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Overview of the National Ignition Facility

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OVERVIEW OF THE NATIONAL IGNITION FACILITY*

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The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory will be the world's largest and most powerful laser system for inertial confinement fusion (ICF) and experiments studying high energy density (HED) science. NIF is a 192 beam Nd-glass laser facility that will produce 1.8 MJ, 500 TW of ultraviolet light making it over fifty times more energetic than present ICF facilities. The NIF Project began in 1995 and is scheduled for completion in 2009. Ignition experiments on NIF, which will use tritium, are scheduled to begin in 2010. Tritium will arrive at the facility in individual target assemblies. The assemblies will be mounted to the Cryogenic TARget POSitioner (TARPOS), which provides the cryogenic cooling systems necessary to complete the formation of the ignition target's fuel ice layer. It also provides the positioning system that transports and holds the target at the center of the NIF chamber during a shot. After a shot, unburned tritium will be captured by the cryopumps Upon regeneration, the cryopump effluent will be directed to the Tritium Processing System, part of NIF's. Personnel and Environmental Protection Systems. These systems also include, local contamination control systems, area and stack tritium monitoring systems, a decontamination area, and waste packaging and characterization capability. This equipment will be used along with standard contamination control practices to manage the tritium hazard to workers and to limit releases to the environment to negligibly small amounts.

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I. INTRODUCTION

The National Ignition Facility (NIF) is a 192-beam laser facility that will produce 1.8 MJ and 500 TW of ultraviolet light for performing ignition target experiments. NIF is the most recent Nd-glass laser constructed at LLNL for Inertial Confinement Fusion (ICF) and High Energy Density (HED) research. The facility is poised to produce fusion ignition in the laboratory for the first time. (Ref. 1) At more than fifty times more energetic than previous capabilities, such as the Nova and OMEGA lasers, NIF will be the world's preeminent facility for performing experiments for ICF and HED science.

The NIF laser beams are based on flashlamp-pumped 1.05-μm Nd-doped glass architecture that has been used in ICF laser facilities at LLNL for more than 30 years. (Ref. 2) At NIF, the main laser systems are installed in two laser bays. After being amplified to full energy, the beams are transported through two switchyards to the target area. At the target chamber, the beams are frequency converted to 0.35-μm light and focused onto the target in the target chamber. A layout of the facility overlaid with a model of the beam transport system is shown in Figure 1. The building is approximately 70,000 m^2 in size. Each beam has a clear aperture of about 40×40 cm and the facility contains about 8,000 large optics. NIF is by far the largest and most complex optical system ever built.

The NIF began as a project in 1995 and is scheduled for completion in 2009. The project is currently over 90% complete. The building and nearly all of the beam path, shown in Figure 1, have been completed. What remains of the project is to complete the installation of optical systems and electronics, and to commission the beams as

