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The NIF: Path to Ignition in the laboratory

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The National Ignition Facility: Path to Ignition in the Laboratory *

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Abstract. The National Ignition Facility (NIF) is a 192-beam, 1.8-MJ, 500-TW ultraviolet laser facility presently under construction at LLNL for inertial confinement fusion (ICF) ignition and high energy density (HED) experiments. Four of the NIF beams were commissioned to demonstrate laser performance. On a single-beam basis NIF has shown that it meets its performance goals and demonstrated its precision and flexibility for pulse shaping, pointing, timing and beam conditioning. Four experiments were also performed for ICF and HED science. Presently, the project is installing production hardware to complete the project in 2009 with the goal to begin ignition experiments in 2010. An integrated plan has been developed including the NIF operations, user equipment such as diagnostics and cryogenic target capability, experiments, and calculations to meet this goal.

The National Ignition Facility (NIF) is presently under construction at the Lawrence Livermore National Laboratory (LLNL). NIF is a 192-beam laser system to study inertial confinement fusion (ICF) and the physics at extreme energy densities and pressures. The NIF facility layout is shown in Figure 1. Details of the laser and building designs can be found elsewhere [1,2]. Presently, the NIF Project is approximately 80% completed. The buildings were completed in 2001 and the beam path enclosures were completed in 2003. Almost all of the subsystem designs are completed. The laser components are assembled and installed in pre-aligned modules called line-replaceable units, or LRUs. Over 5,700 LRUs need to be installed and commissioned to complete the Project.

The Project is being completed in two phases as shown in Figure 1. In the first phase, the LRUs are being installed and beam lines activated in the laser bays to the switchyard wall. Beginning in 2007, the Project will begin to build out the beam lines to the target chamber. Project completion is planned for March 2009. Presently, nearly 1000 LRUs have been installed, and one bundle of eight beams has been commissioned to the switchyard wall. During the activation, the bundle produced over 150 kJ of 1ω light. This is the highest energy pulse produced by a laser system using 4% of NIF's capacity.

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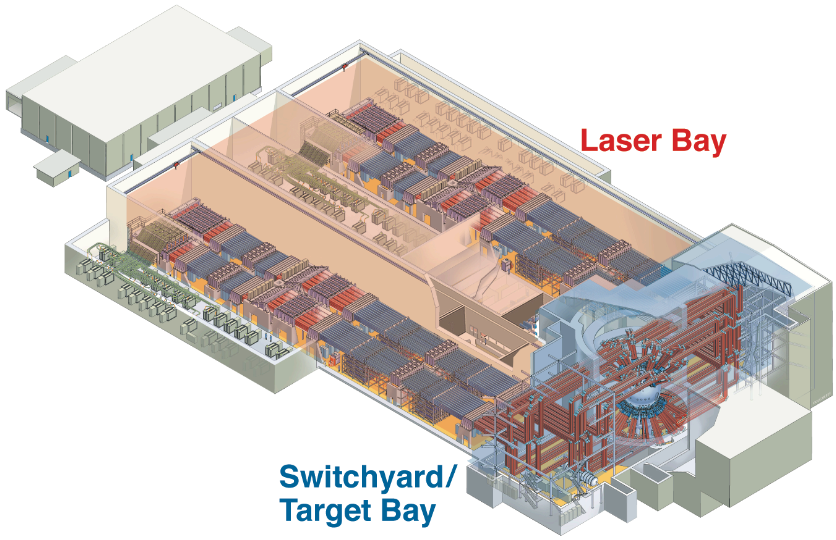

Figure 1. Layout of the National Ignition Facility.

In 2002, NIF activated a quad of four beams to the target chamber for NIF early light (NEL) experiments. Any one of the four activated NIF beams could also be directed to a separate experimental area, the Precision Diagnostic System (PDS), to characterize the performance of a NIF beam. The NEL experiments were used to demonstrate the performance of NIF design architecture and the operability of the facility. Over 400 shots were performed during the lifetime of NEL from January of 2003 to October of 2004. By the end of NEL operations, the facility could routinely perform two shots per operations shift.

Experiments were performed in the PDS [3] to fully characterize NIF's laser performance. On a beam line basis, all Project completion criteria and long-term functional requirements and primary criteria were demonstrated. In separate PDS experiments, NIF produced 10.4 kJ of 3ω light and 11.4 kJ of 2ω light. This is equivalent to 2 MJ and 2.2 MJ, respectively, for 192 beams. The laser demonstrated its capability required for ignition. Laser energy repeatability was demonstrated to better than 2% rms, much better than the 8% rms power balance requirement. Quad pointing was shown to be 30 µm rms for an 800-µm-diameter spot compared with the NIF requirement of 50 µm rms. Beam smoothing with SSD and polarization smoothing required for ignition was also demonstrated.

Four experimental campaigns were performed on NEL. These experiments studied light propagation in a plasma [4], nonlinear hydrodynamics [5], hohlraum physics [6,7], and equation of state. A major value of the experiments was to develop the target area and activate it for experiments. The initial diagnostics were also commissioned [8]. These operated with a 98% success rate. Beam smoothing required for ignition experiments was also demonstrated. Continuous phase plates were deployed to shape the far field focal spot. Experiments used smoothing by spectral dispersion (SSD) and polarization smoothing to study the effects of beam smoothing on beam propagation and hohlraum coupling.

After the NIF Project is completed in 2009, the goal is to begin ignition experiments in 2010. An integrated plan called the National Ignition Campaign has been developed to attain this goal. The plan integrates a number of subsystems with the target physics and NIF operations into a multiyear effort culminating in initial ignition experiments in 2010. The 2010 ignition experiments begin using laser energy of ~1 MJ with the energy ramping up to the full 1.8 MJ in 2011 [9]. A pre-ignition campaign is planned at the beginning of 2010 to study the energetics, symmetry, ablator performance, and shock timing to optimize target performance.

The subsystems needed to begin the ignition experiments include diagnostics, user optics, cryogenic target capability, and personnel and environmental protection systems. Although a number of diagnostic systems were commissioned for the NEL experiments, more systems are needed, especially for ignition experiments [8]. The user optics includes phase plates, polarization smoothing crystals, debris shields, and other special optics required for experiments. The cryogenic target system is required for fielding ignition targets with cryogenic DT fuel layers. Finally, the personnel and environmental protection systems are the neutron and tritium monitors, hazardous material handling systems, and shielding needed to manage the yield and hazardous materials in the target.

In summary, the NIF project is on schedule for completion in 2009. The remaining activities are primarily the completion of LRU installation, utilities, and the control system. One bundle of eight beams has been commissioned to the switchyard wall. NEL experiments have demonstrated that NIF will be able to perform as designed. User experiments with four beams of NIF have demonstrated its ability to operate as a facility. The experiments provided important data showing NIF's value as an experimental facility. Plans are in place to begin ignition experiments in 2010, the year after Project completion.

Acknowledgments

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