The NIF Target Chamber—Ready for the Challenge

THE National Ignition Facility—the largest laser in the world—is a project of extremes. "Very" tends to be attached to descriptions about it: the facility is very large (the size of a sports stadium), the laser's target is very small (the size of a BB-gun pellet), the laser system is very powerful (equivalent to 1,000 times the electric generating power of the U.S.), and each laser pulse is very short (a few billionths of a second). All these extremes converge in the final action that occurs in a 10-meter-diameter aluminum sphere, which is the target chamber.

"The entire system is basically a target shooter, with the target chamber being the business end of the system," says NIF project manager Ed Moses. Once the pulses from the laser's 192 beams have been amplified, shaped, and smoothed, they must pass through the final optics assemblies (FOAs) mounted on the outer surface of the chamber. The FOAs—which contain frequency conversion crystals, vacuum windows, focus lenses, diffractive optics, and debris shields—convert the pulses from infrared to ultraviolet light and focus the light on the target. (See the box on p. 22.) All 192 pulses then focus their total energy of 1.8 megajoules on the target—a gold cylinder holding a 2-millimeter capsule containing deuterium and tritium, two isotopes of hydrogen. Fusion—creating on a minute scale the extreme temperatures and pressures found inside stars and detonated nuclear weapons—is the goal.

Experiments performed on NIF will be essential to the Department of Energy's Stockpile Stewardship Program, which has the task of ensuring the safety and reliability of the nation's nuclear stockpile. NIF will also have basic science applications in such areas as astrophysics, hydrodynamics, and material properties and will forward the scientific pursuit of fusion energy.

What Is Required of the Chamber

The target chamber, the largest single piece of equipment for NIF, is a 118,000-kilogram sphere made of aluminum alloy 5083—the same alloy used to build ship superstructures. It has a diameter of 10 meters and a wall thickness of 11 centimeters.

The chamber must provide a vacuum environment down to 10^{-6} torr and shield personnel and surrounding areas from

Internal view of the target chamber. Precision metrology equipment will be used to survey the chamber and establish the absolute center.

neutrons and gamma rays. And when it's ready for experimental use, it must have 48 FOAs and nearly 100 diagnostic instruments mounted on its surface.

When the chamber was designed in 1993, the design engineering team—led by Livermore's Vic Karpenko and Sandia National Laboratories' Dick Wavrik—consulted with laser scientists, optical experts, target physicists, laser physicists, and facility designers at Lawrence Livermore and Los Alamos national laboratories, the University of Rochester, and the Defense Threat Reduction Agency to come up with design requirements. The list of requirements included laser beams synchronized to arrive at the target simultaneously, fixed focal plane distances from the final optics to the targets, stringent vibration stability, and easy ingress and egress for systems that transport, hold, and freeze the tiny targets. The target chamber designers also had to consider space and cost constraints. Says Rick Sawicki, the laser area integration manager, "The world has made lots of spheres in the past, but all the requirements added together made the NIF target chamber a very challenging project, from an engineering perspective."

Requirements for the entire experimental system also affected the chamber and its subsystems. For example, the lasers must point at the target with extreme precision—on the equivalent of touching a single human hair from 90 meters away with the point of a needle. "Overall," says Sawicki, "we must deliver 1.8 megajoules of energy to the target with a 50-micrometer pointing stability on the target. That means we must accurately and stably point all laser beams and hold the target stable. Fifty micrometers is about the thickness of a sheet of paper, so that's how little wiggle room we have for any vibration in the system. Achieving that alignment on a table-top laser is one thing. Achieving it on a system the size of NIF . . . that's a huge challenge!"

The NIF teams analyzed all NIF structures to determine whether they could collectively meet the requirements. That analysis pointed to the target chamber as an important contributor to vibration. As a result, the target is not supported by the chamber but by a target positioner attached directly to the floor of the facility. Design features were implemented to permit the positioner to pass through the wall of the target chamber without coupling to the chamber's vibration, yet still maintain vacuum continuity. Throughout the facility, other steps were taken to dampen vibration and add stability. Concrete floors—nearly 2 meters thick in the Target Area Building and 1 meter thick in the Laser Building—help deaden stray vibrations. The target chamber is supported on a thick concrete pedestal and connected to the building floors at its waist to minimize vibration-induced motion. The Laser and Target Area Buildings will be temperature-controlled to 0.3°C to maintain laser

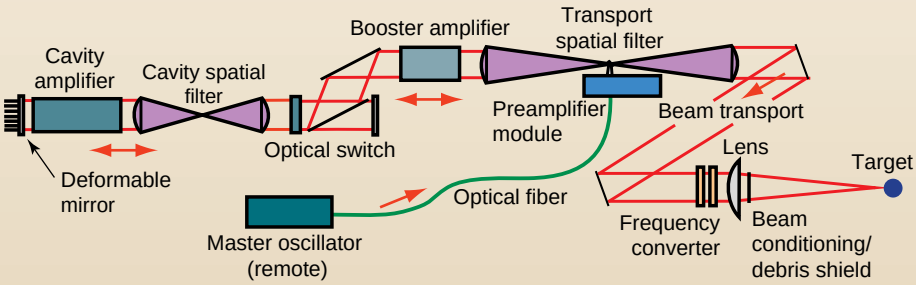
Pulsing the System

Generating enough laser energy to cause fusion, thereby simulating the goings-on in the Sun and stars, is an exacting process.

From start to finish, each pulse of laser light must travel 450 meters before it reaches the target. That pulse begins humbly in the master oscillator system. A small fiber-ring oscillator generates a weak, single-frequency laser pulse on the order of a nanojoule. That pulse is launched into an optical fiber system that amplifies and splits it until there are 192 10-joule pulses.

