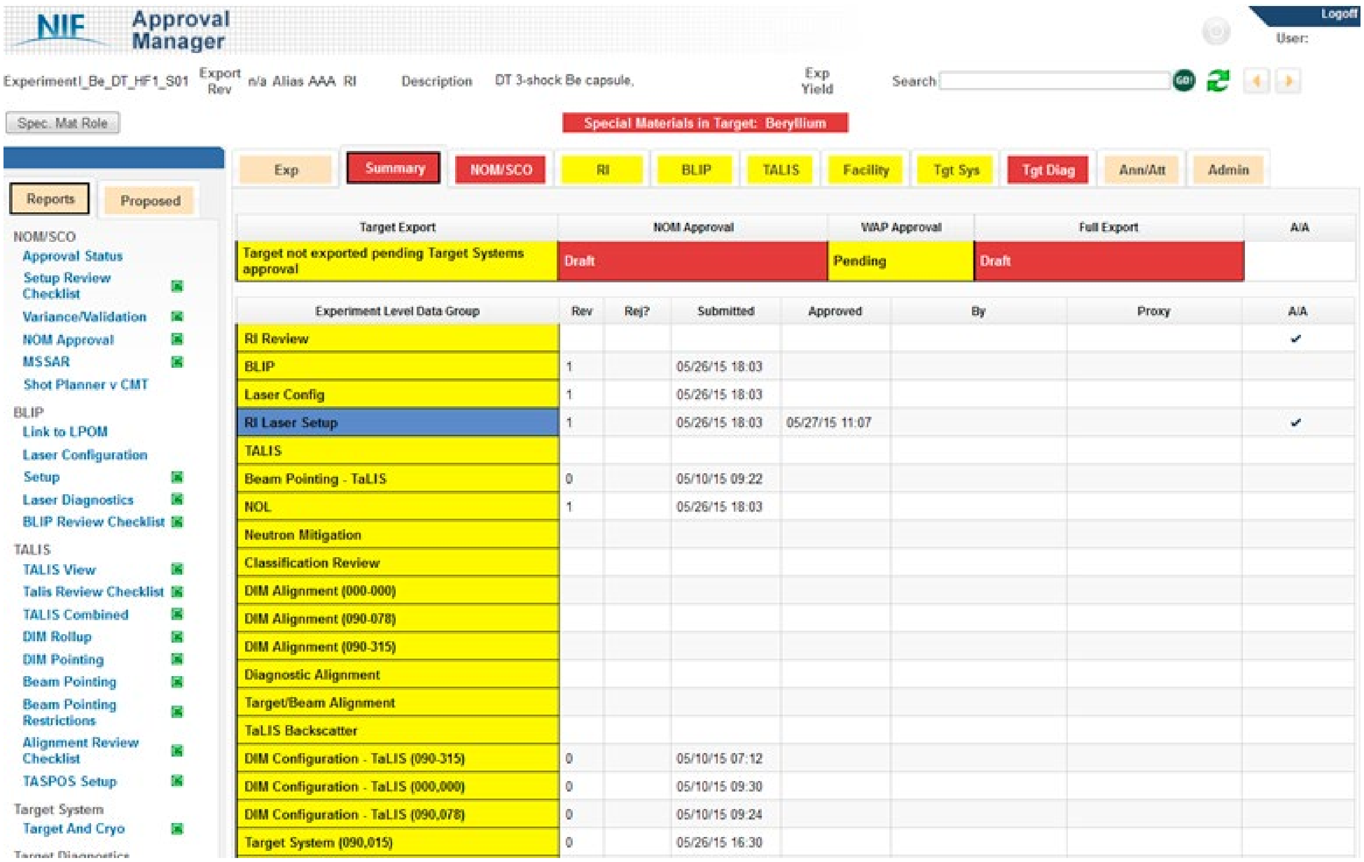

Figure 8-3. Approval Manager guides the responsible individual through the experiment setup approval process.

Archive Viewer

Archive Viewer (see Figure 8-2) is the interface that allows researchers, shot Responsible Individuals (RIs), and NIF personnel to view data from the NIF data repository as a dashboard or in tabular form, or to download data as a zip file or via a WebDAV interface for offline processing and subsequent reloading into the archive. Access to archive data is controlled and granted by the NIF program leads.

Approval Manager

An experiment setup is split up into a number of data groups in order to facilitate review by expert groups. The Approval Manager (see Figure 8-3) provides reports for the reviewers and tracks the status of each review. Once they are all complete, the tool provides the means for the NIF Operations Manager to export the experiment to the control system for execution.

Campaign Management Tool (CMT)

Shot RIs use 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

NIF shot operations personnel use Configuration Checker to help ensure that the configuration of the NIF laser and target chamber meets the defined experimental requirements.

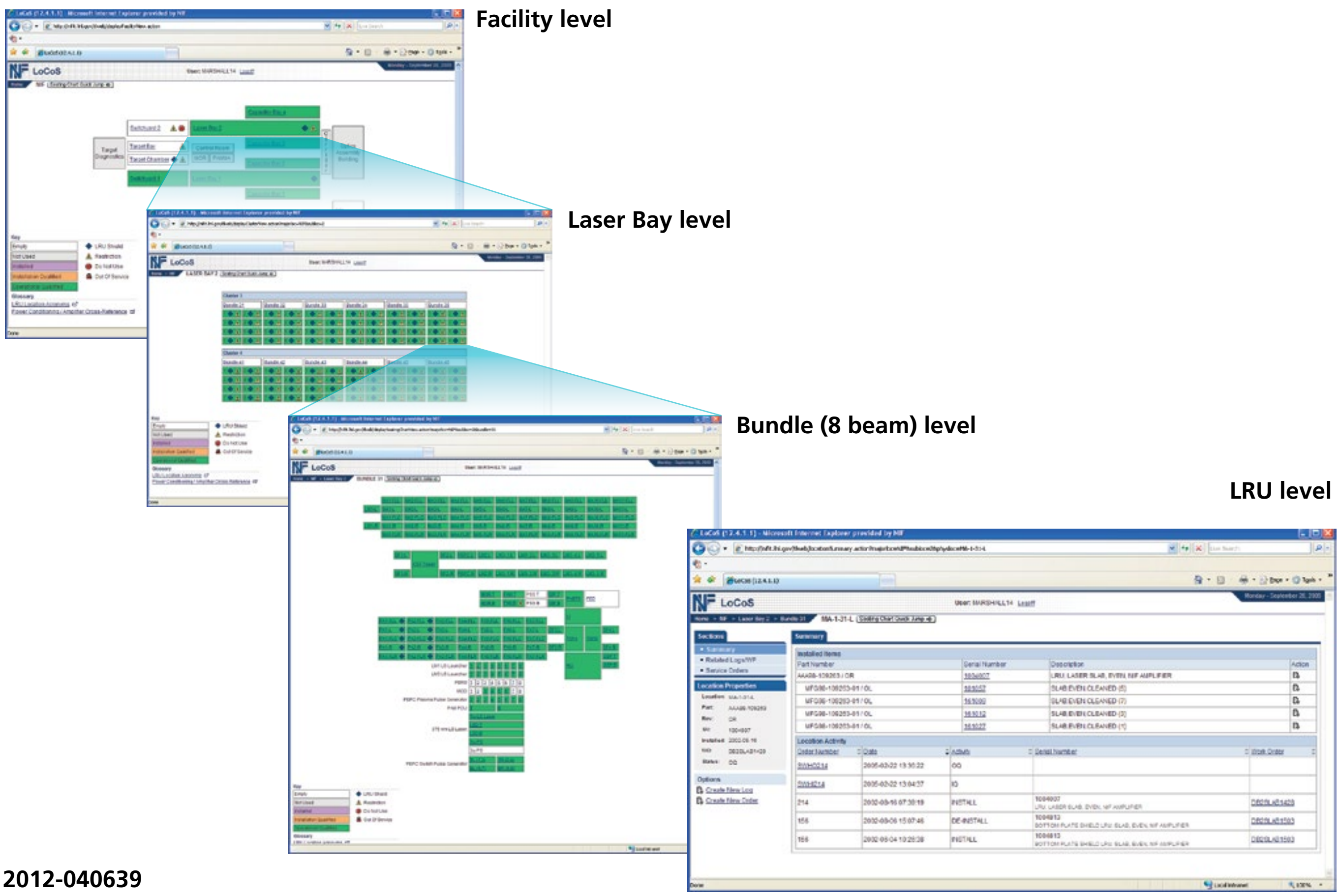

Figure 8-4. Location, Component, and State enables National Ignition Facility staff to track parts at various detail levels, from facility level to individual parts.

Location, component, and state (LoCoS)
NIF personnel use the web-based LoCoS system (see Figure 8-4) 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.

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 (see Figure 8-5) allows NIF personnel and visitors to monitor the progression of the experiment as the NIF control system implements the experimental parameters defined in CMT.

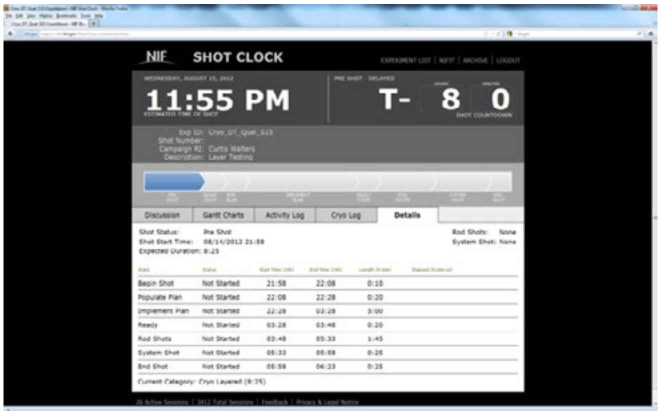

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Figure 8-5. Shot Clock showing the progression of an experiment through the execution phases of the control system.

Shot Planner

The Shot Planner (see Figure 8-6) is NIF's principal tool for shot schedule creation. It is also a way for RIs to define the experimental setup at an early stage, to share the setup with expert groups for analysis, and to communicate optic, target, and diagnostic needs with the factories.

Status Board

The Status Board (see Figure 8-7) provides users with information about the shot currently being executed, the schedule for the week, and the facility sweep status. The tool is displayed on monitors throughout the NIF buildings and is also available online through a Web browser.

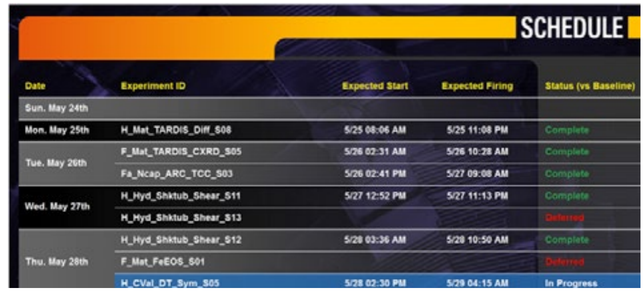


Figure 8-7. The Status Board displays the weekly schedule status.

8.2. Data Ownership and Publication Policy

See Appendices G and H.

8.3. Data Protocol and Availability

NIF is 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. Diagnostics policies are as follows:

- All core diagnostics will be integrated into the NIF data archival system.
- Data obtained from all core NIF target diagnostics belong to the facility.
- Data from core diagnostics will be read by the data archival system and stored along with other shot data.

