NATIONAL IGNITION FACILITY

DOE announces completion of world's largest laser

The National Nuclear Security Administration has certified the completion of the world's largest laser, the Department of Energy announced on March 31. The National Ignition Facility (NIF), located at the DOE's Lawrence Livermore National Laboratory, in Livermore, Calif., took more than 10 years and $3.5 billion to build.

The NIF's 192 laser beams will deliver more than 60 times the energy of any previous laser system.

Three football fields could fit inside the NIF's Laser and Target Area Building. (Photos: DOE)

Experiments conducted at the NIF will use 192 laser beams to deliver to the target more than 60 times the energy of any previous laser system. When all 192 beams are operational, the NIF will direct nearly 2 million joules of ultraviolet laser energy in nanosecond (billionth-of-a-second) pulses to the target chamber center.

As the energy slams into millimeter-sized targets it will generate unprecedented temperatures and pressures in the target materials—temperatures of over 100 million K and pressures more than 100 billion times the earth's atmosphere. These conditions are similar to those in stars and the cores of giant planets or in nuclear weapons, which is why one of the NIF's missions is to provide a better understanding of the complex physics of such weapons.

The United States has not deployed a new nuclear weapon in over 20 years or conducted an underground nuclear test since 1992. Instead, NNSA scientists maintain the nuclear warheads beyond their original life by using sophisticated supercomputers and facilities that test the safety, security, and reliability of the weapons.

"NIF will be a cornerstone of a critical national security mission, ensuring the continuing reliability of the U.S. nuclear stockpile without underground nuclear testing," said Thomas D'Agostino, administrator of the DOE's NNSA.

The NIF's other major mission is to provide scientists with the physics understanding necessary to create fusion ignition and energy gain for future energy production. It will also be used by researchers to explore basic science, materials science, and nuclear science.

The NIF comprises three interconnected buildings: the Optics Assembly Building, the Laser and Target Area Building, and the Diagnostics Building. The DOE said that

Laser Bay 2, one of the NIF's two laser bays, was commissioned on July 31, 2007.

the construction of all of the buildings and supporting utilities was completed in September 2001, and all 192 laser beam enclosures were completed in 2003.

Inside the Optics Assembly Building, large precision-engineered laser components are assembled under stringent clean-room conditions into special modules called line replaceable units for installation into the laser system.

The Laser and Target Area Building houses the 192 laser beams, each about 40 cm^2, in two identical bays. Large mirrors, which are specially coated for the laser wavelength and mounted on highly stable 10-story-tall structures, direct the laser beams through switchyards and into the target bay. There they are focused on the exact center of the concrete-shielded 10-m-diameter, 1-million-lb target chamber.

In the Diagnostics Building, the NIF's precision diagnostic system monitors the performance of a single beam exactly as it will be delivered to the target. The system contains the same optics configuration as the final optics assembly and is able to rapidly analyze the data from an NIF shot, helping reduce the intervals between system shots.

The operation of the NIF's laser beams requires that everything in the beams' enclosures remains perfectly clean at all times. Any bit of debris, oil, or other wayward material could cause the intense light to damage the optics. The DOE said that the space inside the beam enclosures typically exceeds the cleanliness of a semiconductor or pharmaceutical manufacturing plant.

Precision shots

Every NIF experimental shot requires the coordination of up to 60 000 control points for electronic, high-voltage, optical, and mechanical devices, such as motorized mirrors and lenses, energy and power sensors, video cameras, laser amplifiers, and diagnostic instruments. The DOE said that achieving this level of precision requires a large-scale computer control system as sophisticated as any in government service or private industry.

The orchestration of these parts will result in the propagation of 192 separate nanosecond-long bursts of light over a 1-km-long path. The 192 separate beams must have optical path lengths equal to within 9 mm so that the pulses can arrive within 30 picoseconds (trillionths of a second) of each other at the center of the target chamber, and they must strike within 50 micrometers of their assigned spot on a target the size of a pencil eraser. The DOE said that the "NIF's pointing accuracy can be compared to standing on the pitcher's mound at AT&T Park in San Francisco and throwing a strike at Dodger Stadium in Los Angeles, some 350 miles away."

