

nuclear WEAPONS journal

Issue 2 • 2009



Table of Contents

Weapons Programs Performance Snapshot	1
Point of View— Strategic Weapons in the 21st Century: Hedging Against Uncertainty	3
Energy Balance in Fusion Hohlräume	6
Upgrades Made to the Trident Laser Facility	12
Fogbank: Lost Knowledge Regained	20
The Los Alamos Branch of the Glenn T. Seaborg Institute for Transactinium Science	22

About the cover: *Clockwise from left*, Ray Gonzales replaces a flash lamp in the laser amplifier at the Trident Laser Facility. Gonzales adjusts a mirror on the front end of the Trident laser. A 5-ft-diameter vacuum vessel in the north target chamber is used for laser-matter interaction experiments. A graduate student, Sandrine Gaillard, checks laser and diagnostic alignment in the north target chamber before a 0.2-PW experiment. **Photos:** Robb Kramer, ADEPS

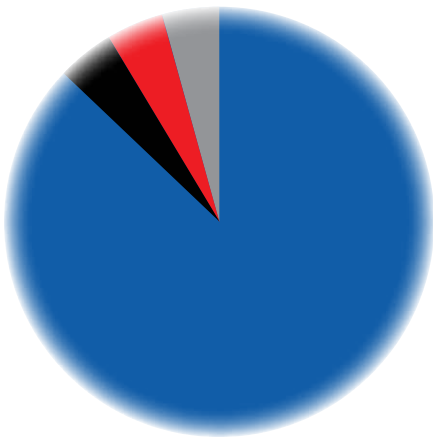


Weapons Programs Performance Snapshot

The Performance Snapshot gives our external customers data on how the weapons programs are performing in three critical areas: Level 1 and Level 2 programmatic milestones, safety, and security.

Weapons Programs Level 1 and Level 2 Milestones (139)

FY09 LANL year-end status



- complete 121
- cancelled 6
- unachievable as stated 6
- no status provided 6 (FY10 dates)

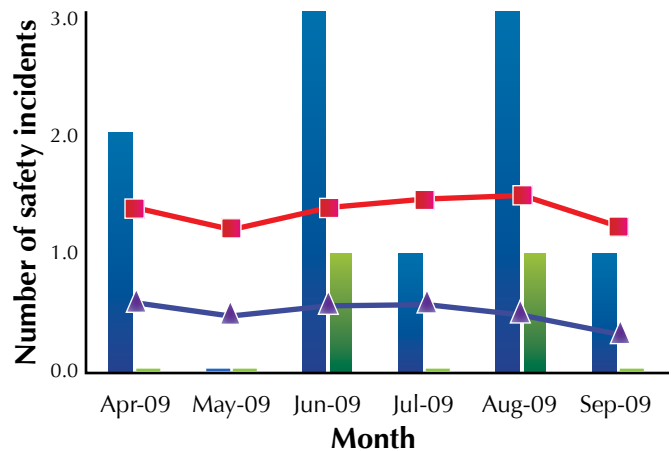
Level 1 (L1) milestones—very substantive, multiyear, supposed to involve many, if not all, sites

Level 2 (L2) milestones—support achievement of L1 goals, annual

Milestones are reported to NNSA program management on a quarterly basis. Progress on milestones is entered into the Milestone Reporting Tool.

