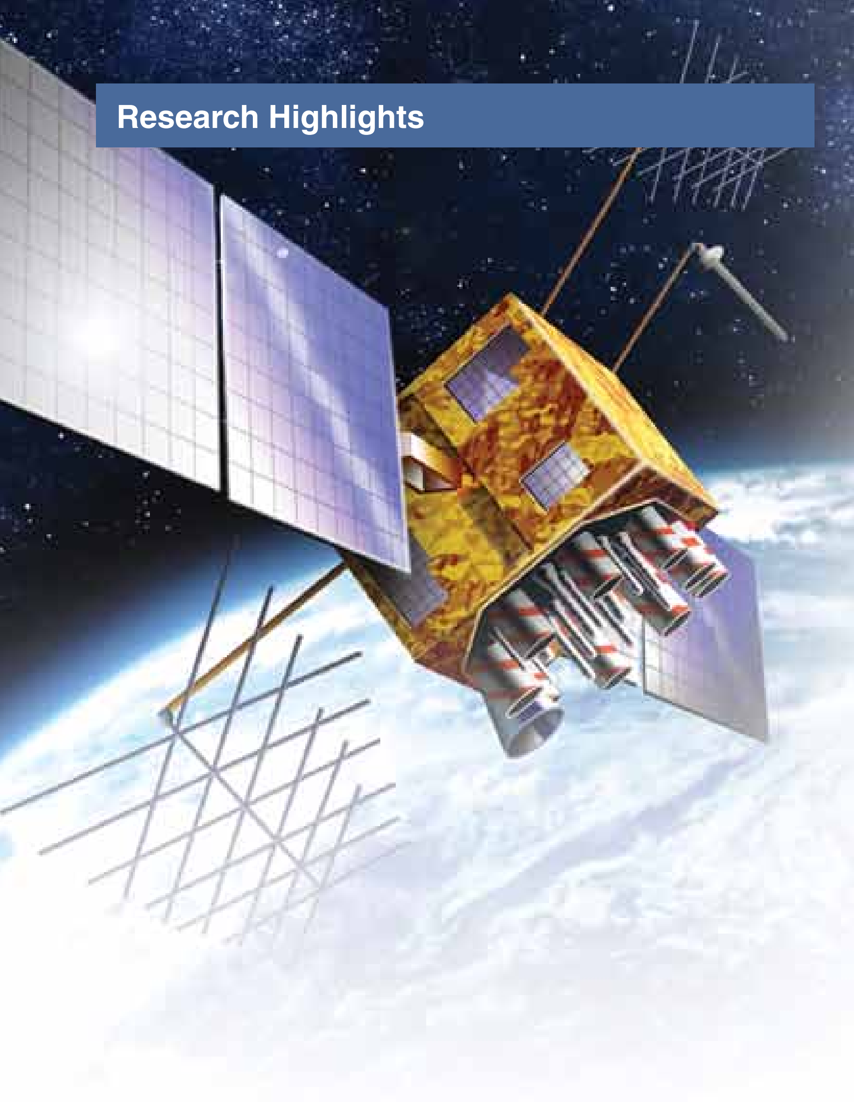
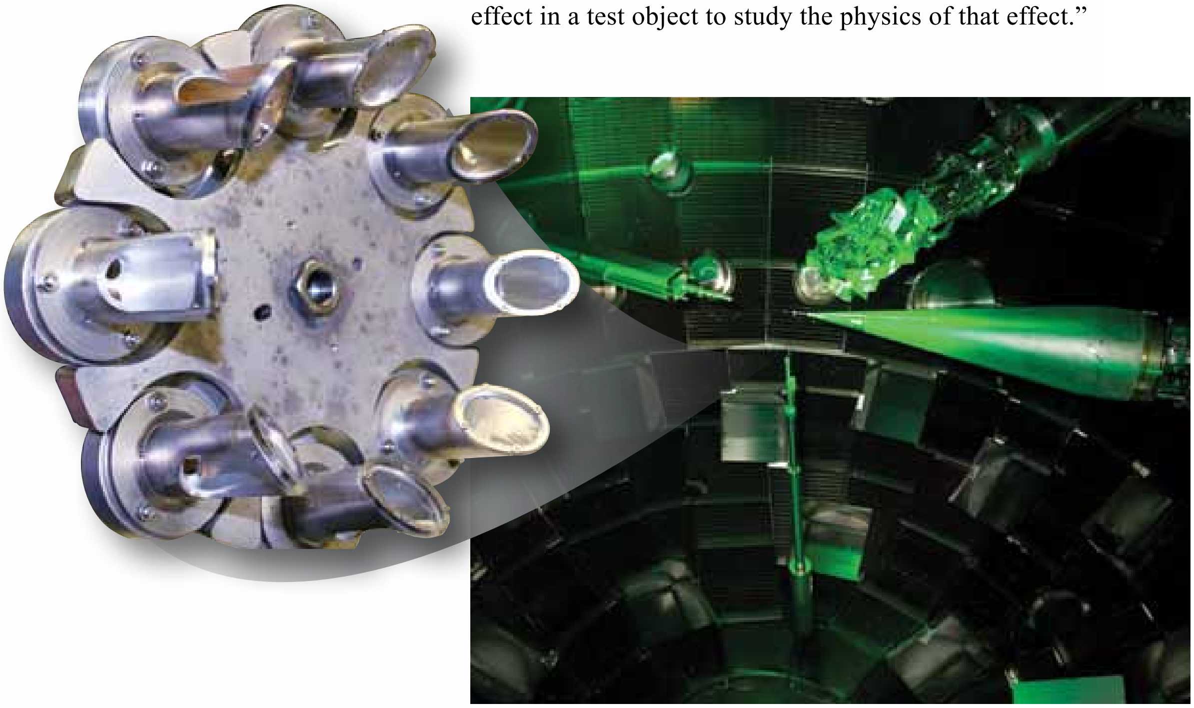