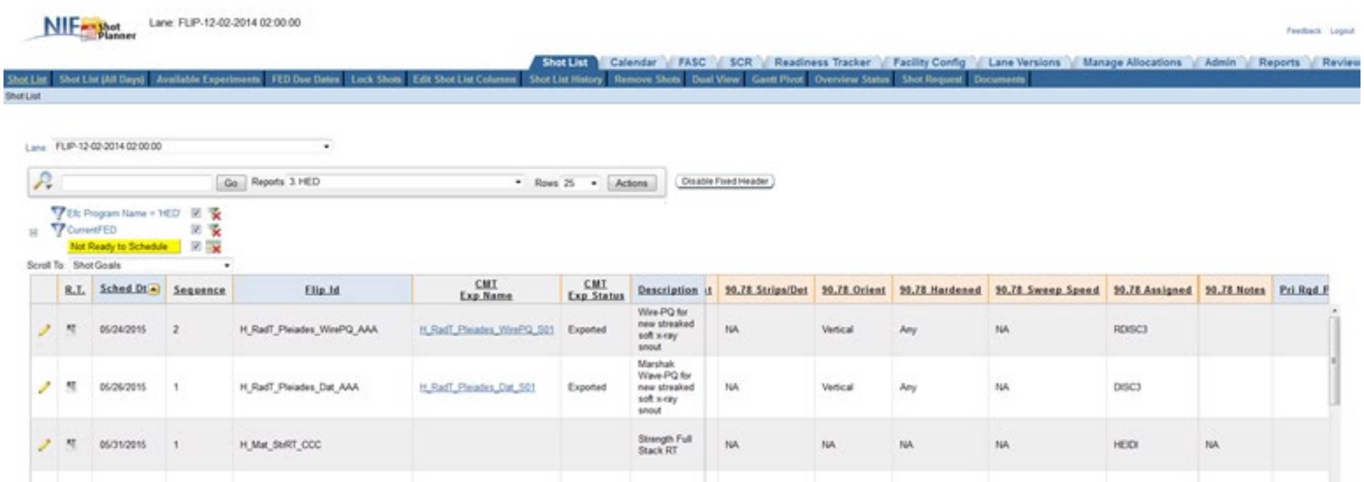


Figure 8-6. The Shot Planner shows the proposed configuration of the 90-78 Diagnostic Instrument Manipulator.

- 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.

8.4. Remote Capabilities

NIF has a geographically disperse user base. The need to travel to NIF to carry out experimental plans could be reduced with proven, commercial technology that provided the ability to execute and monitor many of the tasks associated with conducting experiments at remote sites. Remote implementation of experiments could reduce personnel time commitment and travel costs and make using NIF easier and more transparent.

NIF is in the process of fielding a cloud-based User Portal to allow users to easily access experiment information without logging into NIF applications via Virtual Private Network. The initial deployment will simplify the solicitation and entry of campaign and experiment proposals. Future releases will provide such features as experiment lifecycle visibility, review status, and platform information.

8.5. Classified Operations

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.

8.6. Tool Support

For the new user, knowing how to best use the tools and where to find information about them can be daunting. NIF has a tool support team that is available to assist users. The team can be contacted at **nif-sds-pager@lists.llnl.gov.**

8.7. Data Access

NIF users will be provided with access to the NIF data management system as required. 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.

9. Facility and Safety

9.1. Safety

In the NIF and Photon Science Directorate, safety is a value that pervades all that we do. LLNL and Department of Energy (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 the foremost consideration in all work conducted within the NIF Directorate, and all workers have 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,* DOE/EIS-0348, DOE/EIS-0236-S3,[20] and the *Supplement Analysis of the 2005 Final Site-wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory*,[21] DOE/EIS-0348-SA3. 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* (SBD).[22] The SBD provides a more detailed identification and assessment of hazards, resulting in additional controls to ensure that risks to co-located 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*,[23] *Operational Safety Plan (OSP) 581.11, Installation, Commissioning and Operation of the NIF Laser*,[24] *NIF CIS Radiological Inventory Management System* (RIMS),[25] and other procedures. Configuration Management of these systems is critical to ensure continued functionality at the level assumed in the SBD.

[20] *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.

[21] *Supplement Analysis of the 2005 Final Sitewide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory,* DOE/EIS-0348-SA3.

[22] *NIF Safety Basis Document*, NIF-5019666.

[23] *Facility Safety Plan*, NIF-5019665.

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

[25] *NIF CIS Radiological Inventory Management System*, NIF-5030388.

The safety aspects of specific NIF operations are described in *OSP 581.11* and in additional integration worksheets (IWSs) that authorize those operations. These documents provide a specific, detailed evaluation of hazards associated with working in 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.

9.2. Hazard Mitigation

NIF hazards have been evaluated in detail, and mitigations have been put in place to control these hazards. NIF's primary method for controlling these hazards is through engineered controls. When engineering solutions are not feasible or identified hazards cannot be engineered completely out of normal operations/maintenance work, safe work practice and other forms of administrative controls provide additional protection along with the use of Personal Protective Equipment (PPE). A summary of the key hazards at NIF, their sources, and typical mitigations is provided in Table 9-1.

Figure 9-1. Summary of key hazards at the National Ignition Facility.

Hazard	Source	Typical Mitigation
Hazardous Energy Sources	Electrical equipment Large volumes at vacuum Pressure systems Mechanical equipment	Lockout/tagout Venting systems Procedures and training
Oxygen Deficiency	Argon used in beam tubes Nitrogen used for cryogenic pumps	Containment of gases (tanks, piping) Oxygen deficiency monitoring system and alarms Pressure relief devices Procedures and training Personal oxygen monitors
Fire	Electrical equipment Combustible material	Fire detection and suppression system Fire barriers
Shrapnel	Off-normal electrical events (e.g., Power Conditioning System (PCS))	PCS module design to vent overpressure and trap shrapnel Reinforced capacitor bay walls
Shrapnel and Pressure Hazard	Vacuum-loaded optic failure	Optics designed to crack not shatter Optics inspection system to monitor crack growth Rupture panels on beam tubes

Hazard	Source	Typical Mitigation
Laser Light	Main laser Alignment and diagnostic lasers	Barriers: beam blocks, shutters, laser curtains, enclosures, walls, and doors Lockout/tagout Permissive keys Procedures and training Eyewear
Hazardous Materials (e.g., Be)	Target materials Diagnostic materials	Confinement and contamination control systems Procedures and training PPE (coveralls, booties, gloves, respiratory protection)
Radiation	Target materials Prompt and decay radiation from shots Activation and fission products resulting from shots	Shielding Safety Interlock System, stay-out time Confinement and contamination control systems Procedures and training PPE (coveralls, booties, gloves, respiratory protection)

9.3. National Ignition Facility Facilities

As shown in Figure 9-1, NIF encompasses three interconnected buildings: the Optics Assembly Building (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 Line-Replaceable Units (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 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.

9.4. Accessing the Facility

Access to the NIF site and buildings is controlled and limited to authorized personnel (see Figure 9-1). 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 (see Section 10.5, Training). Upon completion of these courses and authorization of site access, individuals will be provided with an access control card. 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.

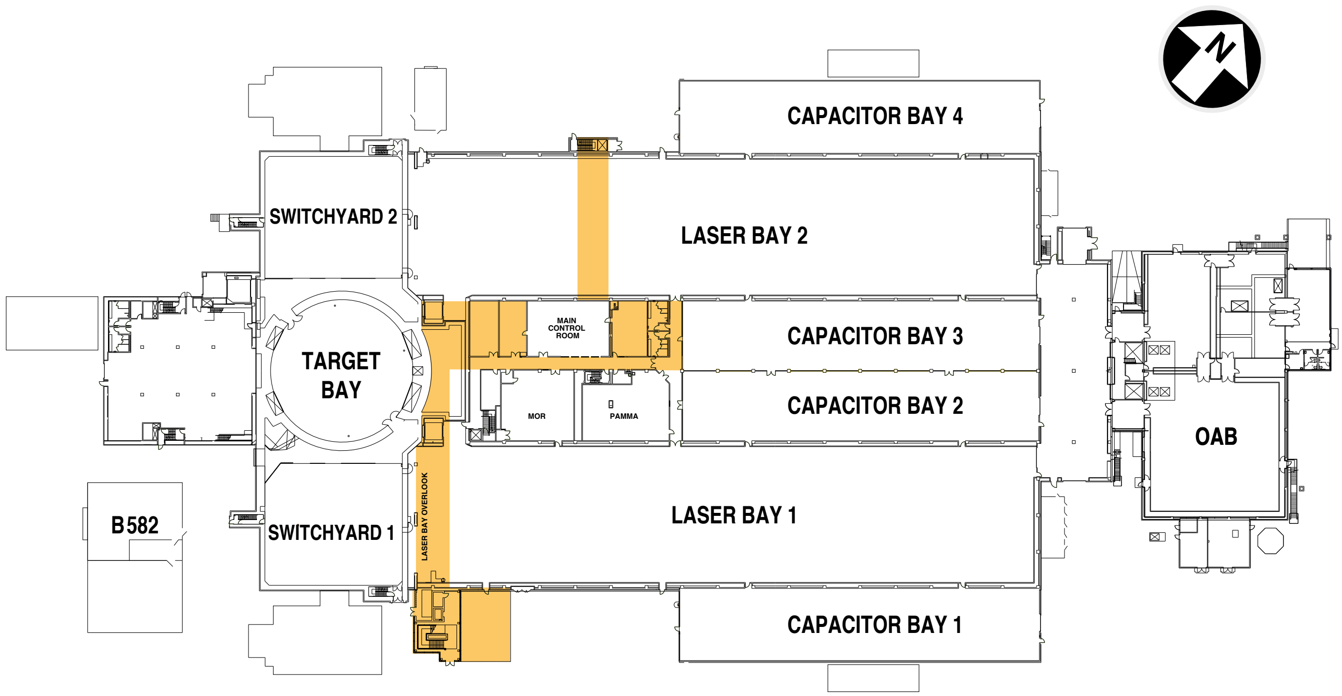


Figure 9-1. General access areas of the Laser and Target Area Building are shown in orange. The areas of the facility shown in white (including the control room) require additional access levels and training. They also require personal protective equipment and clean construction protocol practices.

All workers who are current on the NIF Site Access training (NP0353-W or RW and NP0581-Tour) can escort as needed for work purposes. All escorting information can be found in the *B581 Facility Safety Plan*.[26]

9.5. Cleanliness Protocol and Personal Protective Equipment

Safety and cleanliness are of paramount importance at the 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 and closed-heel shoes with a non-tapering heel that are suitable for various NIF walking surfaces.

The cleanroom environments in B581 are maintained at the same level of cleanliness found in a hospital operating room. 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. 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 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.

Certain areas of the facility or activities may require personal protective equipment (PPE), such as a hard hat, safety glasses, or steel-toe shoes. All PPE must be in good condition and correctly worn. Areas requiring PPE are posted throughout the facility via Health Hazard Communication (HHC) signs located at the entrances to these areas. The PPE requirements posted there represent the minimum requirements for the area. A hard hat

[26] *B581 Facility Safety Plan*, NIF-5019665.

is required in the switchyards and target bays. Individuals performing work on-site are required to wear any PPE identified in the applicable work control documents.

9.6. Control Room Protocol

Unescorted access to the main control room is limited to those on official business who have completed the required training. Uncontrolled access could result in distraction of operators or improper operation of equipment. Control Room Access Training (NP-0131W) provides protocols for working in the control room and communicating with control room personnel.

The control room operates in two modes: shot operations and nonshot operations. During posted shot operations periods, access to the control room is limited to shot operations personnel. Others are allowed entry only when approved by the Lead Operator (LO)/Shot Director (SD) on duty. During non-shot operations periods, access is authorized for those that have completed the training and have been granted access.

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

- The Principal Investigator (PI) shall be identified during the preshot safe plan of action 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 Lead Engineer 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.

To ensure personnel and equipment safety, it is imperative that the control room system operators not be disturbed or distracted during shot operations. Experimentalists may have access to the control room to monitor/observe shot activities only with explicit, advance approval from the SD. 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. Experimentalists without control room access approval may wait in the Strategy Room or other nearby locations until completion of the shot cycle.