Safety Trends

April 2009 through September 2009

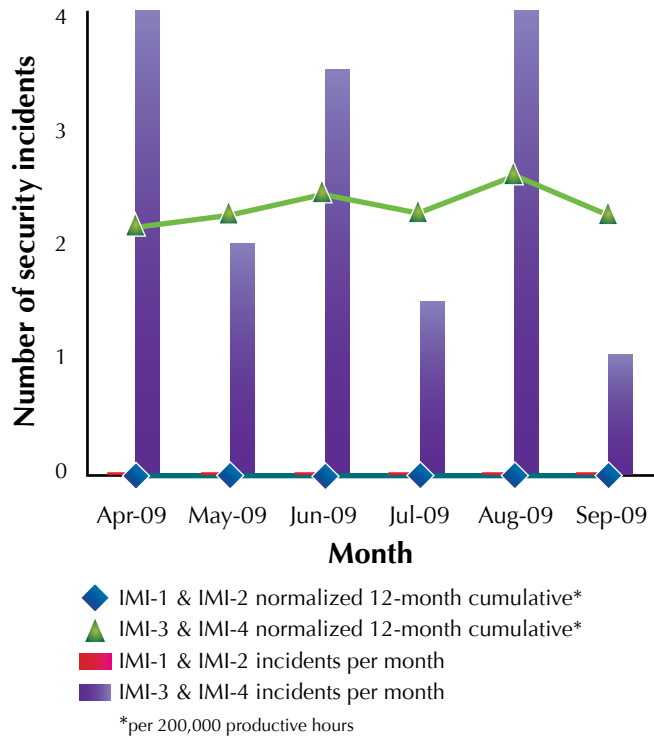


- TRC 12-month cumulative*
- DART 12-month cumulative*
- TRC incidents per month
- DART incidents per month
- *per 200,000 productive hours

- Total reportable cases (TRC)—those that result in any of the following: death, days away from work, restricted work or transfer to another job, or medical treatment beyond first aid or loss of consciousness
- Days away from work, restricted work activity, or transfer (DART) to another job as a result of safety incidents

Security Trends

April 2009 through September 2009



Incidents of security concern (IOSCs) are categorized based on DOE's IMI table (right). The IMI roughly reflects an assessment of an incident's potential to cause serious damage to national, DOE, or LANL security operations, resources, or workers or degrade or place at risk safeguards and security interests or operations.

Categories of IOSCs (DOE M 470.4-1, Section N)	
IMI-1	Actions, inactions, or events that pose the most serious threats to national security interests and/or critical DOE assets, create serious security situations, or could result in deaths in the workforce or general public.
IMI-2	Actions, inactions, or events that pose threats to national security interests and/or critical DOE assets or that potentially create dangerous situations.
IMI-3	Actions, inactions, or events that pose threats to DOE security interests or that potentially degrade the overall effectiveness of DOE's safeguards and security protection programs.
IMI-4	Actions, inactions, or events that could pose threats to DOE by adversely impacting the ability of organizations to protect DOE safeguards and security interests.



Point of View

Strategic Weapons in the 21st Century: Hedging Against Uncertainty

*Patrice Stevens, Staff Member
Los Alamos National Laboratory*

Los Alamos and Lawrence Livermore national laboratories cosponsored the third annual Conference on Strategic Weapons in the 21st Century. Laboratory directors Dr. Michael Anastasio and Dr. George Miller hosted the conference, which took place January 29, 2009, in Washington, DC. The conference theme was hedging against uncertainty.

The Laboratory's mission is to develop and apply science and technology to ensure the safety, security, and reliability of the US nuclear deterrent; reduce global threats; and solve other emerging national security challenges. This conference supports the LANL mission by providing program and policy analysis and enables informed decisions about the strategic direction of our national security programs.

US policymakers and defense experts attended the conference, including former Secretaries of Defense William J. Perry and James R. Schlesinger. Senator Jeff Bingaman of New Mexico and Senator Jon Kyl of Arizona were keynote speakers.

Why Hedge Against Uncertainty?

The post-cold war, post 9/11 international security environment continues to evolve while threats rise from the potential proliferation of weapons of mass destruction and international terrorism. In this environment, the US defense establishment is currently transforming policy (e.g., the Quadrennial Defense Review, the Nuclear Posture Review, and the Comprehensive Test Ban Treaty), forces, operations, and infrastructure needed to assure and defend allies and dissuade adversaries under the Obama administration.

The support that the national laboratories provide for ongoing stockpile maintenance and hedging against uncertainty was part of this year's conference discussions. These discussions include dialogue

pertaining to a national security budget that supports a nuclear weapons complex configured for a smaller stockpile and a corresponding nuclear weapons dismantlement effort.