Testing Valuable National Assets for X-Ray Damage

HIGH-ENERGY x rays produced by high-temperature plasmas, such as the Sun or a nuclear blast in space, can damage surfaces, interfere with electronics, and disturb the interiors of valuable assets such as satellites, space-borne telescopes, solar panels, and components important to U.S. defense systems. Consequently, the Department of Defense's (DoD's) Missile Defense and Defense Threat Reduction agencies are interested in using lasers to create x-ray environments for studying the potentially damaging effects on such systems. DoD's interest aligns closely with the National Nuclear Security Administration's desire to produce advanced laser-based x-ray sources for diagnostic techniques and other applications.

The National Ignition Facility (NIF) produces these environments by using laser beams to heat a target that then releases a bath of x rays into the target chamber. "NIF is fantastic," says physicist Kevin Fournier, who leads the X-Ray Source Development Campaign for the Laboratory's NIF and Photon Science Principal Directorate. "We can make a tailored x-ray spectrum in NIF in such a way that it excites a specific effect in a test object to study the physics of that effect."



A test cassette, 25.6 centimeters in diameter, is assembled with samples and filters and inserted into the 10-meter-diameter target chamber (right) of the National Ignition Facility (NIF).

For example, mirrors coated with many reflective and protective layers on different substrates can be placed in the target chamber. “We can look at how the x rays produced by the laser hitting the target interact with the layers and use what we’ve learned to validate computer models for mirror survivability,” says Fournier.

Specially Tailored Experiments

One reason NIF works so well for this application is that the experimental conditions are very reproducible. The laser energy produced from shot to shot varies less than 2 percent, and the x-ray output varies correspondingly by only 2 to 4 percent. Furthermore, because the laser pulse is highly configurable and thus flexible, experiments can be designed to have specific characteristics.

“If we want the x-ray energy to have a certain shape or the x-ray power to have a certain history,” says Fournier, “we can run a pre-shot design calculation for the requested amount of laser power. In this way, we can tailor the x-ray pulse to be delivered precisely to the experimenter’s requirement. And over time, we can continue to improve our sources, or targets, and develop new ones as needed by our users.”

Before NIF was available, Fournier’s group conducted experiments using the OMEGA laser at the University of Rochester’s Laboratory for Laser Energetics in New York, in collaboration with the two DoD agencies as well as researchers from Sandia National Laboratories and the United Kingdom’s Atomic Weapons Establishment. One project at OMEGA studied aerogel targets doped with titanium or germanium. (See *S&TR*, October 2005, pp. 19–22.) “Part of the activity was to develop x-ray sources matched to available energy at OMEGA that would one day lead to tunable x-ray sources at NIF,” says Fournier, “and now, we have just that.”