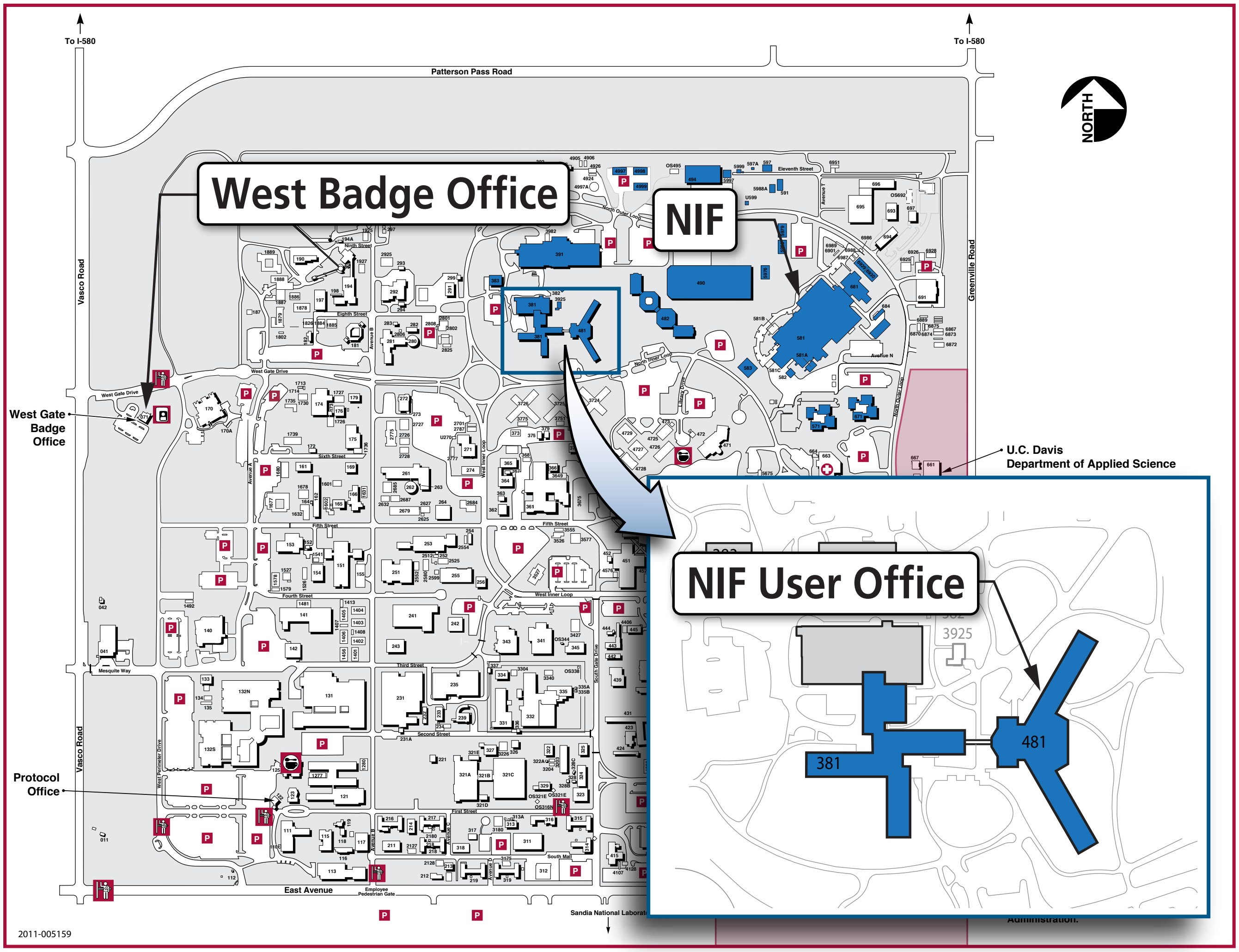
Experimental and diagnostic support staff may monitor radio communications during the shot cycle. Loan radios are available from the LO.

9.7. Lawrence Livermore Facilities

LLNL has many different on-site 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.

9.7.1. Laboratory Space

The NIF and Photon Science (NIF&PS) directorate occupies most of the northeast quadrant of the Laboratory, as shown in Figure 9-2. In addition to NIF itself, the NIF&PS directorate possesses laser labs, optics development labs, target development labs, optics processing facilities, and target fabrication facilities. Further information on NIF&PS laboratory facilities is available from the NIF User Office.



2012-039099

Figure 9-2. Map of LLNL. The NIF high-energy-density research campus, housing the NIF User and Visitor offices, is shown enlarged.

9.7.2. Access to Labs

Access to NIF&PS laboratory space should be coordinated through the NIF User Office. Access requires the explicit permission of that lab's Responsible Individual (RI). Any PPE needed to access the lab is identified on the HHC sign posted on the laboratory door. The RI will review this with the visitor prior to entry.

General access to laboratory space does not authorize performance of work. In order to conduct work in a laboratory, the work scope must be specifically addressed in an IWS, the authorizing document for work. In addition, all workers must be listed by name, read and sign the IWS indicating that they understand the hazards, agree to stay within the specified controls, and complete all required training. Prior to conducting work, a pre-job brief lead by the RI or designee must also be completed.

NOTE: In order to be added to an IWS to perform work, visitors must be classified as a visiting scientist, or explicitly listed on a subcontract.

9.7.3. Shipping Equipment

Visitors should contact the NIF User Office or NIF Visitor's Office for specific guidance and assistance on shipping equipment to and from LLNL.

When shipping equipment to LLNL, it is important to package equipment in a manner that will prevent damage during transit. Each equipment package or crate shall be labeled (as applicable) with part number, revision level, serial number, etc. In addition, a packing slip must be provided for each shipment that includes the LLNL sponsor's name, sponsor's contact information, a brief description of the item, and the final delivery location within LLNL (e.g., "NIF Receiving" and building number).

Visitors and equipment custodians must follow LLNL's requirements when shipping equipment or property to another LLNL worker or to an off-site or on-site organization for repair, reuse, maintenance, storage, or excess. Visitors must coordinate with the LLNL sponsor and shall:

- Follow containment, labeling, and transportation procedures specified by the LLNL sponsor.
- Provide all available information about the property's historical use, including a description of any use or contamination with hazardous or radioactive materials.
- Certify that the equipment or property is free of contamination and encapsulated (no free-flowing liquids).

Packaging materials shall conform to the following requirements:

- All precision-cleaned equipment that will be used in precision-cleaned environments of the NIF beam path shall be packaged and labeled as specified in *Packaging of Precision Cleaned Components for NIF*.[27]
- All gross-cleaned equipment that will be used in gross-cleaned environments of the NIF beam path, including the NIF Target Chamber, shall be packaged and labeled as specified in *Packaging of Gross Cleaned Components for NIF*.[28]
- All equipment that will be used in LLNL-designated clean areas or cleanrooms but that will not be used inside of the NIF precision- or gross-cleaned beam path must be cleaned as specified in Section 4 of *Guidelines for Maintaining a Clean Area or Clean Room,*[29] and then packaged with at least the innermost layer of packaging material in accordance with *Packaging of Gross Cleaned Components for NIF*.
- All other equipment must be packaged in such a way as to maintain the equipment in a standard clean condition as defined in Section 6 of *NIF Clean Protocol*.[30]
  - Only new clean packaging material shall be used.
  - Items shall be dry prior to packaging.
- Large or heavy (over 50 pounds) items shall be packaged in a secured and fully enclosed crate (i.e., merely strapping to a pallet is not acceptable). Crates must have a base capable of supporting the weight of the material safely during transport. In particular, the design must ensure that legs or other features of the packaged equipment will not "punch

[27] *Packaging of Precision Cleaned Components for NIF,* MEL99-014, NIF-5002485.

[28] *Packaging of Gross Cleaned Components for NIF,* MEL99-012, NIF-5002484.

[29] *Guidelines for Maintaining a Clean Area or Clean Room,* MEL98-014.

[30] *NIF Clean Protocol*, NIF-5022420.

through" the base's surface during rough handling and/or transport. Shippers must provide for forklift access from all sides for large crates (pallet-size or larger). Items must be secured in the crate in such a manner as to assure that the cleanliness barrier wrapping layers remain intact.

All material can be shipped from LLNL with the exceptions of hazardous waste, radioactive material, and explosives. When shipping equipment from LLNL, a shipping request application is required for all material shipments with the exception of domestic shipments of printed matter weighing less than 5 pounds. All material leaving LLNL must be inspected by LLNL shipping. The User Office can coordinate and provide additional assistance and guidance upon request.

10. Visitor Logistics

10.1. National Ignition Facility Offices and Services

10.1.1. User Office

The User Office is the primary point of contact for the NIF User Group, which includes all researchers performing experiments on 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 10.1.2).

10.1.2. Visitor Office

The NIF Visitor Office supports frequent or long-term visiting experimentalists and researchers involved with the NIF 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;
- Involve hands-on work or require data access; and
- Have been approved by the NIF User Facility and/or program.

Invited speakers, seminar or conference attendees, consultants, and subcontractors are not served by the Visitor Office; they are instead served by the programs that host them.

For all relevant visits, the office serves as a concierge, coordinating badging, work authorization, office space, computer and IT requirements, training, and all other elements. The visitor's host will notify the Visitor Office of the scheduled visit and the visitor's requirements by submitting a NIF&PS visitor request form to the Visitor Office.

10.2. Livermore Site Access

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 Personally Identifiable Information such as a Social Security number and an approved form of identification such as a passport or driver's license. All National Nuclear Security Administration (NNSA) facilities have implemented the Department of Homeland Security's REAL ID Act requirements for allowable forms of identification for personnel requiring site access. Only driver's licenses from states whose driver's licenses are compliant with REAL ID requirements will be allowed as a primary form of identification for LLNL site access. Contact the User Office for specific details. 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.

Non-U.S. government owned computers and electronic devices **are permitted** in Property Protected Areas and Limited Areas unless otherwise posted. Personally owned electronic devices **are prohibited** from being connected to LLNL equipment without approval from the Computer Security Program. Bluetooth and wireless headsets **are not permitted** in Limited Area buildings. Non-U.S. government owned cameras and recording devices may be brought on site but **may not be used**, including the function in a cell phone or other devices, without a Controlled Items Permit issued by the LLNL Security Organization. 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/visiting.

10.3. National Ignition Facility Physical 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 completion of web-based classes, including site access policies and safety training. An in-person orientation tour is also mandatory. Upon completion of the courses and tour and authorization of site access, an access control card will be provided. Personnel who have not completed site access training must be escorted while on site. Personnel must remain current in required training to maintain access. Performing work (any task covered under an IWS; this does not include standard office work) on-site requires additional training. The NIF User Office, located on the first floor of B481, facilitates the site access process for visiting researchers.

10.4. Computer Access

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

These resources include systems on the unclassified, restricted (yellow) network; foreign national unclassified (blue) network; and unclassified, unrestricted (green) visitor network. To be granted a computer account with access to unclassified resources, off-site 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 non-LLNL owned computers or personal electronic devices for all visitors and users during business hours while on-site in designated areas.

Access to NIF setup tools currently requires a virtual private network (VPN).

10.5. Training

All on-site visitors and users are required to complete a standard series of institutional site training requirements.

Additional training is required to access the special access areas of the NIF facility (e.g., control room, capacitor bay, and the Velocity Interferometer System for Any Reflector) and to be qualified as a site worker. Additionally, performing work requires training as specified by the integration worksheet. 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.

10.6. Office Space

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

10.7. Housing

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

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

10.8. Airports

LLNL 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 10-1, 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 funded for travel by LLNL need to follow the U.S. carrier rules and DOE government guideline rates.