Progress toward achieving the US goal of a world without nuclear weapons can only be made by verification and negotiated reductions such as the Strategic Arms Reduction Treaty. The Nuclear Posture Review, due in early 2010, will establish US nuclear deterrence policy, strategy, and force posture for the next 5 to 10 years.

The Obama administration faces great economic and national security challenges. The scientific and engineering challenge of maintaining a viable deterrent has been neglected. This situation is illustrated by the fact that the nuclear weapons complex is deteriorating and we are losing expertise in nuclear design and manufacturing.

Therefore, we face increasing uncertainty about and have insufficient capacity to respond to problems related to national security threats such as the hedging strategies that preserve or provide the ability to wisely and effectively posture our forces in response to changes in our adversaries' intent.

As some states modernize their nuclear capabilities, they may be tempted to compete with the US in the area of nuclear weapons. The erosion of the Nuclear Nonproliferation Treaty, military developments in China, and North Korea's nuclear weapons capability may push Japan and South Korea to consider developing nuclear weapons over the next 3 to 5 years, thereby increasing the likelihood of a proliferation cascade. Such a cascade is not inevitable, but the probability has increased and should be addressed by US policymakers. Iran's actions also threaten to collapse nonproliferation efforts. Thus, the US must continue to counter threats by maintaining a safe, secure, reliable, and effective nuclear deterrent not





LANL Director Michael Anastasio



LLNL Director George Miller



New Mexico Senator Jeff Bingaman

only as our defense, but as the defense of our allies as well. In essence, a safe, secure, and effective US deterrent curbs proliferation. While the overall security environment is less certain than it was, assurance to our allies is still a vital US national security objective. According to some experts, nuclear weapons also make conventional warfare less likely.

The US hedge against surprise consists of nuclear warheads coupled with a corresponding infrastructure and human resources. Relative to the cost of an attack and the benefits derived, deterrence influences the thinking of our adversaries. Having credible tools in place to influence our adversaries' goals, objectives, and decisions is all part of the deterrence equation. One must have an accurate warning of the intent as well as the actions of adversaries, and communication must be consistent, reliable, and accurate with adversaries and with one's own forces. Those forces must be ready and capable of acting. And if deterrence fails, then those actions must be sufficient at least to achieve one's aims. Ensuring that forces are sufficient requires adaptability, tailored deterrence, and regular exercises that build capability and confidence and demonstrate that capability to potential adversaries.

Our agenda must also include emphasis on preventing diversion of nuclear materials and weapons. Furthermore, we need renewed emphasis on our ability to attribute the origins of any materials used in a nuclear attack.

What Are Our Hedging Options?

Options for hedging against an uncertain future include technical diversity. There has been an international consensus favoring fewer nuclear states at the same time that there is a trend toward greater availability of nuclear technology. Diversity among operationally deployed and stockpiled warhead types helps us integrate strategic offense and defense capability. Reduced numbers of warheads demand new investment in nuclear warheads. For example, aging stockpiles must be sustained by replicating current designs and/or devising new designs to achieve the same capability. These systems must be responsive

to the new security environment (post 9/11) confronting the US.

In addition, warning time can be increased by our investment in better intelligence, attack warning, attack assessment, and greater reliance on international data

exchange centers. Not only must we rely on our operationally deployed mechanisms, but we must also rely on policy to help maintain a balance of the continuing needs of nuclear deterrence against the needs of diplomacy being used to achieve greater nuclear security and to counter proliferation.

How Do We Counter Risk and Develop Effective Hedges?

The two most important risks in today's strategic climate are that deterrence could fail and that the US might fail to provide adequate security assurance to its allies.

For hedging against uncertainty, deterrence provides assurance that rational adversaries will see the cost of attack as higher than any benefits.



Arizona Senator Jon Kyl



Vice Admiral Carl V. Mauney



NNSA Admin. Thomas D'Agostino

A principal hedge against deterrence failure lies in the degree of intelligence the US possesses about potential adversaries. Such knowledge includes their organizations and hierarchies, their values, their degree of determination, and whether or not their states can be deterred. It is also important to know whether or how to communicate directly or indirectly with potential adversaries. It is necessary to have such understanding for many potential adversaries, and no number of weapons or other military capability has much value in the absence of such knowledge. A wide range of communication and other channels for influencing behaviors and directing sanctions is vital.

