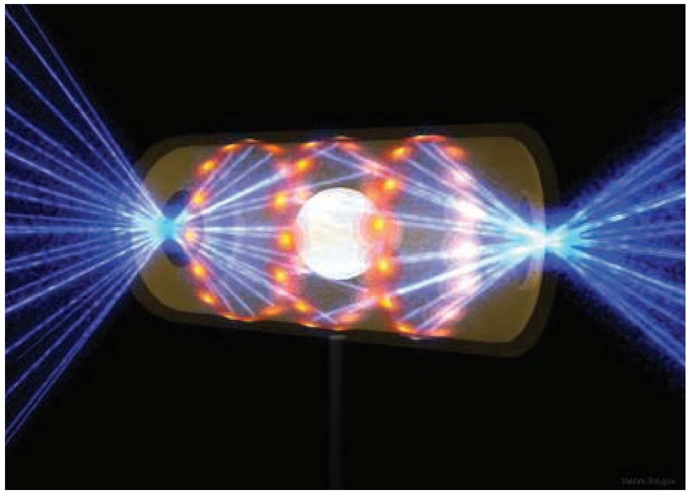
PHYSICS

Test Shots Show Laser-Fusion Experiment Is on Target



Hot cell. To implode the central fuel capsule, NIF fires 192 beams into an eraser-sized gold cylinder, heating it to x-ray temperatures.

As the managers of the Large Hadron Collider at CERN near Geneva, Switzerland, can testify, building your giant research facility is one thing, but getting it to work properly when you switch it on is definitely another. Perhaps with CERN's setbacks in mind, those in charge of the National Ignition Facility (NIF), a huge laser for nuclear fusion experiments at Lawrence Livermore National Laboratory in California, have been gingerly putting their huge machine through its paces since it was completed nearly a year ago.

In a study published online this week by *Science* (www.sciencemag.org/cgi/content/abstract/1185634), NIF researchers describe their first experiments using all 192 of the facility's beams on test targets empty of fuel. They were able to couple the laser's energy into the target efficiently and implode the target symmetrically—so far, so good. The scientists say they are on target to attempt ignition—a self-sustaining fusion reaction that produces excess energy—before the end of this year. "It's come up better than anyone thought. They're ahead of the curve predicted," says Mike Dunne, director of the Central Laser Facility of Rutherford Appleton Laboratory near Oxford, U.K.

NIF is the sledgehammer to crack a nut, writ huge (*Science*, 17 April 2009, p. 326). The sledgehammer is a laser that occupies a building the size of three football fields and 10 stories high. Inside it, hundreds of optical amplifiers, beam splitters, and other devices take a normal laser beam, split it 192 ways, and boost the combined energy of the beams to 1.8 megajoules.

The nut is a tiny spherical capsule the size of a peppercorn made of beryllium, which in later experiments will encase a dash of deuterium and tritium (D-T)—isotopes of hydrogen. The aim is to use the power of the laser to heat the capsule so fast that it explodes, propelling the D-T fuel inward toward the center and crushing it to a temperature and pressure greater than those in the core of the sun. As nuclei in the very center begin to fuse, the energy produced will cause all the D-T fuel to burn in a flash of energy—with luck, more energy than was pumped into the capsule in the first place.

Livermore has spent more than 10 years and $3.5 billion building NIF, and researchers hope successful ignition experiments will pay back that investment in future fusion power stations. But a main part of NIF's role is to test computer simulations of nuclear explosions to ensure that the U.S. nuclear weapons stockpile is reliable.

In the paper, Siegfried Glenzer of Livermore and his colleagues there, at Los Alamos National Laboratory, and at General Atomics in San Diego, California, describe shots using a beam energy of 0.7 megajoules, about 40% of NIF's maximum. "We're doing the real thing, and it's going better than expected," Glenzer says.

The team addressed the problem of getting the most laser power onto the capsule and doing so symmetrically so that it implodes evenly. The laser's output is in the ultraviolet, but for a better implosion you need x-rays. So instead of shining the beams directly onto the capsule, they put it in the center of a gold cylinder about the size of a pencil eraser, called a hohlraum. By shining the beams through holes in the ends of the hohlraum, they can make its inner surface hot enough to emit x-rays, which cause the capsule to implode. In the experiments described, the team produced a radiation temperature inside the hohlraum of 3.3 million kelvin, exactly in line with models. Robert McCrory, director of the Laboratory for Laser Energetics (LLE) at the University of Rochester in New York state, calls the feat a major achievement. "If you don't get the hohlraum temperature you're not going to get the implosion you need."

But the peril of this "indirect" approach is that gold atoms kicked off the inside wall of the hohlraum create a plasma that can interfere with the incoming beams in unpredictable ways. In the experiments, the NIF team managed to tune the many beams to keep these laser-plasma interactions to an acceptable level. "They were sufficiently benign at this energy, which is a huge success," says Dunne.

In fact, the team turned some of these interactions to their advantage. In the past few years, theorists had suggested that with so many beams converging into the narrow ends of the hohlraum, the beams could nudge the plasma into a regular repeating pattern, producing a sort of diffraction grating that might scatter the beams. It was potentially a "terminal problem," says Dunne. But early last year, Livermore researchers suggested that they could use the gratings to steer the beams toward hard-to-reach parts of the hohlraum interior—in particular halfway down the inside wall, farthest from the entrance holes. The recent experiments have proved their theory right. "You can deposit energy where you need it," Glenzer says. LLE's David Meyerhofer is impressed. "It's the first time laser-plasma interactions have been used in a beneficial manner. Usually, you try to avoid them," he says. "There's no suggestion that this won't work at full energy."

The next major hurdle is ensuring that the implosion of the fuel is smooth and symmetrical. This remains "an open question," Dunne says, because experiments so far have used empty capsules and the explosions "were not uniform on a microscopic scale, and that can cause problems later." Even so, he says, he's "not too worried yet," because the capsules used were not machined to the same precision used for ignition shots.

Experiments at NIF are currently stopped, and the ignition campaign will begin in earnest in May, Glenzer says. If all goes well, Dunne says, a decision will be made in July on whether to push ahead with full D-T fusion experiments and an attempt at ignition in October. Successful ignition this year is "not out of the question," McCrory says. "But I'd be surprised if it happens."

–DANIEL CLERY

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