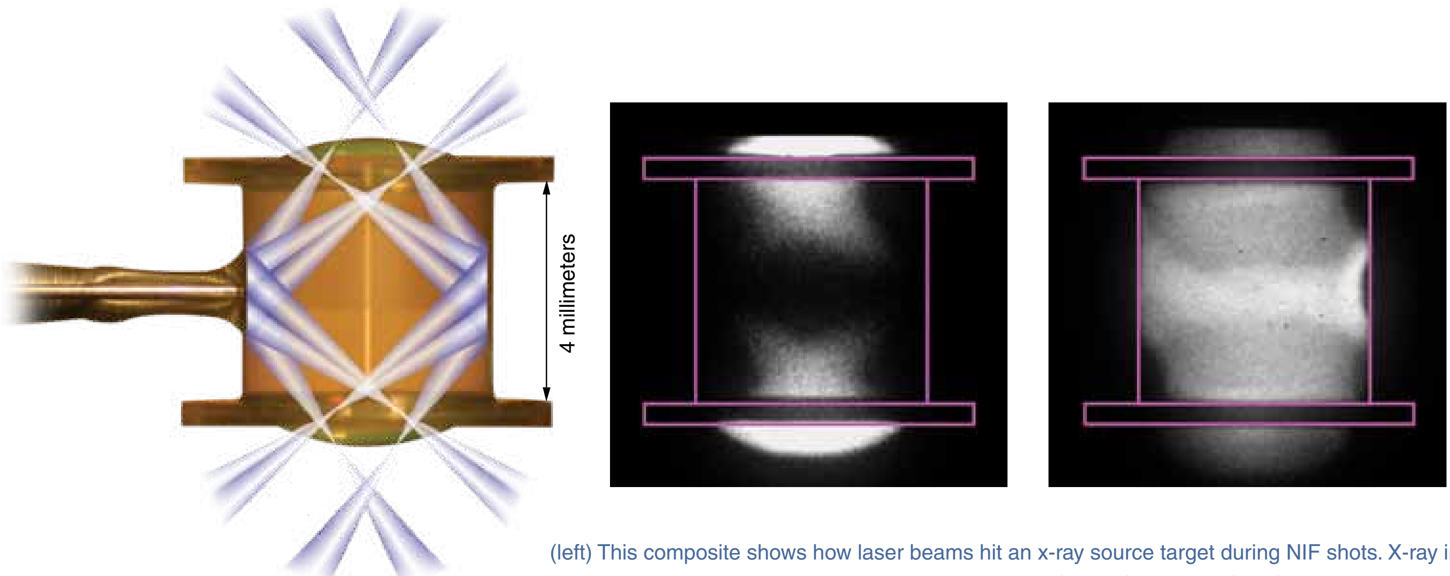
NIF experiments produce higher levels of x-ray energy than OMEGA, which is important for studying macroscopic test objects, and they offer greater flexibility in terms of controlling spectral content. “NIF also allows tailored x-ray pulses of longer duration than OMEGA,” says Fournier. In addition, the high levels of x-ray output from NIF targets let researchers place test objects at a sufficient distance, depending on the size of the object, from the x-ray source so that the resulting flux of x rays onto a large object is very uniform across the entire test body.

Another important feature is NIF’s target chamber. The 10-meter-diameter sphere is so large that in the future, full-sized subsystems could be placed inside—a setup called, “hardware in the loop,” says Fournier. “Probes placed around a device to monitor it will provide us with data that reveal how the device functions during an x-ray event.”