Should deterrence actually fail, the US needs active and passive means to defend itself and the capability to attribute a nuclear attack to an adversary.

Upsets to the international security system, such as intelligence failures, help us develop hedges that minimize potential consequences to the US and our allies. Such surprises become consequences for international security, for example, underestimating Soviet penetration of the Manhattan Project, overestimating the pace of proliferation in the 1960s, underestimating Iraq's nuclear efforts in 1991, and overestimating Iraq's weapons of mass destruction capabilities in 2001. The US hedges against potential failure of key US technologies and technological surprise from an adversary that truly undermines our deterrent strategy. Hedging against these uncertainties involves many things, including maintaining an effective scientific and industrial infrastructure and key technologies essential to deterrence.

What Is the Path Forward?

The first issue regarding the path forward is the unclear future of nuclear weapons as part of the US deterrent even though the path to a smaller nuclear weapons

inventory is becoming clear. In the interim, the US nuclear deterrent is fundamental to the security of many countries. The debate continues about the need for conventional weapons options rather than new nuclear military capabilities. Conventional weapons have great destructive power and offer a greater range of options than do nuclear weapons, but the two types of weapons are not equivalent. Conventional weapons can be stabilizing insofar as they offer great range and can respond to situations quickly.

The second issue revolves around different elements of the Russian nuclear posture. For example, was the push toward de-alerting (making reversible changes to nuclear weapons so that they cannot be deployed rapidly) driven by concern over Russian command and control weaknesses, and if so, how should the US deal with those weaknesses? Some concern has been expressed that Russian political and military posturing with respect to neighboring countries proved destabilizing, leading to a commonly held European view that nuclear weapons are important but dangerous. The US must engage in serious discussions with allies over such matters. With respect to arms control objectives, perhaps some asymmetry in weapons production might be acceptable. However, it should be noted that Russia is now producing more nuclear weapons than the US.

For hedging against uncertainty, deterrence provides assurance that rational adversaries will see the cost of attack as higher than any benefits. Yet, there is uncertainty in the gamut of adversaries today and it is hard to know what is in their minds. When intent is unknown, we must deal with capabilities. **NWJ**

Energy Balance in Fusion Hohltraums

Nuclear fusion could supply man's energy needs for millions of years. Fusion fuels can be cheap, nonpolluting, of almost unlimited supply, useless to terrorists or rogue states, and unlikely to provoke geopolitical conflict. One such fusion fuel is deuterium, an isotope of hydrogen found in seawater. The deuterium in a gallon of seawater could produce as much energy as 300 gallons of gasoline. And, depending on the fuel cycle, the radioactive waste produced by nuclear-fusion reactors could be negligible compared with the waste produced by nuclear-fission reactors.

Presently, only the cores of stars regularly produce fusion energy on a large scale. Hydrogen bombs also produce fusion energy on a large scale but only briefly, and their energy cannot easily be fed into the grid. But the current absence of nuclear-fusion power plants is not for scientists' lack of effort.

For more than 50 years, scientists have worked to produce fusion energy on Earth in a controlled way. In one approach, the fuel—in the form of a hot, dense ionized gas (a plasma)—is confined by a magnetic field long enough for significant fusion reactions to occur. A second approach uses intense beams of photons, electrons, or ions to heat and compress the fuel very rapidly; the fuel's mass, or inertia, confines it long enough for significant fusion reactions to occur. This second approach is called inertial-confinement fusion (ICF).

Recent advances in both approaches strongly suggest that nuclear fusion could begin to play a significant role in our energy future within a few decades, but some difficult technical problems remain to be solved. This article addresses one of the outstanding problems for many ICF experiments, including those about to be conducted at Lawrence Livermore National Laboratory's National Ignition Facility (NIF).