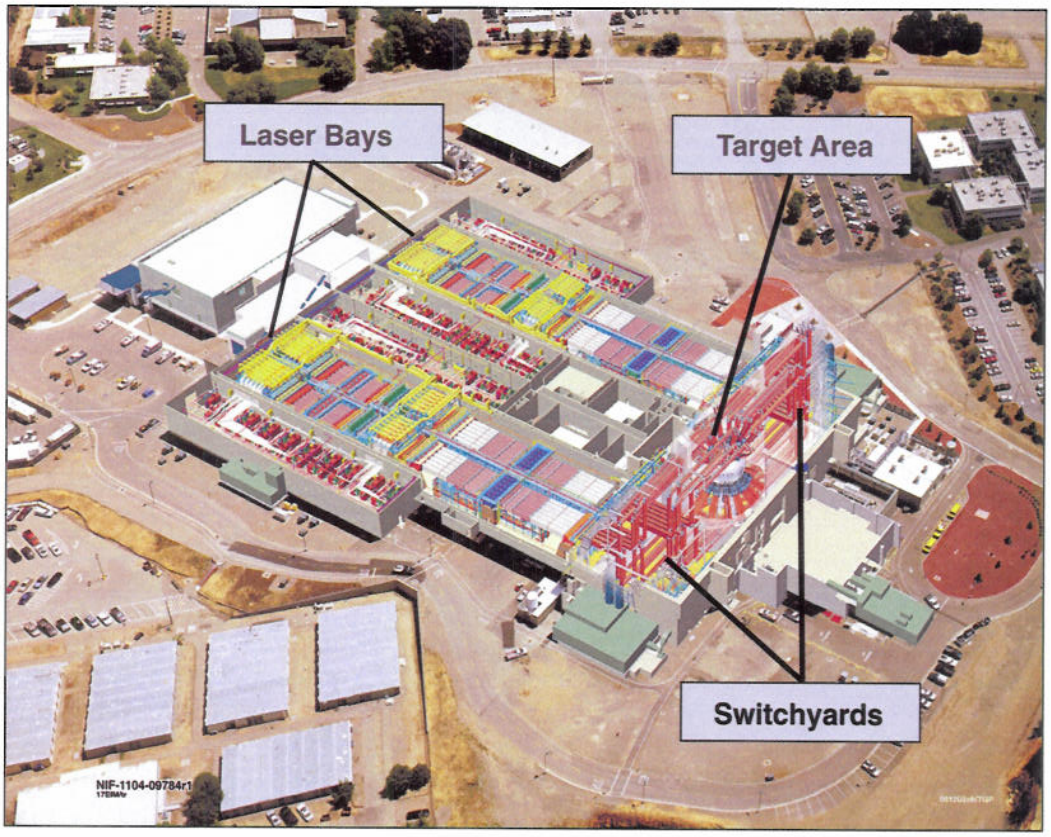

Fig. 1. Layout of the NIF facility with an overlay of the laser beampath.

operational to target chamber center. The optics and electronics are installed as line replaceable units (LRUs), which are modular assemblies designed for ease of maintenance and replacement. Presently, over 90% of the LRUs have been installed in the laser bays, with installation in one of the laser bays completed. The transport optics are being installed in the switchyard and target area to complete building out the laser beam path.

Beam commissioning qualifies the hardware for operation after installation. In the laser bays, the beams are grouped in sets of 8 beams called a bundle, and each laser bay has two clusters of six bundles each. Each bundle is split into two sets of four beams, or quads, as they are transported to the target area and focused on target. Presently, twelve bundles, or 100% of the beams, in one laser bay have been commissioned. These lasers have demonstrated that they can produce over 2 MJ of 1.05-μm light, making NIF the only megajoule-class laser system in the world. Commissioning of the rest of the beams in the other laser bay is scheduled to be completed in 2008.

Beginning in the fall of 2007, beams will be commissioned through frequency conversion and final focusing to target chamber center. By June 2008, the plan is to have half of the beams commissioned to target chamber center in a symmetric geometry to begin indirect drive target experiments with 96 beams.

II. TRITIUM USE ON NIF

NIF will begin ignition experiments soon after the project is completed with a goal of performing the first ignition experiment in 2010. The path to ignition will begin with experiments in 2008 when 96 beams are available. Experiments with 192 beams will begin after project completion. These experiments will test the energetics, drive symmetry and ablator performance, and optimize the target performance. The Ignition Campaign will begin after this optimization.