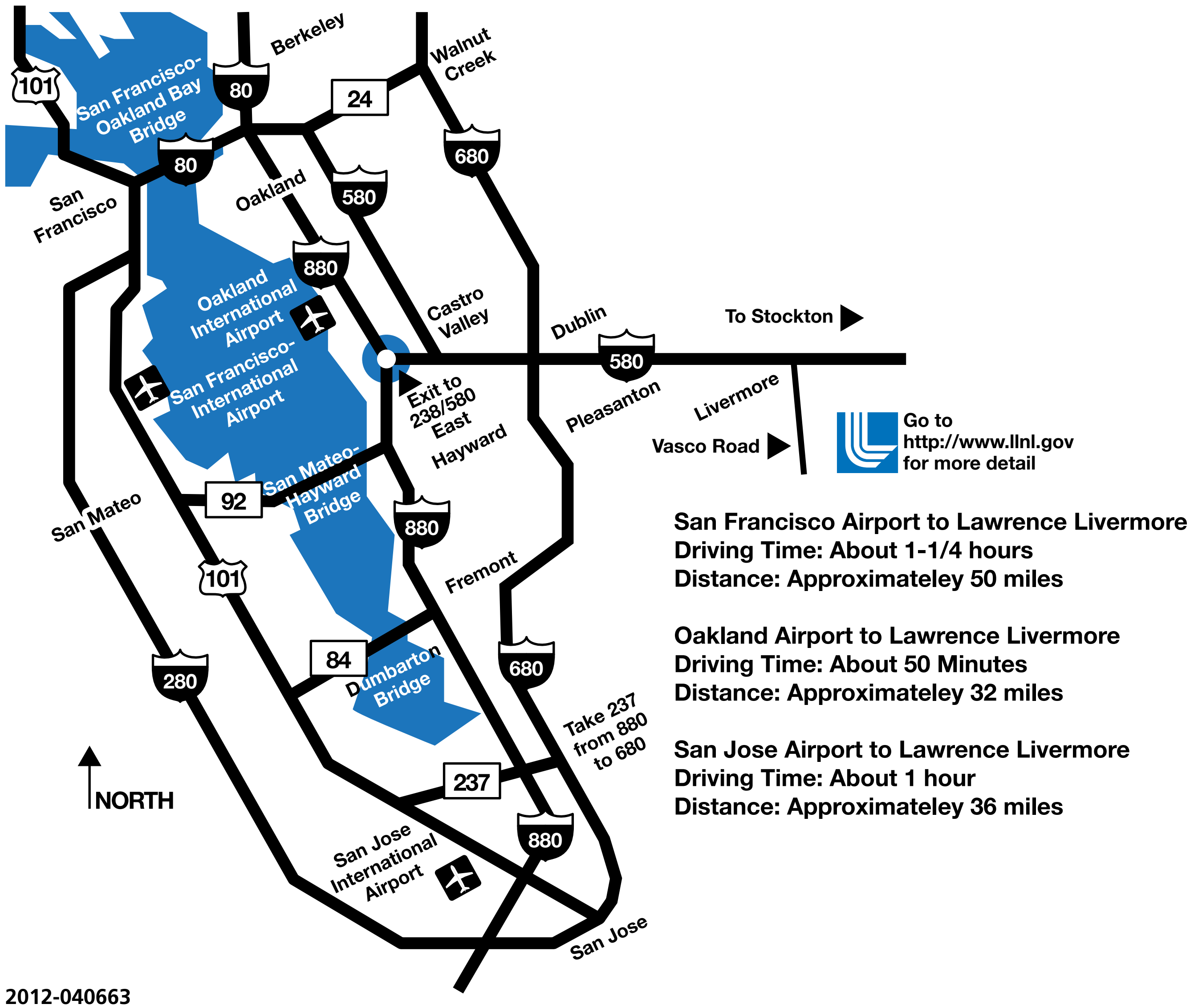


Figure 10-1. Map of the San Francisco Bay Area and transportation routes to LLNL.

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11. Revision Log

Rev. No.	Effective Date	Pages Affected	Brief Description of Revision
AA	10/1/12	All	Initial release
AB	1/30/16	All	Miscellaneous updates throughout

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Appendix A: Acronyms

ADT	ARC Diagnostic Table
ARC	Advanced Radiographic Capability
AWG	Arbitrary Waveform Generator
BLIP	Beamline and Laser Integrated Performance
CCB	Change Control Board
CCD	charge-coupled device
CCRS	Chamber Center Reference System
CMT	Campaign Management Tool
CPP	continuous phase plate
DIM	Diagnostic Instrument Manipulator
DKDP	potassium di-deuterium phosphate
DOD	Department of Defense
DOE	Department of Energy
DS	Discovery Science
EP	Executive Plan
FASC	Facility Advisory and Scheduling Committee
FM	frequency modulated
FOA	Final Optics Assembly
FODI	Final Optics Damage Inspection
FWHM	full width at half maximum
FY	fiscal year
GA	General Atomics
HEDSS	High-Energy-Density Stewardship Science
HHC	Health Hazard Communication
HMMA	Hazardous Materials Management Area
ICCS	Integrated Computer Control System
ICF	inertial confinement fusion
ID	indirect drive
ILS	Injection Laser System
ISMS	Integrated Safety Management System
ISP	input sensor package
IWS	integration worksheet
JNSAC	Joint National Security Applications Council
LC	Livermore Computing
LEH	laser entrance hole
LLNL	Lawrence Livermore National Laboratory
LPOM	Laser Performance Operations Model
LO	Lead Operator
LoCoS	Location, Component, and State
LRU	line-replaceable units
LTAB	Laser and Target Area Building
MAC	Management Advisory Committee
MCP	microchannel plate
MOR	Master Oscillator Room
MRB	Management Review Board
NEL	NIF Early Light
NEPA	National Environmental Policy Act
NIC	National Ignition Campaign
NIF	National Ignition Facility
NNSA	National Nuclear Security Administration
NOM	NIF Operations Manager
NOL	NIF Optics Loop
NSA	National Security Applications
NSC	NIF Scheduling Committee
OAB	Optics Assembly Building
OSB	Operational Support Building
OSP	output sensor package
PCS	Power Conditioning System
PEPC	Plasma Electrode Pockels Cell
PI	Principal Investigator
PPE	personal protective equipment
PRP	Peer Review Panel
PS	polarization smoothing
R&D	research and development
RI	Responsible Individual
RVP	requirements verification process
SAVI	Shot Analysis, Visualization, and Infrastructure
SBD	safety basis document
SCR	Schedule Change Request
SD	Shot Director
SHG	second harmonic generator
SME	subject matter expert
SSD	smoothing by spectral dispersion
SSP	Stockpile Stewardship Program
TaLIS	Target and Laser Interaction Sphere
TANDM	Target and Diagnostic Manipulator
TARPOS	NIF Target Positioner
TAS	Target Alignment Sensor
TCC	Target Chamber Center
TD	Target Diagnostic
TDS	Target Diagnostic Shot
TIC	Target Insertion Cryostat
TGM	Target Gas Manifold

THD	tritium–hydrogen–deuterium
THG	third harmonic generator
TMP	thermal mechanical package
TRF	target request form
VBL	Virtual Beamline
VISAR	Velocity Interferometer System for Any Reflector
WAP	Work Authorization Process

Appendix B: National Ignition Facility User Group Charter and Bylaws

Revised 2015 Version

A. Overview

The purpose of the NIF Users' Group (NUG) is to provide an organized framework and independent vehicle for interaction between the scientists who use the NIF for "Discovery Science" experiments (DS users) and NIF Management. Responsibility for the NIF and the research programs carried out at the NIF resides with the NIF Director. The NUG shall advise the NIF Director on matters of concern to users, as well as provide a channel for communication for the NIF users with funding agencies and the public in general. The NUG is thus broadly concerned with representing the interests of the NIF users in order to facilitate the availability and effective use of the NIF for the broader research community.

The NIF Users' Group Executive Committee (NUG UEC) is a formal organizational unit of the NUG. The NUG UEC members are elected by the members of the NUG, and they typically meet several times each year. The UEC communicates the needs and desires of users regarding NIF operating policies, use of NIF, user support, and other relevant issues of concern to those engaged in research at this facility.

NIF management has agreed to engage the NUG (through the NUG UEC) as follows. The NUG Chair (or a designee) shall be included in discussions regarding current and/or future strategic plans for the facility to ensure evaluation of user interests and the most efficient and optimal utilization of the facility. To this end, a representative of the NUG UEC shall be invited to attend selected meetings where issues impacting users are discussed. The NUG UEC shall be provided an opportunity for input regarding the proposal solicitation, the selection process, and governance for the Discovery Science Program. NIF management shall appoint, in consultation with the NUG Chair, a liaison scientist with experience performing shots on NIF, who will serve as an ex-officio member of the NIF UEC, to make available knowledge regarding technical details of NIF and its procedures to the UEC.

B. Functions

The NUG shall be advisory to the NIF Director. Toward this end, the Users' organization shall:

- Serve as an advocacy group for the Facility and its user community;
- Provide a channel of communication between the NIF user community and NIF management; and
- Provide advice to the NIF Director.

C. Membership

All scientists involved in a "Discovery Science NIF proposal" and all participants in any resulting experiments will be automatically enrolled in the NUG. All scientists who attend workshops of the NUG will be automatically enrolled in the NUG. In addition, members will be welcome to join via a NUG website. Every member of the NUG may opt out at will and shall receive instructions regarding how to do so.

The NUG UEC has authority to adjust the terms of membership, in the event that open enrollment leads to unforeseen difficulty.

D. Executive Committee

The NUG UEC will conduct the business of the NUG, including organizing an annual users' meeting. There will be 11 members of the UEC plus the past Chair and two ex-officio members. Ten of these will normally serve rotating three-year terms. The eleventh member will be a student or post-doctoral fellow, who will serve a two-year term. Member terms will be staggered so that ideally about 30% of new members will be elected to the NUG UEC each year.

The Executive Committee is to be composed of 11 members of the following types:

- Four representatives, each from either a U.S. university or a small business (three-year term each, having staggered end dates)
- Three representatives, each from either a U.S. national laboratory or major industrial laboratory (three-year term each, having staggered end dates)
- Three non-U.S. researchers (three-year term each, having staggered end dates)
- One junior researcher (two-year term)
- The past Chair
- An (ex officio) representative appointed by NIF (the liaison scientist)
- An (ex officio) representative from the Executive Committee of the Omega Laser Users Group

There may normally be no more than one member of the UEC from any specific institution. Any exceptions must be approved by the UEC annually.

In the event that a position on the UEC should be vacated before expiration of its term, the UEC shall appoint a member of the NUG to fill the vacant position. The NUG UEC may appoint other subcommittees composed of UEC or NUG representatives, as it deems appropriate.

The ex-officio members will include the NIF liaison scientist, described above, and a member of the Executive Committee of the Omega Laser User Group (when feasible).

E. Elections

Members of the NUG UEC are elected as follows:

1. The Chair of the NUG UEC shall appoint the chair of the Nominating Committee (NC) by July 1 in each year. The UEC chair and NC chair shall jointly recruit four additional members. At least two members for the NC must not be current members of the UEC.
2. The NC shall solicit candidates for open UEC positions from the NUG membership in August and September, with an open nomination period of a minimum of four weeks.
3. The NC shall solicit additional candidates as needed to assure adequate breadth of representation across all elements of the community and adequate candidates of each type identified above. As far as practically possible, the NUG NC will aim to have diverse representation covering the broad range of techniques, disciplines, and scientific interests that comprise the NUG community.
4. The NC shall prepare a slate of candidates, balancing the desires of the membership with item three. If eligible and from a needed type of institution, the candidate receiving the most (and a minimum of 10) nominations from the membership at large shall appear on the slate.
5. The open election period shall occur during November, and shall last no less than two weeks. A brief biography of each candidate will be distributed to NUG membership prior to the election or as part of the online voting material.
6. All NUG members are eligible to vote.
7. Candidates are elected through an electronic voting procedure on a “first past the post” basis: the candidates with the highest number of individual votes are selected for membership of the NUG UEC.
8. New members of the NUG UEC will be announced at the annual users’ meeting or before it.

F. Meetings

An annual NUG meeting will be held. The NUG UEC shall be responsible for the meeting program, and shall provide appropriate advance notice of the meetings to NUG members. A general meeting of the NUG will be held annually, to coincide with the annual NUG Users’ meeting. The NUG UEC shall meet, either in person or electronically, at the time of the users’ meeting and at such other times as called for by the Chair or by a majority of the UEC membership. A quorum consists of a majority of the NUG UEC membership. NIF management will be responsible for providing coordinated administrative and financial support for the NUG annual users' meetings.