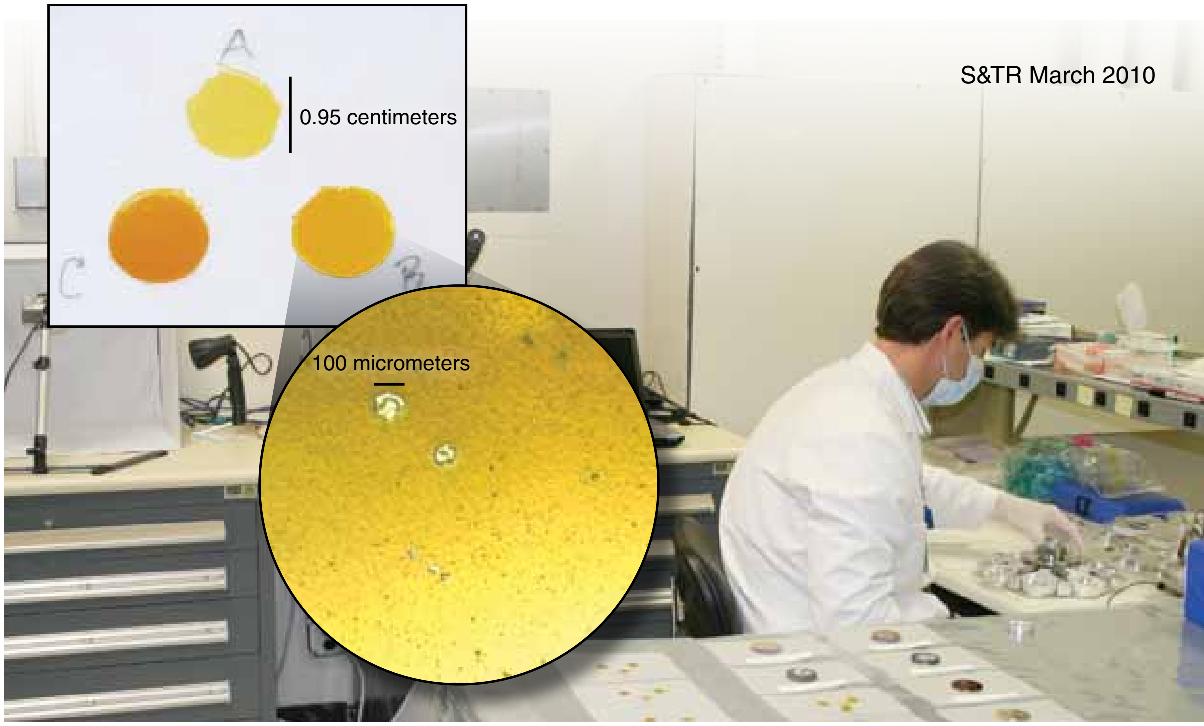
Unique Gas-Filled Targets

To produce the x rays needed for these studies, Fournier’s team used a gas-filled tube containing a mixture of argon and xenon as the target. As laser beams propagate through the tube, they heat the gas and ionize material to produce a plasma, which at 50 million degrees, is an efficient source of x rays. This novel target design converts laser energy to x rays with efficiencies approaching 75 percent. Two diode-based detectors measure the x-ray yield during experiments.

The goal of these experiments is to develop and validate a platform for repeatedly exposing test objects to high-power, high-total-dose x rays with a specific energy and pulse shape. (For more information on NIF’s experimental capabilities, see lasers.llnl.gov/for_users/experimental_capabilities/index.php.) One important aspect of these experiments is to determine if debris produced by



(left) This composite shows how laser beams hit an x-ray source target during NIF shots. X-ray images from an experiment captured the target’s response at (middle) 0.80 and (right) 1.87 nanoseconds. The shot used 112 beams with a 5.2-nanosecond, 350-kilojoule square pulse.



Livermore collaborator Richard Horton works in the NIF laboratory set up for photographic and microscopic investigation of filter and sample surfaces. Filter films (top inset) shape the x-ray spectrum onto a sample. A micrograph (bottom inset, at 50× magnification) of a film's central region shows an intact surface and small amounts of splattered prefilter material.

the target could affect the results. A five-shot campaign completed in November 2009 fielded 24 to 48 witness films in the target chamber during each shot. "When we examined the films with a microscope, we found only tiny droplets of filter material and no target debris or pinholes," says Fournier. "We concluded that the platform will allow us to study x-ray interactions without the complication of target–debris interactions."

International Collaborations

Fournier's team has partnered not only with other U.S. agencies and laboratories but with researchers in other countries as well. For example, work with colleagues in France to develop metallic-foil-cavity targets shows great promise for efficient laser-to-x-ray conversion. "The United Kingdom is also strongly involved," Fournier says. "Both the Atomic Weapons Establishment and Ministry of Defence are interested in pursuing radiation-effects experiments at NIF."

When nuclear weapons were being developed in the 1970s and 1980s, scientists didn't have the computer simulation capability available today. "Now, we have the computing power to perform real three-dimensional simulations of components. What is unknown is the quality and validity of the detailed physics models in the computer codes," says Fournier.

"With NIF's precisely controlled environment, we can isolate the physical properties when radiation interacts with materials. These results can be modeled in the computer codes. We can then investigate the microphysics in the regimes of interest to see if the simulations are valid."

Fournier adds that Livermore has always excelled at high-temperature plasma physics. In fact, this expertise is one of the things that attracted him to work at the Laboratory. In 1992, while studying atomic spectroscopy and theory applied to high-temperature plasmas in a graduate program at Johns Hopkins University, Fournier was sent to Livermore for two weeks to learn how to run one of the Laboratory's computer codes. As it turned out, he never left. "I was like a kid in a candy store," he says. "Livermore was a wonderful place to complete my graduate work."

In 2001, Fournier jumped to experimental work under the guidance of scientists focused on weapons effects testing. Then he got involved with the NIF Radiation Science Users Group, which eventually led to his current assignment.

Fournier enjoys experimental work. "I like being able to do a test, get results, and write a report. I like the task-oriented, results-driven culture of DoD."

When discussing the team's recent experiments, Fournier realizes that "NIF time" is deceiving. The work had taken place only the previous week, although it seemed to him like a month ago so much had happened since. "We get so involved, we lose track of time."

Researchers working to develop x-ray sources continue to focus on the campaign's mission. "The end game is to demonstrate a robust, repeatable, tunable platform for generating x-ray-driven radiation effects testing," says Fournier. "The survivability of systems operating in a nuclear environment is key to our national defense."

—Cindy Cassady

Key Words: gas-filled target, National Ignition Facility (NIF), OMEGA laser, plasma physics, radiation effects testing, x rays, x-ray source.

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