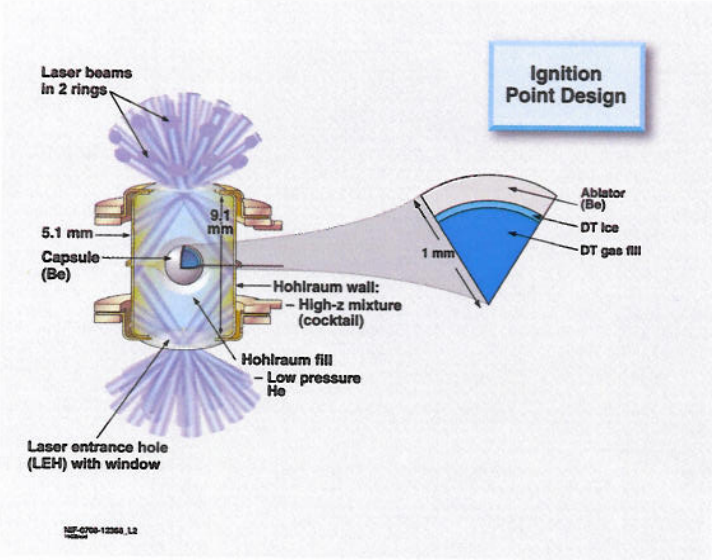

Fig.2. Schematic of the cryogenic ignition target showing the 48 "quads" of laser beams entering the hohlraum from above and below. There are 4 laser beams to each quad.

The goal of the ignition experiments will be to produce fusion ignition and burn of a deuterium-tritium (DT) fuel mixture in millimeter-scale target capsules. The Ignition Campaign is organized around the ignition target point design. (Ref. 3) A schematic is shown in Figure 2. The indirect-drive target has a high-Z radiation case (hohlraum) with a cryogenic DT-filled capsule in the center. The hohlraum wall is a composite of uranium and gold, and the hohlraum is filled with low-density He gas to control plasma filling. The point design capsule has a beryllium shell; alternate designs with high-density carbon are also being pursued. The capsule contains a uniform layer of DT ice on its interior surface.

The ignition target point design puts more stringent tolerances on target fabrication. Processes and characterization techniques are being developed to reliably produce ignition targets meeting specifications. As part of this, engineering prototypes have been fabricated and assembled. An example is shown in Figure 3. (Ref. 4) The Be capsule has a 2-mm outer diameter with a 10-μm fill tube attached. In the future, manufacturing processes will be put in place to produce these capsules and package them into sub-assemblies at a rate to meet the NIF shot plan.

The Cryogenic TARget POSitioner (TARPOS) provides the cryogenic cooling systems necessary to complete the formation of the ignition target's fuel ice layer, and it also provides the positioning system that transports and holds the target at the center of the NIF chamber during a shot. See Figure 4. To be able to form DT ice layers of sufficient uniformity, the target must control temperature axisymmetrically to within +/- 0.5-mK. (Ref.4) Many hours before a NIF ignition shot, the target assembly, containing the fuel reservoir and capsule, is mounted to the cryogenic cooling system within the CryoTARPOS. Just prior to layering, the DT fuel is transferred, using temperature differentials, from the fuel reservoir into the capsule through a fine 10-μm-diamter fill tube. The cooling system ultimately cools the target to 18 K. The DT will freeze and form a thick ice

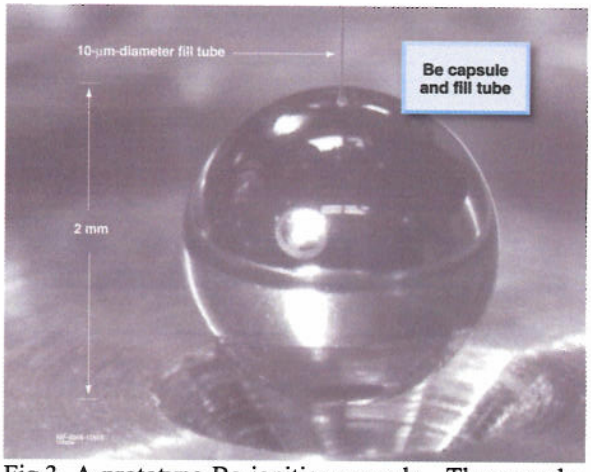

Fig.3. A prototype Be ignition capsule. The capsule has a 2-mm outer diameter with a 10-μm-daimeter fill tube attached. (Ref. 4)