The Vice-Chair of the UEC will assume primary responsibility for organizing the annual users' meeting, in collaboration with local organizers and other members of the UEC.

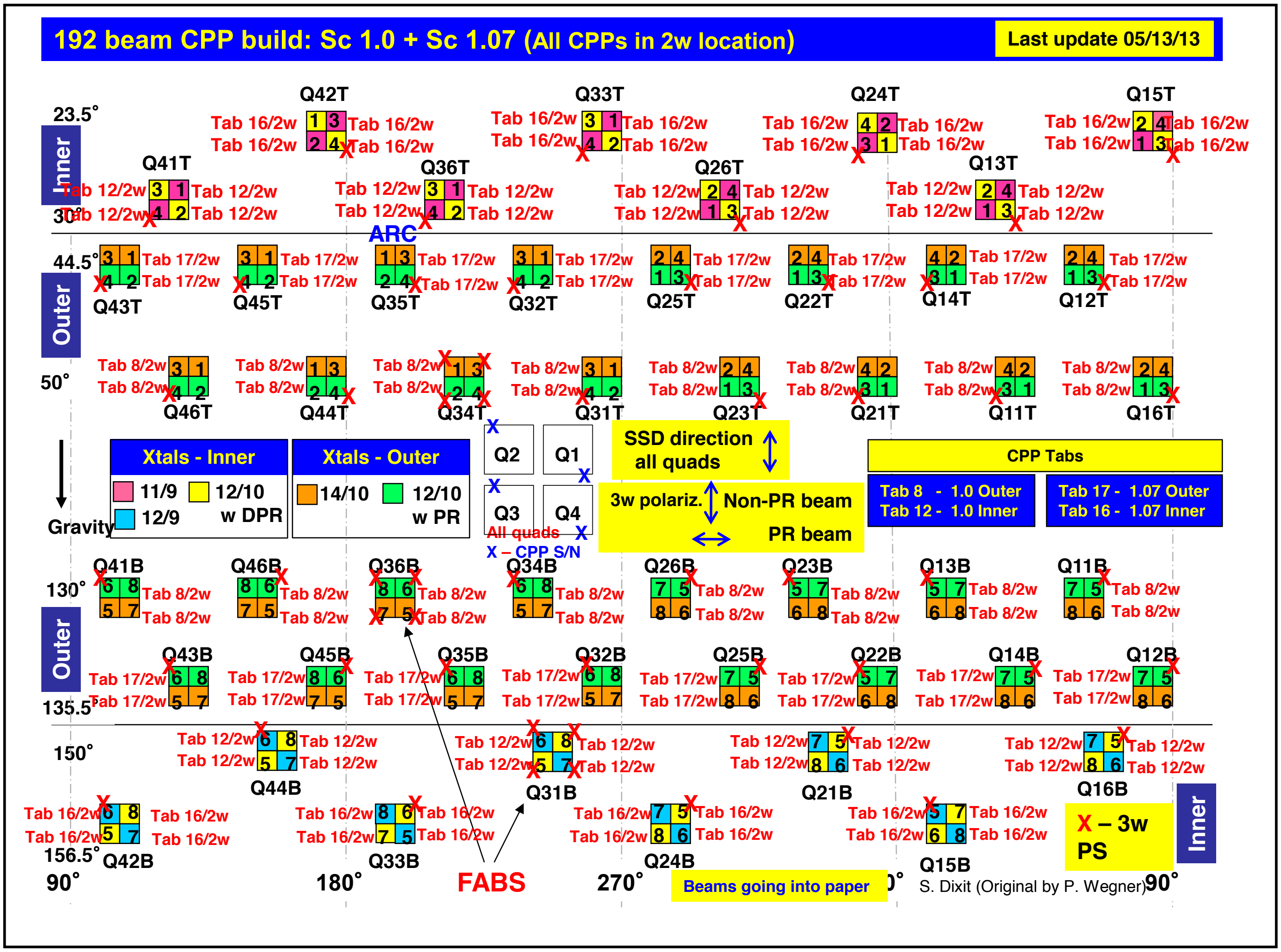
G. Officers

The officers of the NUG UEC will be a Chair and a Vice-Chair. The Chair of the NUG UEC will also be Chair of the NUG. The UEC shall set the term of the UEC chair. A new Chairperson's term shall begin immediately after an annual users' meeting. To assure continuity and to realize benefit from the experiences gained as a UEC officer, the past Chair shall continue to serve on the NUG UEC until the next election of a new Chair. The Vice-Chair shall be elected by the Users' Executive Committee from among its members at the first NUG UEC meeting following the election of new officers. The Vice-Chair shall stand in for the Chairperson if he/she is unavailable and shall assist the Chair in the discharge of his/her duties. The term of office for Vice-Chair shall equal that of the Chair, upon expiration of which term the Vice-Chair will normally succeed the Chair at the first meeting following the election of new UEC members. In the event that a Chair or Vice Chair is unable to complete the term of office, the remaining officer will serve as Chair and Vice Chair, and a new Vice Chair will be elected by the NUG UEC.

H. Amendments

Proposed changes to the bylaws shall be presented to the NUG membership, who will cast votes through electronic means. An open voting period of no less than two weeks is required. These bylaws shall be amended by a favorable vote.

Appendix C: Polarization Smoothing Seating Chart



NIF seating chart showing the Continuous Phase Plates (CPP) and the Polarization Rotator (PR) configurations.

Appendix D: Standard Gas Fills for Targets

TGM Target Fills						Target Fill	
Manifold	**Target**	**Gas container**	**Gas**	**Gas Bottle Fill Pressure**	**Temp., K**	**TARPOS**	**cryoTARPOS**
M1	Hohlraum (primarily cryogenic gases); 2 gas lines	Gas cylinder	^4He	N/A	17.6K–RT	12–650 torr	12-650 torr
		300cc gas bottle	97.55% ^4He / 2.45% Ne	1750 Torr			
M2	Capsule; 1 gas line	75cc gas bottle	Propane/D-Propane	5000 Torr	RT	~2200 Torr	~2200 Torr
			$D_2/^3He$	5700 Torr	24–32K	<3400 Torr	<3200 Torr
		150cc gas bottle	$D_2/^3He$			3990 torr	3990 Torr
			$D_2/^3He$	7000 Torr			
			Propane	5000 Torr	RT	~2900 Torr	~2900 Torr
			.01% Kr / Propane	5000 Torr		~2900 Torr	~2900 Torr
		300cc gas bottle - HiP	D_2 (900 psig fill)	<950 psig		~40000 torr	NA
		1000cc gas bottle	.01% Ar / D_2	6700 Torr	24–32K	~4650 torr	4350 torr
			D_2		21.5K	Liquid D_2	Liquid D_2
			Kr		RT	<5000 Torr	<5000 Torr
		11cc reservoir, ITIC	DT	<250 psig	32K	NA	<4000 torr
		1.7cc reservoir, EFS	T_2	<212 psig	32K		<3600 torr*
			D_2,T_2,DT,THD	150 psig	<18K		layer
M3	Hohlraum/ gas pipe (primarily non-cryogenic gases); 2 gas lines	1000cc gas bottle	Neopentane	1100 Torr	RT	25–750 torr	25–750 torr
			57% Kr / 43% Xe	1750 Torr		<1400 Torr	<1500 Torr

Appendix E: Diagnostics Implemented on the National Ignition Facility

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
Nuclear and Particle Diagnostics					
EMP	Electro-magnetic Power	102-84	LLNL	EMP measures the electromagnetic frequency spectrum in the target chamber.	Brown, C.G., et al. (2011), “Analysis of Electromagnetic Pulse (EMP) Measurements in the National Ignition Facility’s Target Bay and Chamber,” at International Fusion Science and Applications (IFSA), Bordeaux, France, LLNL-PROC-512731.
GRH	Time and spectrally-resolved Gamma Reaction History (GRH)	64, 20	LANL, LLNL	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 (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 deuterium–tritium (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.	Malone, R.M., et al. (2010), “Overview of the gamma reaction history diagnostic for the National Ignition Facility (NIF),” in *Proc. SPIE.* (International Optical Design Conference), vol. 7652, p. 76520Z. Wilson, D.C., et al. (2008), “Diagnosing ignition with DT reaction history,” *Rev. Sci. Instrum.* **79**, 10E525. McEvoy, A.M., et al. (2010), “Gamma bang time analysis at OMEGA,” *Rev. Sci. Instrum.* **81**,10D322. Hoffman, N.M., et al. (2010), “Using gamma-ray emission to measure areal density of inertial confinement fusion capsules,” *Rev. Sci. Instrum.* **81**, 10D332. Herrmann, H.W., et al. (2010), “Diagnosing inertial confinement fusion gamma ray physics,” *Rev. Sci. Instrum.* **81**, 10D333. Sayre, D.B. et al. (2012), “Multi-shot analysis of the gamma reaction history diagnostic,” *Rev. Sci. Instrum.* **83**, 10D905.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
MRS	Magnetic Recoil Spectro-meter	77,324 with use of DIM appendage	MIT, LLE, LLNL	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 CR-39 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 detector films. Ion temperature is also recorded with lower resolution than the Neutron Time-of-Flight, dependent on the thickness of the plastic foil.	Frenje, J.A., et al. (2010), "Probing high areal-density cryogenic deuterium-tritium implosions using downscattered neutron spectra measured by the magnetic recoil spectrometer," *Physics of Plasmas*. **17**, 056311. Casey, D.T., et al. (2011), "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. Casey, D.T., et al. (2012), "Measuring the absolute deuterium–tritium neutron yield using the magnetic recoil spectrometer at OMEGA and the NIF," *Rev. Sci. Instrum*. **83**, 10D912. Johnson, M. Gatu, et al. (2012), "Neutron spectrometry—An essential tool for diagnosing implosions at the National Ignition Facility," *Rev. Sci. Instrum*. **83**, 10D308.
Mag-PTOF	Magnetic-Particle Time-of-Flight Proton Detector	DIM Appen-dage	MIT, LLE, LLNL	The diagnostic, which measures proton emission time, has four main components: a Chemical Vapor Deposition (CVD)-diamond detector, x-ray shielding (tungsten, configurable in units of 0.5 cm up to 4 cm) to shield the detector from hohlraum x-ray background, a permanent dipole magnet with 1 T peak field to deflect protons around the shielding and onto the detector, and an optional annular piece of CR-39 around the CVD-diamond, to confirm proton fluence and energy on each shot. The MagPTOF detector, cables, and electronics are identical to the existing ones for the PTOF.	Rinderknecht, H. G. (2014), "A magnetic particle time-of-flight (MagPTOF) diagnostic for measurements of shock- and compression-bang time at the NIF." *Rev. Sci. Instrum*. **85**, 11D901.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
NAD (Thulium)	Neutron Activation Detector	DIM Appen-dage	LANL, LLNL	NADs measure the integrated neutron yield of a target capsule by activating a sample material, removing it from the chamber, and determining the activation level using nuclear counting techniques. The Thulium NAD is a neutron activation diagnostic sample specifically for measuring neutrons with energies higher than the DT primary neutrons. It requires specialized gamma counting capability to analyze.	Grim, G.P., et al. (2014), "Measurement of reaction-in-flight neutrons using thulium activation at the National Ignition Facility," in *Proc. SPIE*, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion III, vol. 9211.
NAD—WRF mount	Neutron Activation Detector	DIM Appen-dage	LLNL	NADs measure the integrated neutron yield of a target capsule by activating a sample material, removing it from the chamber, and determining the activation level using nuclear counting techniques. The Wedge Range Filter mount package places the samples very near the target. An indium sample material is often used in this configuration to measure low energy deuterium–deuterium neutrons.	
NAD Cu (20 m)	Neutron Activation Detector	116, 316	SNL, LLNL	NADs measure the integrated neutron yield of a target capsule by activating a sample material, removing it from the chamber, and determining the activation level using nuclear counting techniques. The NAD Cu (20 m) measures the neutron yield from a DT-filled capsule by activating a copper foil in a neutron line-of-sight in the neutron alcove. 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.	Cooper, G. W., et al. (2012), "Copper activation deuterium-tritium neutron yield measurements at the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10D918.