NIF Experiments

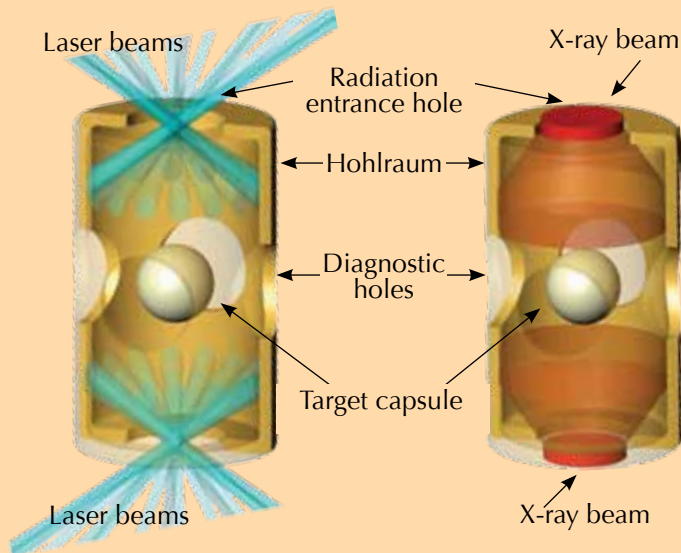
In experiments expected to occur in the next year or so, NIF's 192 pulsed laser beams will pass through a small hole at each end of a hohlraum (German for "cavity")—in this case, a hollow gold cylinder about the size of a pencil eraser (see figure on page 7). The laser beams will strike the inner surfaces of the hohlraum's walls and heat them to very high temperatures. In this indirectly driven ICF technique, the hot inner surfaces of the hohlraum will then emit x-rays that will compress (implode) a target capsule—a hollow, BB-sized sphere of beryllium or plastic suspended at the hohlraum's center. The capsule will contain fusion fuel—in this case, a 50/50 mixture of deuterium

and tritium (another hydrogen isotope). If all goes well, the fuel will be sufficiently compressed and heated during the implosion for a significant number of fusion reactions to occur.

Code-validation studies represent a necessary step to fully realizing the potential of inertial-confinement fusion.

The efficiency of the compression and burn will depend on the conditions inside the hohlraum. Those conditions will in turn depend on how much of the energy delivered to the hohlraum remains inside it and how much escapes as wall-emitted x-rays through holes in the hohlraum's wall that initially allowed energy to be delivered or allow diagnostic instruments to view the implosion. The loss of x-rays through these holes will affect the energy balance of the implosion and could seriously affect the implosion's quality and its fusion yield.

A team of Los Alamos and Sandia researchers studied this x-ray leakage using a special hohlraum designed for easy comparison of experimental measurements of the x-ray leakage with simulations of it performed by LASNEX, a 2-D hydrodynamics computer code widely used by NIF and other fusion researchers. The results of these studies could directly impact ICF experiments at NIF and elsewhere.



In the NIF experiments, the walls of a hohlraum will be heated by laser beams (*left*, blue beams). The inner surfaces of the hot walls will then emit x-rays that impinge on the spherical target capsule at the center of the hohlraum. The capsule's outer surface will absorb the x-rays and explode, producing a reaction force that implodes the capsule and compresses and heats the fuel inside to densities and temperatures high enough for a fusion burn to occur. The hohlraum's walls could be heated instead by an external source of x-rays (*right*, solid red cones). Either way, the energy heating the walls' inner surfaces will pass through an entrance hole at each end of the hohlraum. However, the x-rays emitted by the heated walls can also escape through these holes and other holes present to let diagnostic instruments view the implosion. X-rays that are lost through the holes or that are not emitted from the missing wall material where a hole is located can reduce the energy available to drive the implosion or cause nonuniform illumination of the capsule. Either effect can reduce the implosion's efficiency and thereby reduce its fusion yield.

In LANL's experiments, the inner surfaces of the hohlraum's walls were heated by x-rays rather than laser beams. The source of those x-rays was the Dynamic Hohlraum (DH), driven by the Z-accelerator at Sandia National Laboratories in Albuquerque, New Mexico. The DH source delivered approximately 100 kJ of 200-eV x-rays into a small hohlraum placed above the source.