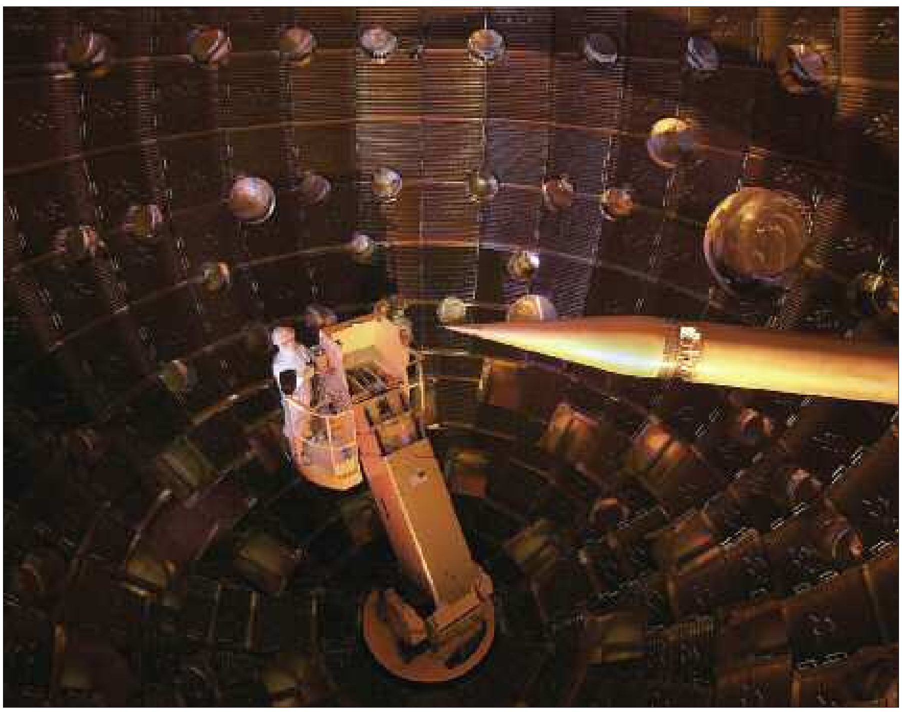
Because the precise alignment of the NIF's laser beams is important for successful operation, the requirements for vibrational, thermal, and seismic stability are unusually demanding. Critical beam-path component enclosures (generally for mirrors and lenses), many weighing tens of tons, were located to a precision of 100 microns using a rigorous engineering process for design validation and as-installed verification.

192 beams

Researchers used high-energy lasers to study the conditions required to compress tiny spherical capsules to fractions of their initial diameter while still maintaining the capsules' symmetry, a crucial requirement if the NIF is to achieve fusion ignition. The NIF's designers arrived at 192 focused spots as the optimal number to achieve the conditions that will ignite a target's hydrogen fuel and start fusion burn.

A variety of experiments

The DOE said that not all experiments using the NIF need to produce fusion ignition and that researchers are planning other types of experiments that will take advantage of the NIF's energy and flexible geometry in nonignition shots. Nonignition experiments will use a variety of targets to derive a better understanding of material



Technicians adjust the target positioner inside the NIF's target chamber.

properties under extreme conditions. These targets can be as simple as flat foils or considerably more complex. By varying the shock strength of the laser pulse, scientists can obtain equation-of-state data that reveal how different materials perform under extreme conditions for nuclear stockpile stewardship and basic science. They can also examine hydrodynamics, which is the behavior of fluids of unequal density as they mix.

The NIF experiments will also use some of the beams to illuminate "backlighter" targets to generate an X-ray flash. This will allow detailed X-ray photographs, or radiographs, of the interiors of targets as the experiments progress. In addition, moving pictures of targets taken at 1 billion frames per second are possible using sophisticated cameras mounted on the target chamber. These diagnostics can freeze the motion of extremely hot, highly dynamic materials to see inside and understand the physical processes taking place.

New technologies

Amplifying the NIF's beams to record-shattering energies, keeping the highly energetic beams focused, maintaining cleanliness all along the beams' paths, and successfully operating the complex facility required the NIF's designers to make major advances in existing laser technology, as well as to develop entirely new technologies. Innovations in the design, manufacture, and assembly of the NIF's optics were especially critical.

The NIF has already produced historic scientific advances. In March, the NIF became the first fusion laser in the world to break the megajoule barrier (a megajoule is the energy consumed by 10 000 100-watt light bulbs in one second) by delivering 1.1 million joules of ultraviolet energy to the center of its target chamber—more than 25 times more energy than the previous record-holder.