Acronym	Name	Port Location	Builder/ Commissioner	Function	Published References
NAD Zr (Flange)	Neutron Activation Detector	20 fixed locations	LLNL	NADs measure the integrated neutron yield of a target capsule by activating a sample material, removing it from the chamber, and determining the activation level using nuclear counting techniques. The Flange NAD uses a set of up to 20 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 off of the NIF site. 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.	Bleuel, D. L., et al. (2012), “Neutron activation diagnostics at the National Ignition Facility,” *Rev. Sci. Instrum.* **83**, 10D313.
NAD Zr (Well)	Neutron Activation Detector	Fixed	LLE, LLNL	NADs measure the integrated neutron yield of a target capsule by activating a sample material, removing it from the chamber, and determining the activation level using nuclear counting techniques. The Well NAD uses activation of a single Zr sample inserted into a well on the NIF target chamber. The three-day half-life of the Zr activation product allows the samples to be counted off of the NIF site.	Bleuel, D. L., et al. (2012), “Neutron activation diagnostics at the National Ignition Facility,” *Rev. Sci. Instrum.* **83**, 10D313. Yeamans, C. B., et al. (2012), “Enhanced NIF neutron activation diagnostic,” *Rev. Sci. Instrum.* **83**, 10D315.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
NIS	Neutron Imager System	93-315 (With use of DIM)	LANL, LLNL	NIS measures static neutron images of the primary (14 MeV) and the down-scattered (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 down-scattered ratio.	Merrill, F. E., et al. (2012), "The neutron imaging diagnostic at NIF," *Rev. Sci. Instrum.* **83**, 10D317. Wilke, Mark D., et al. (2008), "The National Ignition Facility Neutron Imaging System," *Rev. Sci. Instrum.* **79**, 10E529. Volegov, P., et al. (2014), "Neutron source reconstruction from pinhole imaging at National Ignition Facility," *Rev. Sci. Instrum.* **85**, 023508. Wilson, D. C., et al. (2010), "Modeling the National Ignition Facility neutron imaging system," *Rev. Sci. Instrum.* **81**, 10D335. Loomis, E. N., et al. (2010), "Progress toward the development and testing of source reconstruction methods for NIF neutron imaging," *Rev. Sci. Instrum.* **81**, 10D311.
NITOF	Neutron Imager Time-of-Flight	93-315 (With use of DIM)	LANL, LLNL	NITOF measures neutron yield, ion temperature, and areal density along the NIS line of sight. It is essentially the same as the other neutron time-of-flight diagnostics in concept. As it is the furthest from Target Chamber Center (TCC), it has the highest spectral resolution among NTOFs, but because it usually has Neutron Imager or Velocity Interferometer System for Any Reflector (VISAR) hardware along its line of sight, it is more difficult to maintain calibration.	Grim, G. P., et al. (2008), "A spatially resolved ion temperature diagnostic for the National Ignition Facility," *Rev. Sci. Instrum.* **79**, 10E537.
NTOF20 IgHi	Neutron Time-of-Flight	116, 316	LLE, LLNL	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.	Yu, V., et al. (2010), "The National Ignition Facility neutron time-of-flight system and its initial performance," *Rev. Sci. Instrum.* **81**, 10D325. Lerche, R. A., et al. (2010), "National Ignition Facility neutron time-of-flight measurements," *Rev. Sci. Instrum.* **81**, 10D319.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
NTOF 4.5 BT NTOF DTHi NTOF DTLo	Neutron Time-of-Flight	64-136 64-309 64-330	LLE, LLNL	NTOF detectors measure the time-of-flight of neutrons emitted from the target. There are 3 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 1E10–1E13 neutrons from TCC.	Yu, V., et al. (2010), "The National Ignition Facility neutron time-of-flight system and its initial performance," *Rev. Sci. Instrum.* **81**, 10D325. Lerche, R. A., et al. (2010), "National Ignition Facility neutron time-of-flight measurements," *Rev. Sci. Instrum.* **81**, 10D319.
NTOF20 SPEC-A NTOF20 SPEC-E NTOF 18M-SP	Neutron Time-of-Flight	90-174 116-316 161-156	LLE, LLNL	NTOF detectors measure the time-of-flight of neutrons emitted from the target. Three NTOFs located at a distance of 18–20 m (alcove/equatorial) from TCC are used to measure neutron yield, ion temperature, and areal density.	Yu, V., et al. (2010), "The National Ignition Facility neutron time-of-flight system and its initial performance," *Rev. Sci. Instrum.* **81**, 10D325. Lerche, R. A., et al. (2010), "National Ignition Facility neutron time-of-flight measurements," *Rev. Sci. Instrum.* **81**, 10D319.
PTOF	Particle Time-of-Flight Proton Detector	DIM Appendage 90-78 only	MIT, LLE, LLNL	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 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.	Rinderknecht, H., et al. (2012), "A novel particle time-of-flight diagnostic for measurements of shock- and compression-bang times in D3He and DT implosions at the NIF," *Rev. Sci. Instrum.* **83**, 10D902.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
RAGS	Radio-chemistry Analysis of Gaseous Samples	180, 0 Fixed	SNL, LLNL	RAGS is used to collect and measure neutron activation products that are gaseous at room temperature. For example, pre-loading low levels of noble gases such as Kr and Xe into the ablator enables them to be used as activation detectors. 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.	Grim, G. P., et al. (2008), "Prompt radiochemistry at the National Ignition Facility," *Rev. Sci. Instrum.* **79**, 10E503. Nelson, S. L., et al. (2011), "RAGS: The Gaseous Sample Collection Diagnostic at the National Ignition Facility," *IEEE Transactions on Plasma Science*. **39**. Stoyer, M. A., et al. (2012), "Collection of solid and gaseous samples to diagnose inertial confinement fusion implosions," *Rev. Sci. Instrum*. **83**, 023505.
SRC	Solid Radio-chemical Collection Diagnostic	DIM Appendage	LLNL	Bulk target materials as well as trace elements in the targets can be activated by neutrons or possibly even charged particles to produce radioactive species. SRC units placed about 50 cm 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 postshot, and the presence of radioactive isotopes is determined by nuclear counting techniques in facilities off of the NIF site. Using this technique, radioactive gold isotopes resulting from activation of the target hohlraums have been detected.	Stoyer, M.A., et al. (2012), "Collection of solid and gaseous samples to diagnose inertial confinement fusion implosions," *Rev. Sci. Instrum*. **83**, 023505.
TOAD	TOAD Solid Radio-chemical Collection Diagnostic	DIM Appendage	LLNL	TOAD is a specialized sample holder for holding potentially radioactive or hazardous samples in the Solid Radiochemistry diagnostic package. It allows for simplified handling. It has been used for depleted uranium samples.	Gharibyan, Narek, et al. (2015), "First fission yield measurements at the National Ignition Facility 14-MeV neutron fission of ^{238}U." *J. Radioanal. Nucl. Chem.* **303**:1335–1338.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
SPBT	South Pole Bang Time Neutron Channel	Uses port 161, 146 records on the LOS of 0-180	LLE, LLNL	The SPBT Neutron Channel measures through the lower Laser Entrance Hole (LEH) the time of peak x-ray emission (peak compression) relative to the laser pulse.	Edgell, D. H., et al. (2012), "South pole bang-time diagnostic on the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10E119.
WRF	Wedge Range Filter	DIM Appendage	MIT, LLE, LLNL	WRFs are used for D_3He 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 various parts of a wedge of material and measuring the energy of the protons 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.	Zylstra, A. B., et al. (2012), "Charged-particle spectroscopy for diagnosing shock ρR and strength in NIF implosions," *Rev. Sci. Instrum.* **83**, 10D901.
			Optical Diagnostics		
FABS Q31B FABS Q36B	Full Aperture Backscatter Station	150-236 130-185	LLNL	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).	Bower, D. E., et al. (2004), "Full aperture backscatter station measurement system on the National Ignition Facility," *Rev. Sci. Instrum.* **75**, 4177. Moody, J. D., et al. (2010), "Backscatter measurements for NIF ignition targets," *Rev. Sci. Instrum.* **81**, 10D921. Datte, Philip, et al., "Operational experience with optical streak cameras at the National Ignition Facility," *Proc. SPIE*. 8850, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion II, 88500G. (September 26, 2013)

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
NBI Q31B NBI Q33B NBI Q33B	Near Backscatter Imager	150-236 130-185 Fixed for NBI33	LLNL	Light 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.	Moody, J. D., et al. (2010), "Backscatter measurements for NIF ignition targets," *Rev. Sci. Instrum.* **81**, 10D921. Datte, Philip, et al., "Operational experience with optical streak cameras at the National Ignition Facility," *Proc. SPIE*. 8850, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion II, 88500G. (September 26, 2013)
SOP	Streaked Optical Pyrometer	Shared LOS 90-315 DIM	LLNL	SOP measures the breakout time of an optically emitting shock.	Malone, R. M., et al., "Combining a thermal-imaging diagnostic with an existing imaging VISAR diagnostic at the National Ignition Facility," *Proc. SPIE*. 5874, Current Developments in Lens Design and Optical Engineering VI, 587409. (August 18, 2005) Miller, J. E., et al. (2007), "Streaked optical pyrometer system for laser-driven shock-wave experiments on OMEGA," *Rev. Sci. Instrum.* **78**, 034903.
VISAR	Velocity Interfer-ometer System for Any Reflector	90-315 DIM	NSTec, LLNL	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 the 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.	Malone, R. M., et al (2007), "Overview of the line-imaging VISAR diagnostic at the National Ignition Facility," *Proc. SPIE*. 6342.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
GFD	Glint Fast Diode	90-315 with VISAR installed	LLNL	The GFD diagnostic measures 351 nm laser light that shines on the capsule via reflection from the hohlraum for a fraction of a ns early in the laser drive. This glint can produce early-time imprint on the capsule that may then grow to significant shape perturbations. In addition it may provide a measure of pre-pulse at the target.	Moody, J. D., et al. (2014), "Hohlraum glint and laser pre-pulse detector for NIF experiments using velocity interferometer system for any reflector," *Rev. Sci. Instrum.* **85**, 11E608.
4ω Fiducial	4ω Fiducial	DIM 90-78 DISC SPIDER	LLE, LLNL	The 4ω fiducial for x-ray streak cameras is used for absolutely correlating the x-ray streak camera signals with respect to laser timing. The 4ω fiducial is used with SPIDER and DISC.	Homoelle, Doug, et al., "A compact UV timing fiducial system for use with x-ray streak cameras at NIF." *Proc. SPIE*. 8505, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion, 850504. (October 15, 2012) Hatch, Ben, et al., "Performance and operational upgrades of x-ray streak camera photocathode assemblies at NIF." *Proc. SPIE*. 9211, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion III, 92110H. (September 10, 2014)
X-Ray Diagnostics					
ARIANE	Active Readout in a Neutron Environment (gated x-ray imager)	90-89 (but uses DIM)	LLNL	ARIANE is a gated x-ray detector measuring x-ray output at yields up to ~1E16 neutrons from TCC. ARIANE uses gated microchannel plate (MCP) technology adapted to operate in this neutron regime by moving the detector to a position just outside of the target chamber wall. ARIANE is typically used in the ignition program to measure the time-dependent symmetry of the hot central fuel region, similar to the Time-Gated X-ray Detector and the Hardened Gated X-ray Diagnostic at lower neutron yields. A plan is in place to use a mirrored version of ARIANE for experiments with yields in excess of $1E^{16}$ neutrons from TCC.	Bell, P. M., et al. (2010), "Radiation hardening of gated x-ray imagers for the National Ignition Facility," *Rev. Sci. Instrum.* **81**, 10E540. Ayers, Jay, et al., "Design and implementation of high magnification framing camera for NIF (ARIANE Light)," *Proc. SPIE*. 8505, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion, 85050J. (October 15, 2012) Smalyuk, V. A., "X-ray imaging in an environment with high-neutron background on National Ignition Facility," *Proc. SPIE*. 8144, Penetrating Radiation Systems and Applications XII, 81440N. (September 08, 2011)