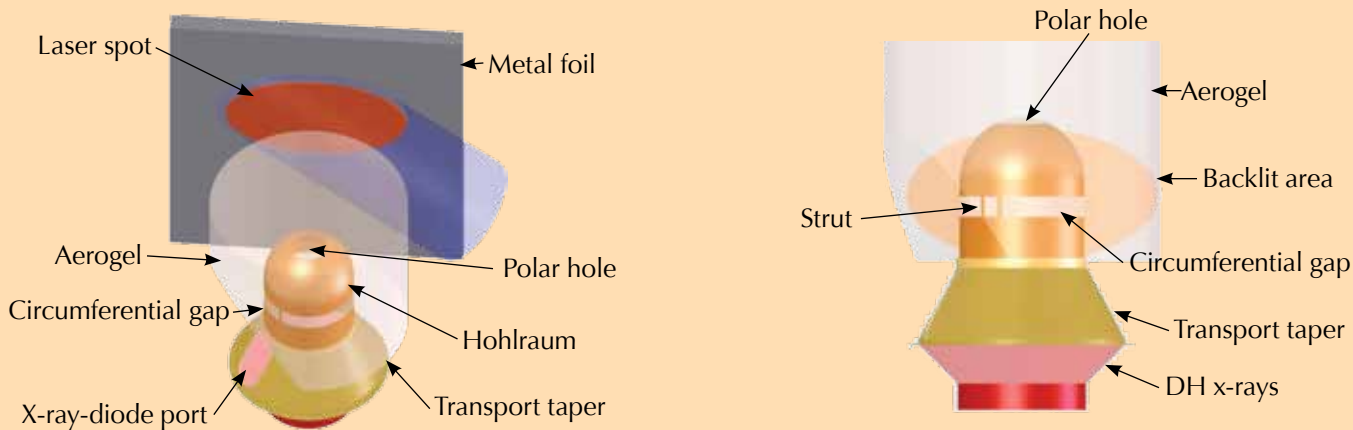
Two-Way Holes

When the x-rays emitted by the hohlraum's hot inner walls strike the target capsule, the capsule's outer surface will absorb the x-rays and be quickly heated. The outer surface will then melt, vaporize, and ionize. Some of the outer-surface material will fly radially outward at high speed, essentially exploding and producing a reaction force that implodes the capsule.

If too much x-ray energy is lost through the holes, the implosion will be too slow and the temperature of the ions in the imploded capsule will be too low for a good fusion burn.

The presence of the holes can also cause nonuniform illumination of the capsule by the wall-emitted x-rays. The effects of nonuniform illumination depend on what happens to the capsule during the implosion. As the outside of the shell ablates, nonuniform illumination can excite hydrodynamic instabilities in the ablated shell material. These instabilities can disrupt the shell if allowed to grow to large amplitude. If an instability breaks up the shell and causes holes to form all the way through it, fuel can leak through them. The loss of fuel can reduce the fusion yield. More importantly, material from the broken shell can inject impurities into the fuel that, once again, reduce the ion temperature—this time through radiation—and thereby reduce the quality of the fusion burn.

Studies of x-ray loss through holes in the hohlraum wall can help determine exactly how they affect the implosion's efficiency and symmetry. It is therefore crucial to validate computer-code predictions of x-ray energy loss through the holes.



Computer renderings of the 25- μm -thick copper hohlraum and the laser-driven x-ray-backlighter system used to image the hohlraum and its vicinity in these code-validation experiments. The 1-mm-diameter hole at the top of the hohlraum corresponds to the polar holes in the hohlraums illustrated on page 7. The 0.4-mm-wide circumferential gap in the hohlraum is the equivalent (for a 2-D simulation) of a midplane hole (see page 7). The part of the hohlraum above the gap is supported by three thin struts spaced equally azimuthally.