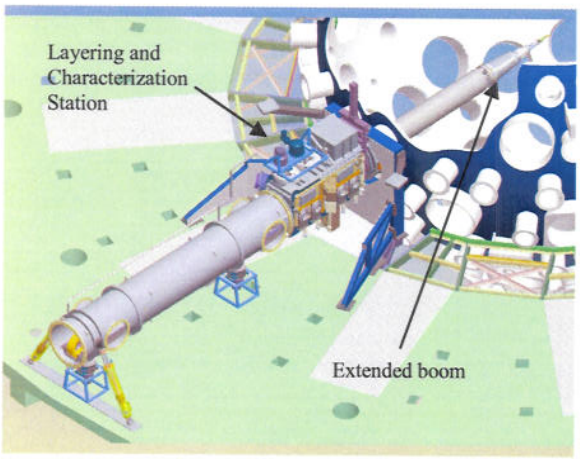

Fig. 4. The Layering and characterization station is integral with the CryoTARPOS. The target assembly is mounted to the end of the boom, shown extended into the target chamber.

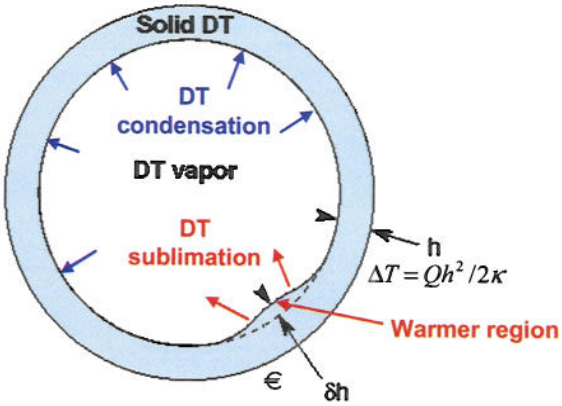

Fig. 5. Beta-layering causes the bump height to decrease as DT sublimes from the warmer region (due to beta-decay of tritium) and condenses on colder surfaces (Ref. 5)

layer on the interior surface of the capsule. The beta particle from tritium decay facilitates the formation of a uniform ice layer by causing localized heating and sublimation of fuel, which then recondenses on cooler surfaces elsewhere. This "beta-layering" process, illustrated in Figure 5, creates the smooth ice layer required for ignition.

Capsules fielded for an ignition experiment require a 75-µm thick DT ice fuel layer. The CryoTARPOS provides a target characterization tool that is used to provide feedback during the ice layer formation process. The Layering & Characterization Station is mounted to the forward portion of the CryoTARPOS as shown in Figure 4. This system ultimately determines when the ice has met the thickness and roughness specification. The characterization system is based on phase contrast x-ray imaging and provides three orthogonal views of the target. This technique results in good contrast at the edges of even extremely low absorbing materials like hydrogen ice. (Refs. 6 and 7) This approach has allowed quantitative evaluation of the quality of the DT ice surface in optically opaque materials like Be. Figure 6 shows an x-ray projection of solid DT in a capsule with a resolution of approximately 3 µm using this technique. (Ref. 4) Images are taken every few minutes to provide feedback for the ice formation process. At the conclusion of a successful fuel ice layer formation process, the imaging system is stowed, and the target is transported on the boom to target chamber center. Having the layering and characterization capability integral with the positioning system allows the target to be moved into the target chamber through the chamber isolation valve with minimum vibration or time delays. The CryoTARPOS positions the capsule and holds it steady to within a few microns at chamber center, all the while maintaining the temperature within milli-Kelvin to preserve the carefully formed ice layer.