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
Dante1 Dante2	Broadband, time-resolved x-ray spectrometer	143-274 & 64-350	LLNL	Dante1 and 2 are fixed soft x-ray power diagnostics for the lower and upper hemispheres. Each Dante has 18 time-resolved channels; spectral ranges are controlled by the filters, metallic mirrors, and x-ray diode material. Dante1 has five channels with mirrors, and Dante2 has eight mirrored channels. Dante measures the absolute radiant x-ray power versus time. With knowledge of the size of the LEH, this can be converted to the radiation temperature of the source.	Dewald, E. L., et al. (2004), "Dante soft x-ray power diagnostic for National Ignition Facility," *Rev. Sci. Instrum.* **75**, 3759. Kline, J. L., et al. (2010), "The first measurements of soft x-ray flux from ignition-scale hohlraums at the National Ignition Facility using DANTE," *Rev. Sci. Instrum.* **81**, 10E321.
DISC1 DISC2 DISC3	DIM Insert able Streak Camera	DIM	GA, LLNL	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.	Opachich, Y.P., et al. (2012), "X-ray streak camera cathode development and timing accuracy of the 4 omega ultraviolet fiducial system at the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10E123. Kimbrough, J. R., el at. (2001), "National Ignition Facility core x-ray streak camera," *Rev. Sci. Instrum.* **72,** 748. Kalantar, D. H., et al. (2001), "Optimizing data recording for the NIF core diagnostic x-ray streak camera," *Rev. Sci. Instrum.* **72**, 751. Kimbrough, J. R., et al. (2010), "Standard design for National Ignition Facility x-ray streak and framing cameras," *Rev. Sci. Instrum.* **81**, 10E530. Hicks, D. G., et al. (2010), "Streaked radiography measurements of convergent ablator performance," *Rev. Sci. Instrum.* **81**, 10E304.

Acronym	Name	Port Location	Builder/ Commis- sioner	Function	Published References
DIXI	Dilation Imager for X-rays at Ignition	90-89 (but uses DIM)	LLNL	Core Diagnostic Instrument Manipulator (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 reduces to 100 ps.	Hilsabeck, T. J., et al. (2010), "Pulse-dilation enhanced gated optical imager with 5 ps resolution," *Rev. Sci. Instrum.* **81,** 10E317. Nagel, S. R., et al. (2012), "Dilation x-ray imager a new/ faster gated x-ray imager for the NIF," *Rev. Sci. Instrum.* **83**, 10E116. Ayers, J., et al., "Design and implementation of Dilation X-ray Imager for NIF "DIXI," *Proc. SPIE.* 8850, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion II, 88500C (September 26, 2013). Nagel, Sabrina R., et al., "2D magnetic field warp reversal in images taken with DIXI (dilation x-ray imager)." *Proc. SPIE.* 8850, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion II, 88500I. (September 26, 2013). Nagel, Sabrina R., et al., "Performance measurements of the DIXI (dilation x-ray imager) photocathode using a laser produced x-ray source." *Proc. SPIE.* 8505, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion, 85050H (October 19, 2012).
EHXI	Equatorial Hard X-ray Imager	90-110	AWE, LLE, LLNL	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 the Thermal Mechanical Package (TMP). The low energy cutoff is typically set by the x-ray absorption in the hohlraum wall, TMP, and a thinned-out target chamber flange.	Döppner, T., et al. (2012), "Hard x-ray (>100 keV) imager to measure hot electron preheat for indirectly driven capsule implosions on the NIF," *Rev. Sci. Instrum.* **83**, 10E508.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
FFLEX FFLEX TR	Filter Fluorescer Diagnostic	90-110	LANL, LLNL	FFLEX measures the absolute radiant hard x-ray power vs time in ten spectral bands (18 keV to 400 keV). The hard x-ray spectrum is typically used to determine the fraction of laser energy that went into hot electrons and the electron temperature that characterizes this electron energy distribution.	Hohenberger, M., et al., "Measuring the hot-electron population using time-resolved hard x-ray detectors on the NIF," *Proc. SPIE*. 8850, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion II, 88500F. (September 26, 2013). Dewald, E. L., et al. (2010), "Hot electron measurements in ignition relevant hohlraums on the National Ignition Facility," *Rev. Sci. Instrum*. **81**, 10D938.
GXD1 GXD2 GXD3 GXD4	Time-Gated X-ray Detector	DIM	LLNL	A 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 onto a detector. Typically, these detectors are located about 1 m from TCC. An electrically gated MCP coated with a microstrip, in conjunction with a Charge-Coupled Devices (CCDs) detector and phosphor, is used as the detector. The use of this GXD is limited to yields up to approximately 1E13 neutrons from TCC. For experimental campaigns involving capsule implosions, such as the ignition program, GXD is typically used to study time-dependent symmetry of the hot central emission region of a compressed Inertial Confinement Fusion (ICF) target.	Oertel, John A., et al. (2006), "Gated x-ray detector for the National Ignition Facility." *Rev. Sci. Instrum*. **77**, 10E308. Glenn, S., et al., "Advanced gated x-ray imagers for experiments at the National Ignition Facility." *Proc. SPIE*. 8144, Penetrating Radiation Systems and Applications XII, 814409. (September 08, 2011). Park, J., et al. (2010), "Calibration of a flat field soft x-ray grating spectrometer for laser produced plasmas," *Rev. Sci. Instrum*. **81**, 10E319.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
HEIDI		DIM	LLNL	HEIDI is a high-energy (30–70 keV) point projection recording system. It utilizes time-integrated image plates to record the signal of interest.	Ahmed, Maryum F., "Target material collection for High-Energy Imaging Diagnostic," *Proc. SPIE*. 9211, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion III, 92110F. (September 10, 2014).
HEMPI	High Energy Multipinhole Imager	Snout	LLNL	HEMPI images high-energy x-rays with a large field-of-view using an array of 18 pinholes with four independent filter combinations. A spectrum of the hard x-rays emitted from different regions of the hohlraum can be constructed through analyzation of the differentially filtered images.	Park, H., 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).

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
HGXD1 HGXD2 HGXD3	Hardened Gated X-ray Diagnostic	DIM	LLE, LLNL	HGXD measures spatially and temporally resolved x-ray emission from an imploding core containing DT/hydrogen-deuterium-tritium fuel to determine core temperature and shape. 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. HGXDs can operate at yields up to about $1E^{15}$ neutrons from TCC. For experimental campaigns involving capsule implosions, such as the ignition program, HGXD is typically used to study time-dependent symmetry of the hot central emission region of a compressed ICF target.	Glenn, S., et al., "A hardened gated x-ray imaging diagnostic for inertial confinement fusion experiments at the National Ignition Facility," *Rev. Sci. Instrum.* **81**, 10E539 (2010). Glenn, S., et al., "Advanced gated x-ray imagers for experiments at the National Ignition Facility," *Proc. SPIE*. 8144, Penetrating Radiation Systems and Applications XII, 814409. (September 08, 2011). Hargrove, D. R., et al., "Improvements to a MCP based high speed x-ray framing camera to have increased robustness in a high neutron environment." *Proc. SPIE*. 9211, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion III, 92110D (September 10, 2014). Benedetti, L. R., et al., "Investigation and suppression of artifacts in x-ray framing cameras due to advance radiation incident on microchannel plates" *Proc. SPIE*. 8850, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion II, 88500J. (September 26, 2013). Kyrala, G. A., et al. (2010), "Measuring symmetry of implosions in cryogenic hohlraums at the NIF using gated x-ray detectors," *Rev. Sci. Instrum.* **81**, 10E316 Bell, P. M., et al. (2010), "Radiation hardening of gated x-ray imagers for the National Ignition Facility," *Rev. Sci. Instrum.* **81**, 10E540. Pak, A., et al. (2012), "Diagnosing radiative shocks from deuterium and tritium implosions on NIF," *Rev. Sci. Instrum.* **83**, 10E507. Ma, T., et al. (2012), "Imaging of high-energy x-ray emission from cryogenic thermonuclear fuel implosions on the NIF," *Rev. Sci. Instrum.* **83**, 10E115.

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
NXS	NIF X-ray Spectrometer	DTRA, LLE, LLNL	SNL, LLNL	NXS complements the existing absolutely calibrated, time-integrated Super Snout II x-ray spectrometer. This spectrometer consists of a Bragg crystal and associated mount, attached to a DISC streak camera and installed in a standard NIF Diagnostic Insertion Manipulator. NXS has a spectral coverage range in the 3 to 16 keV by selectable configurations, a temporal resolution of ≈100 ps, and a spectral resolving power E/ΔE≈500.	Perez, F., et al. (2014), "The NIF x-ray spectrometer calibration campaign at Omega," *Rev. Sci. Instrum.* **85**, 11D613.
RFPI	Ross Filter Pair Imaging	Append-age	LLNL	An array of "Ross filtered" pinholes measures the temperature- and density-sensitive Bremsstrahlung emission. This data provides 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.	
SPBT	South Pole Bang Time	Uses port 161, 146 records on the LOS of 0-180	LLE, LLNL	SPBT has a fixed x-ray detector measuring the x-ray diffracted off an x-ray crystal spectrometer at a distance of about 2 meters from TCC. 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 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.	Edgell, D. H., et al. (2012), "South pole bang-time diagnostic on the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10E119. Kimbrough, Joseph R., et al., "Performance improvements of PCDs for measuring x-ray bang time." *Proc. SPIE.* 8505, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion, 850506. (October 15, 2012)

Acronym	Name	Port Location	Builder/ Commis-sioner	Function	Published References
SPIDER	Streaked Polar Instru-mentation for Diagnos-ing Energetic Radiation	7,90	SNL, LLNL	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. Spider is designed to run in a 5E16 neutron yield by design.	Opachich, Y. P., et al. (2012), "X-ray streak camera cathode development and timing accuracy of the 4 omega ultraviolet fiducial system at the National Ignition Facility," *Rev. Sci. Instrum.* **83**, 10E123. Khan, S. F., et al. (2012), "Measuring x-ray burn history with the Streaked Polar Instrumentation for Diagnosing Energetic Radiation (SPIDER) at the National Ignition Facility," *Proc. SPIE.* **8505.**
SXI-L SXI-U	Static X-ray Imager	161,326 18-123	LLNL	The SXI diagnostics are two pinhole cameras, mounted on retractable positioners at 18o from top of the target chamber and 19o to bottom of the target chamber. They deliver time-integrated pinhole images in the x-ray energy band of 3–5 keV, defined by a titanium filter. One camera also has a multilayer mirror + copper filter to produce an image at 900 eV, the x-ray energy at the peak of a 300 eV black body. The images are recorded on either image plates or CCDs, depending on the expected neutron yield. For hohlraum experiments, the SXIs 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.	Landon, M. D., et al. (2001), "Design of the National Ignition Facility static x-ray imager," *Rev. Sci. Instrum.* **72**, 698. Schneider, M. B., et al. (2010), "Images of the laser entrance hole from the static x-ray imager at NIF," *Rev. Sci. Instrum.* **81**, 10E538. Schneider, M. B., et al. (2012), "Soft x-ray images of the laser entrance hole of ignition hohlraums," *Rev. Sci. Instrum.* **83**, 10E525.
Super-snout II (multi-wave-length)	Multi-wavelength X-ray Spectrometer	Snout		Two four-channel elliptical crystal Supersnout spectrometers with medium resolution are used to record K shell x-rays from dopants such as germanium and copper from the plastic ablator once they mix into the hot spot and emit x-rays.	