The pulses enter the main laser system, where each light pulse makes four passes in a beampath of mirrors, lenses, amplifiers, switches, and spatial filters. This multipass concept was one of the design breakthroughs of NIF. Without it, the facility would have had to be over a kilometer long for the pulses to gain the required energy. In its multipass journey, each laser light pulse bounces off the equivalent of 54 mirrors and goes through the equivalent of 2 meters of glass. Each pulse is reflected off a deformable mirror to correct for aberrations that accumulate in the beam because of minute distortions in the optics. The mirror uses an array of actuators to create a surface that will compensate for the accumulated wavefront errors.

Once the beams have completed their passes through the main laser system, they proceed to two switchyards on either side of the target chamber. The switchyards take the 192 beams—which up to now have been traveling in bundles of 8 beams, 4 high and 2 across—and split them into quads of 2-by-2 arrays of beams. The quads are "switched" into a radial, three-dimensional configuration around the sphere. Just before entering the target chamber, each quad of pulses passes through a final optics assembly, where the pulses are converted from infrared to ultraviolet light and focused onto the target. The entire journey takes 1.5 microseconds.



positioning. Sophisticated, low-vibration air-handling systems have been installed and are being activated.

Moving Right Along

Work on the target chamber has continued apace since the chamber was lowered into the Target Area Building nearly two years ago (see *S&TR*, September 1999, pp. 16–19). Once the chamber was settled onto its massive concrete pedestal, workers used hydraulic jacks, roller assemblies, shims, and anchor bolts to align the chamber and establish its proper elevation and tilt. Then the chamber was leak-tested with helium gas. This testing had to be accurate because all the weld joints are covered by shielding material, which prohibits leak repairs. Next, the chamber was prepared for its shielding, a 40-centimeter-thick skin of gunite—a mixture of cement, sand, and water similar to that used to line swimming pools. The gunite was combined with 0.1 percent boron, a neutron-absorbing, activation-limiting material. Some 200 tons of the mixture was sprayed onto the chamber surface, which was then sealed with epoxy paint. NIF workers then opened the more than 70 ports for the FOAs and conducted a precision survey to pinpoint where all the laser beams would intersect.

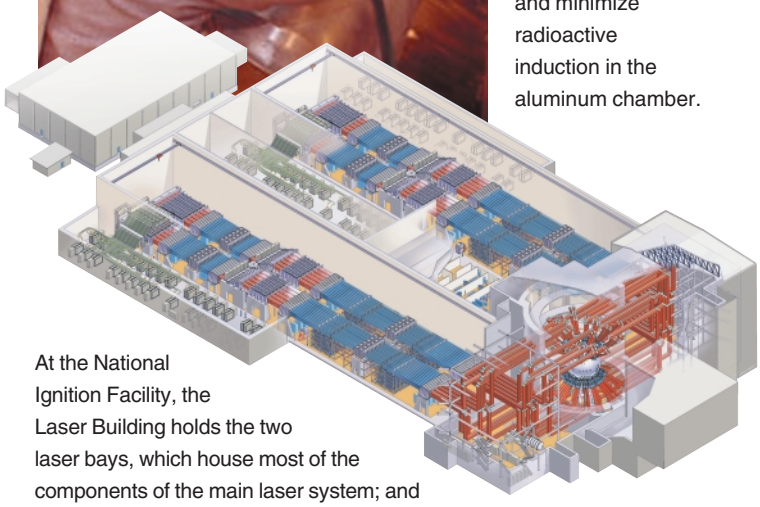
"With all that concrete, we expected the chamber to sag somewhat," says Sawicki. That sagging would throw off the beam angles. Sagging also might be compounded by mounting the FOAs, which will add another 200 tons to the structure. Precision surveys have been performed to determine this impact as well. "Once everything is in place," says Sawicki, "we will make our final adjustments to the angle of the FOAs with simple spacers that can be accurately machined."

In the meantime, conventional construction throughout the facility has proceeded to 96 percent completion as of February 2001. Since the first of the year, both laser bays have been certified for clean room protocols; and vessel setting, steel framework fabrication, and installation of beampath infrastructure have begun. All in all, more than 11,500 metric tons of steel has been erected and more than 56,000 cubic meters of concrete has been poured.

What's Next?

In February 2001, leak-testing was completed, and the target chamber was officially "in acceptance," that is, ready to accept the final optics assemblies, utilities, and diagnostics. "The chamber was designed for the lasers, the diagnostics, and the Target Area Building," notes Moses. "Completing it and putting it in place was an important stepping stone in building the project." In both the Laser and Target Area Buildings, the next major task is to install the beampath enclosures that connect the target chamber to all of the other vessels in the facility and to connect these enclosures to the utility systems (such as vacuum, helium, argon, compressed air, and water). All this will be accomplished while maintaining Level 100 cleanliness conditions inside the enclosures.

At the target chamber exterior, the surface of the vessel is prepared for an application of gunite. The shielding material is specially formulated to absorb neutrons and minimize radioactive induction in the aluminum chamber.



At the National Ignition Facility, the Laser Building holds the two laser bays, which house most of the components of the main laser system; and the Target Area Building is divided into the switchyards, the target diagnostic areas, and the target area. The target area, a circular space, contains the target chamber and its attendant equipment.

Elsewhere in the facility, 80 percent of the large components of the beampath infrastructure (such as vacuum vessels, support structures, beam tubes, and beam enclosures) have been procured and are either on the way or on site being installed. Over the next couple of years, the project will be making nearly $1 billion in procurements of special equipment and putting it all together inside the space of the beampath enclosures. "The design of the facility is essentially done," Moses says. "Now, we need to turn from being an organization primarily focused on design and engineering to an organization focused on procurement, installation, and commissioning of the facility. That'll be our next big challenge."

—Ann Parker

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