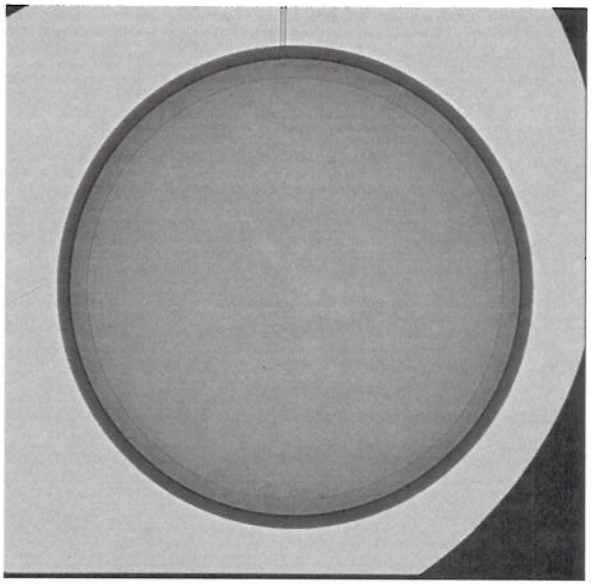

Fig. 6. X-ray phase contrast image of a deuterium-tritium ice layer in a 2-mm diameter beryllium capsule. (Ref. 4)

III. TRITIUM MANAGEMENT FOR NIF

During an ignition experiment, only some of the tritium will be consumed. The majority of the unburned tritium released to the target chamber interior will be collected on the cryopumps. Periodically, the cryopumps will be regenerated. The tritium evolved from the pumps will be routed to the Tritium Processing System for recovery. Some tritium will also be adsorbed onto the chamber walls and the surfaces of entrant items. After an experiment, the CryoTARPOS and entrant diagnostics will be retracted and isolated from the target chamber. In preparation for opening the positioner or diagnostic vessels, tritium levels will be monitored and residual tritium will be routed to the Tritium Processing System for tritium recovery. Using the vent and pump technique, room air will be introduced into the vessels and then evacuated with the target area roughing pumps. Tritium will evolve from vessel interior surfaces due to exchange with moisture introduced from the room air. The exhaust of the roughing pumps is routed directly to the Tritium Processing System. The vent and pump process will be repeated several times until tritium levels are reduced and the vessel can then be opened to the exhaust stack and placed in ventilation mode.

The Tritium Processing System will consist of two independent recovery systems and will use the well established process involving catalytic oxidation of the tritiated effluent with the resultant water species collected on drier beds. The total process flow rate will be 500 scfm. The concept is illustrated in Figure 7.

Tritium room, process, and stack monitors will be installed in the tritium work areas to monitor the work environment and any releases from the facility. Tritium monitoring systems consist of commercially available instruments and components integrated into a standard design that can be used for multiple applications. The output from the real time tritium monitoring systems will be sent to the NIF Industrial Controls System where it will be used to make operational decisions.

A decontamination facility located adjacent to the target bay will be provided. This area will contain a variety of contamination control enclosures including glove boxes, fume hoods and walk-in ventilated enclosures, as illustrated in Figure 8. The HVAC system in this space has been designed as a single pass system. All exhaust from the target and decontamination areas is routed to the main exhaust stack where the effluent is monitored for tritium before release. The Tritium Processing System will be located in the decontamination area and will be interfaced to the various tritium work stations. The decontamination area will also house a waste management/storage area where waste quantities will be estimated. Operations, maintenance, monitoring, packaging, inventory control and disposal procedures are in the development phase.