Acronym	Name	Port Location	Builder/ Commis- sioner	Function	Published References
TARDIS	Target Diffraction	90,239 TARPOS		The TARDIS diagnostic contains a diffraction crystal, image plate detectors, and diffraction target inside a shielded box. There is a backlighter target external to the box. Drive beams heat a carefully designed ablator to ramp compress the target to a high pressure, and, at the appropriate time, backlighter beams produce a quasi-monochromatic K-shell x–ray source which diffracts off the compressed target onto the image plates.	Ahmed, Maryum F., et al., "X-ray diffraction diagnostic design for the National Ignition Facility." *Proc. SPIE.* 8850, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion II, 88500N. (September 26, 2013)

Appendix F: Available Target Characterization Techniques

General Atomics (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 National Ignition Facility (NIF) target chamber coordinates for that specific target.
- **Contact radiography (CR):** A nondestructive technique to precisely profile graded dopants in Inertial Confinement Fusion (ICF) shells, this quantitative CR method can detect dopant variation to better than 0.1 at. %. CR 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. Three-dimensional (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.
- **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.

Appendix G: Data Policies

Policy on Data and Dissemination of Results obtained from use of the National Ignition Facility

A. Purpose of this Policy and Responsible Individuals

The National Ignition Facility (NIF) is an NNSA facility operated in support of national security and related missions. Experiments on the NIF generate data of broad national and international interest. These data arise in a variety of forms, including NIF performance information, raw data from target diagnostics, scientific data in the process of interpretation, and analyzed data ready for publication.

The purpose of this document is to provide policy regarding the handling and sharing of such data, and any publications generated from research programs connected to the NIF.

The term "Publication" is used in the broadest possible sense of the word, including conference presentations, abstracts, colloquia, patents, as well as peer-reviewed papers.

The objectives of this policy are threefold:

1. To provide a consistent framework for use and publication of data obtained from the NIF facility.
2. To ensure that data from NIF experimental campaigns are made available in a suitably protected manner to researchers involved in each experiment, and subsequently made available to the broader scientific community as appropriate.
3. To define data-handling responsibilities for the NIF facility and parties with access to NIF data, such that the integrity of NIF data is protected

The NIF publication policy is consistent with generally accepted guidelines for scientific conduct, including the right for individual researchers to publish their data results and analysis.[31, 32, 33]

There is a broad diversity of the user communities utilizing NIF with a widely varying nature of the research activities, ranging from small, investigator-led experiments through to large-scale international campaigns spanning many years. While general guidance is provided herein, *it is a fundamental tenet of this policy that responsibility for detailed implementation is vested in each of the program areas*. This will ensure that execution of the policy conforms to the individual constraints of each program.

As such, it is the responsibility of the programs themselves to provide adequate mechanisms for administration of this policy, including a mechanism for resolving conflicts (disputes).

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

[32] Office of Science and Technology Policy, *"Memorandum on Scientific Integrity,"* Washington, DC, December 2010.

[33] National Research Council, *"On Being a Scientist- Responsible Conduct in Research,"* National Academy Press, Washington, DC, 1995.

The following programs require specific implementation mechanisms for this policy:

a. High Energy Density Stockpile Stewardship (SSP-HED);
b. Inertial Confinement Fusion (SSP-ICF);
c. Discovery Science (DS);
d. National Security Applications (NSA); and
e. Facility

B. Definitions

1. Data

This policy distinguishes between facility related data (“NIF facility data”) and data related to and from experiments (“NIF experimental data”). Appendix H contains a detailed definition of these data types. All data fall under the purview of this policy.

This policy applies to NIF non-proprietary data. All such data is ultimately owned by the NNSA, and other sponsoring federal agencies or organizations if applicable.

2. Principal Investigator (PI)

The term “PI” is an accepted term regarding the role of the person responsible for the use of data obtained in a research project. PIs may be established for leading experimental campaigns, for developing new diagnostics or experimental techniques, or for developing other new experimental capabilities on the NIF. For the particular case of the NIF, the term “PI” applies whether data are obtained directly from an experimental campaign, or the result of scientific analysis of previously obtained experimental data being used in connection to the current campaign. The PI also has responsibility for the management and dissemination of numerical or theoretical analyses connected with data interpretation for a NIF campaign.

There shall always be a single person identified as the PI with regard to the responsibilities laid out in this policy, even if for practical or technical reasons there are multiple senior investigators on a given campaign

3. Program Publication Committees

Each Program active on the NIF is responsible for establishing a Publication Committee to implement this policy for its experimental campaigns. It is also understood that Program Publication Committees can include members from multiple laboratories and universities.

C. Policies and Responsibilities

1. NIF Director Responsibilities

With respect to NIF data, the NIF Director shall:

a. Maintain this policy.
b. Maintain the NIF database and provide data access consistent with DOE and NNSA policy, program guidelines, security considerations, and accepted principles of scientific conduct.
c. Appoint a Program Leader for facility data.
d. Ensure that each Program Publication Committee has defined and implemented a program-specific process for authorship, publication review and resolving publication disputes.

2. Programs

The primary organization or individual responsible for the data (meaning final authority for its utilization) is dependent on the program area, as follows:

- *SSP-HED, SSP-ICF, and Facility*: Data owned by program leadership
- *DS*: Data owned by the Principal Investigator
- *NSA*: Data owned by the sponsoring organization

All Programs will follow accepted principles of scientific conduct as described in Section I, and have the following responsibilities:

Oversight: The SSP-HED, SSP-ICF Programs and the Facility shall each appoint a Publication Committee (with a named Chair) to administer this policy with regard to data use and dissemination. This Committee will be responsible for developing, issuing and administering a program-specific policy for authorship, publication review and conflict (dispute) resolution. When Programs have participants from multiple laboratories, at least one representative from each laboratory shall be appointed to the committee. In addition, at least one NIF representative shall also be appointed to the committee, designated by the NIF Director through the NIF User Office.

The NIF User Office will work with leadership of the DS and NSA Programs to establish Publication Committees and program-specific data policies. Programs are accountable to the NIF Director for implementing this umbrella policy, for establishing Publication Committees and developing program-specific detailed publication policies. The Publication Committees shall be accountable to the Programs for implementing these specific policies.

a. *Principal Investigator:* Each program shall appoint a PI for each experimental campaign executed on the NIF and ensure that the PI and their team are aware of their accountability. For large research programs, the programs may appoint multiple PIs for each phase of a campaign. The Roles & Responsibilities of the PI with respect to publication shall be established and documented prior to the start of the campaign.
b. *Authorship:* Authors and co-authors will have made significant technical contributions that are specific to the publication which does not include routine operation of the NIF. Examples of significant technical contributions include the collection and reduction of key experimental data, novel aspects of target design and fabrication, application of new diagnostic techniques, and any other elements of fielding the experiments that go outside the boundary of routine operations. Specifically, these guidelines shall address:
   - Seminal work of great significance to the HED community that may have several primary authors as well as a large group of additional co-authors who have made significant contributions. Publications with a primary author and a limited set of co-authors
   - Coordination of publications based on new diagnostics and experimental techniques with the application of diagnostics and techniques to experimental campaigns

3. Principal Investigator Responsibilities and Interaction with Sponsoring Programs

In all instances, the PI shall adhere to any instructions from the sponsoring program with regard to management of the experimental campaign, data use, and dissemination. The PI shall also adhere to any instructions arising from the dispute resolution process.

With respect to NIF data, the PI shall:

a. Oversee the preparation, execution and analysis of their experiment, and act as the senior point of contact between the NIF facility and sponsoring program.
b. Ensure that the data are made available to an appropriate set of individuals, consistent with

delivering the required information to the sponsoring program.

c. Determine the appropriate author list for a given publication or presentation, consistent with program policy.
d. Ensure that publication drafts are reviewed by the proposed authors, and others as determined by the program's policy.
e. Publish in a timely manner.

To the best of their ability and consistent with Program policy, the PI shall identify likely publications and lead authors prior to the start of a campaign.

4. **Data Access and Use**

a. *Data access:* Programs shall provide a list of members who require data access to the NIF User Office. These members will have access to all data (facility and experimental) associated with that Program.
b. *Data ownership:* Programs shall have exclusive rights to the data from a given experimental campaign for up to 18 months. Any data published within this timeframe is released from exclusivity. In this context "published" refers to material that has been published in a peer-reviewed journal, or in a conference proceedings which is peer-reviewed. Beyond this period, each program shall provide a pathway for access to the data by a wider community of researchers, consistent with ensuring full value is extracted from NIF experiments, while maintaining appropriate need-to-know restrictions for sensitive data. On occasion, programs may extend the period of exclusive rights for certain data sets to ensure the integrity of the data analysis and publication process. If deemed necessary, such a request may be made to the NIF Director through the NIF User Office.
c. *Data access for NIF diagnostic Responsible Scientists:* NIF policy is to provide the named Responsible Scientists (RSs) for each facility diagnostic with access to data from the set of diagnostics under their control. Acting in the role of a PI (see Section II.2), the RS will also be provided exclusive use of data for up to one year to allow time for presentation and publication of results related to the development, construction, and performance of the instrument. In this case the RS/PI is responsible for ensuring this is performed in a manner that does not impact publication efforts of a related PI's team. The RS/PI shall inform the PI and the Program Publication Committee prior to submission of a publication to ensure that any disputes can be addressed prior to submission. Consistent with Section III.3, Diagnostic RS/PIs and Experimental PIs are expected to coordinate their efforts such that these data are published in a timely manner.
d. *Facility*: With regard to the use and dissemination of "NIF experimental data," there is no formal role for the NIF facility in experimental campaigns under the purview of the programs, except at the discretion of the PI or program. For facility publications and dissemination of "NIF facility data," the NIF Director or designee will assume the equivalent responsibility to a Program Leader, as detailed above.
e. *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. Requests for data access shall be communicated through the NIF User Office. The User Office will facilitate agreements for data access and data use with affected programs such that

all data rights and privileges are appropriately protected.

5. **Publication Review and Release and Public Communication**
   a. *Review and release of NIF facility and experimental data*: All NIF facility and experimental data to be published or presented outside of LLNL shall be approved via the LLNL Information Management process. Per the *NIF User Manual*, copies of all publications shall be provided to the NIF User Office prior to release.
   b. *Public communication and press guidelines*: The PI's home institution has the right to issue the first public communication regarding NIF results. Such press releases shall be coordinated with NIF via the User Office. In the event the PI's home institution does not choose to issue public communications, NIF or other members of the team involved may choose to do so, following the above policy.

D. Change Control

The NIF Director is responsible for this policy. Proposed changes to this policy shall be submitted to the NIF Director via the NIF User Office. The NIF Director is responsible for approving changes to this policy, and for appropriate consultation with external stakeholders. A record of changes shall be appended to future versions of this document.

Appendix H: Definition of Facility Data and Experimental Data

A. 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:

1. NIF laser, diagnostics, optics, data acquisition, data analysis, and other system capabilities.
2. NIF facility configuration, including that of laser, target diagnostics, optics, hazardous materials handling, and other subsystems as appropriate.
3. General information supplied to all users regarding conduct of experiments at NIF and roles and responsibilities of NIF staff and the user community.

B. NIF Experimental Data

NIF experimental data includes NIF target shot information relevant to analysis of data from NIF experiments, including:

1. Shot-specific setup information for laser, target diagnostics, target, optics, hazardous materials, and other subsystems, including pre-shot target characterization information.
2. All raw data obtained from target diagnostics and target systems.
3. All processed data produced by the NIF data analysis systems for target diagnostics and target systems, including calibration data and analysis software.
4. Interim data analysis products produced by scientists in the course of analysis of NIF experimental data.
5. 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.
6. NIF data published in peer-reviewed journals.

C. Information Not Covered under this Policy

NIF facility data and NIF experimental data do not include:

1. All information regarding management of NNSA and other user programs at the NIF, including details of NIF operational budgets.
2. 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.
3. Private, individual-specific analysis not required for analysis, presentation, or publications involving NIF data.

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