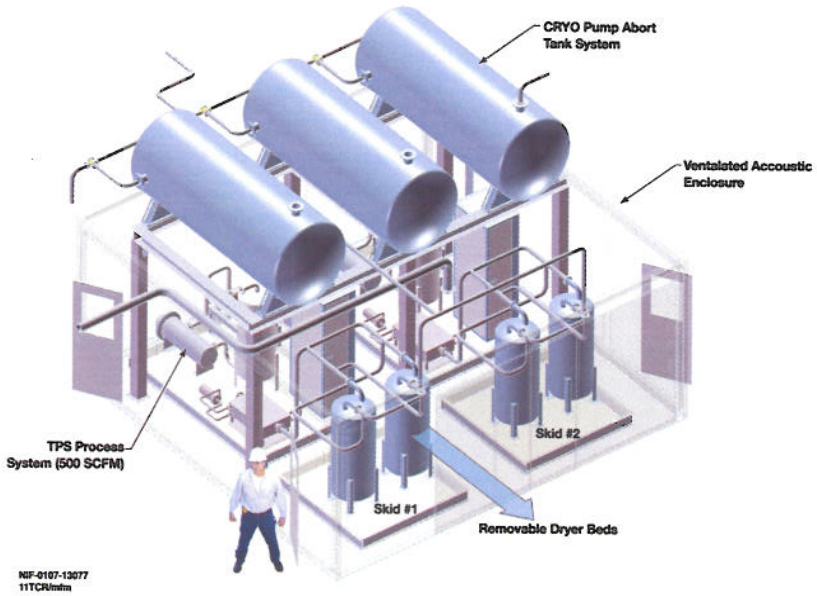

Fig. 7. Tritium processing system concept with abort tanks and ventilated enclosure.

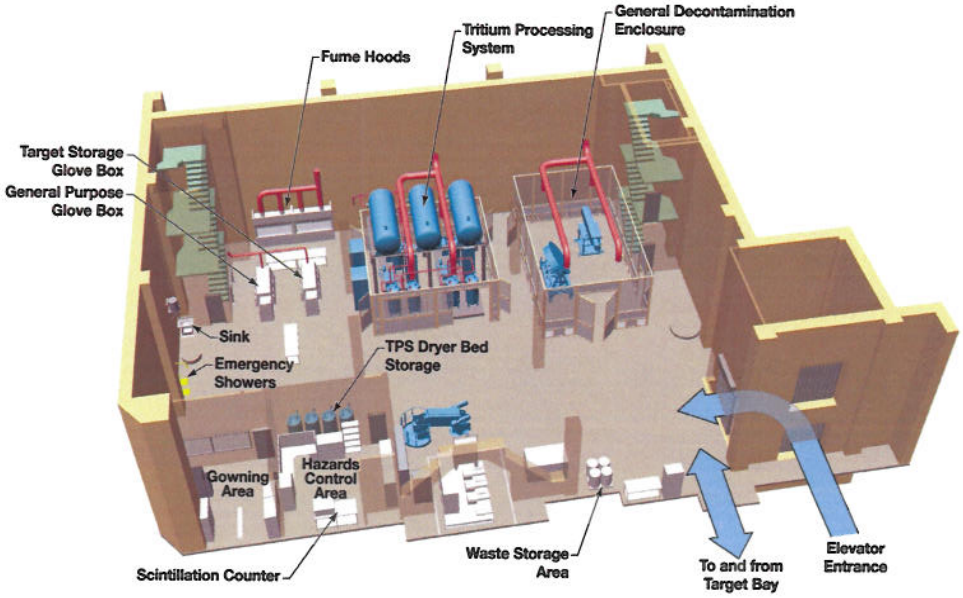

Fig. 8. Layout of the NIF Decontamination Facility

Designs for the tritium recovery, monitoring, and decontamination area equipment, NIF's Personnel and Environmental Protection Systems, are approximately 50% complete. Requirement and conceptual design reviews for all systems have been conducted. Preliminary and final design packages are being generated and the systems will be completed in the order needed to meet experimental needs of the Ignition Campaign.

SUMMARY

Preparations for tritium introduction into NIF in 2010 are well underway. Target fabrication technology has been developed, and a means for fielding cryogenic targets has been provided. Standard capabilities and practices will be used to manage the tritium hazard to workers and to limit releases to the environment to negligibly small amounts. These capabilities and practices will be in place and available to support the Ignition Campaign in 2010.

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