A pulse of 200-eV x-rays (solid red cone) from the DH radiation source enters the open bottom of the hohlraum. The pink hole in the lower tapered part of the hohlraum (the transport taper) gives an array of x-ray diodes a clear view of the x-rays entering the hohlraum. The inside of the hohlraum—from the bottom of the transport taper to the top of the hohlraum—is filled with 20-mg/cm³ silica aerogel to tamp inward motion of the copper walls, which are heated by the DH x-rays and ultimately become a hot radiating plasma. The semitransparent structure on top of the hohlraum is a 60-mg/cm³ silica-aerogel foam used as a diagnostic to follow the progress of blast waves produced by x-rays leaking from the hohlraum through the polar hole and the circumferential gap.

During an experiment, an intense laser pulse (red ellipse in diagram at left) strikes a metal foil (gray rectangle in diagram at left), which then emits x-rays used to produce shadowgraphs of the blast waves. The backlighter x-rays are produced by shining the Z-beamlet laser at the Z-accelerator Facility onto a manganese foil. The backlighter x-rays have a very narrow energy spread centered at 6.15 keV due to the discrete radiative transition of the x-ray emission source and the use of a reflective Bragg crystal in the detection path. It is easier to uniquely determine a material's density from x-ray attenuation if the x-ray energy spread is narrow rather than broad. Using x-rays with a narrow energy spread means the synthetic shadowgraphs we compare with experimental shadowgraphs can be more accurately generated from LASNEX's calculations. The orange ellipse in the diagram at right suggests the areal extent of the source of backlighter x-rays generated by a laser source shown on the left. In real experiments, the red ellipse extends over a much larger section of the foil so the entire foam cap is backlit. A curved crystal that reflects and focuses the x-ray image of the backlit hohlraum onto a sheet of film is not shown. This setup produced the shadowgraph on page 9.

Follow the Blast Waves

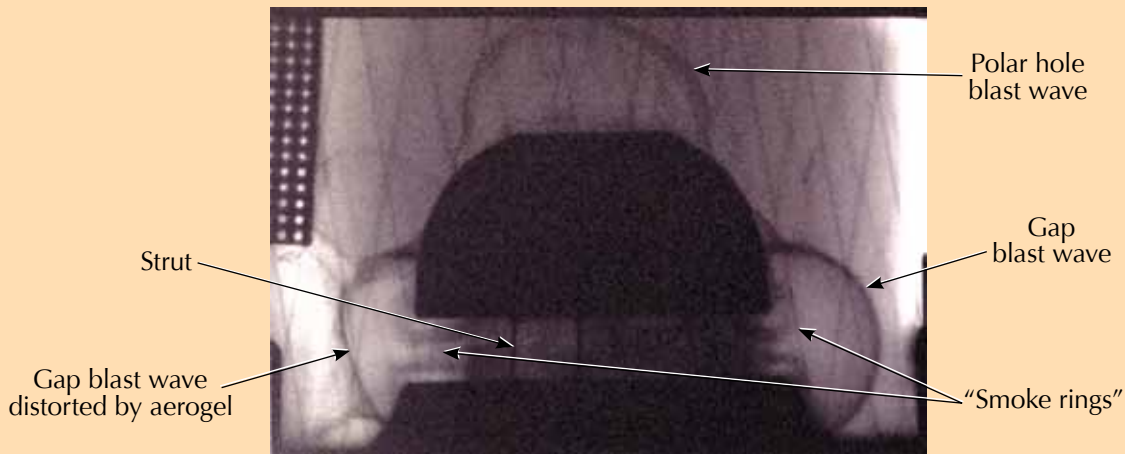
We have validated LASNEX by comparing its predictions with experimental measurements of x-rays escaping through a polar hole and a circumferential gap—the 2-D equivalent of a midplane hole (required for a 2-D simulation)—in the special hohlraum shown above.

X-rays leaking out through the polar hole and the circumferential gap enter the silica aerogel encasing the top of the hohlraum. (Silica aerogel is a glass foam much less dense than normal solid glass, in this case only 10–20 times the density of room-temperature air at sea level.) As the x-rays enter the aerogel, they produce supersonic radiation waves that quickly become blast waves, which generate density variations visible in x-ray shadowgraphs such as those shown

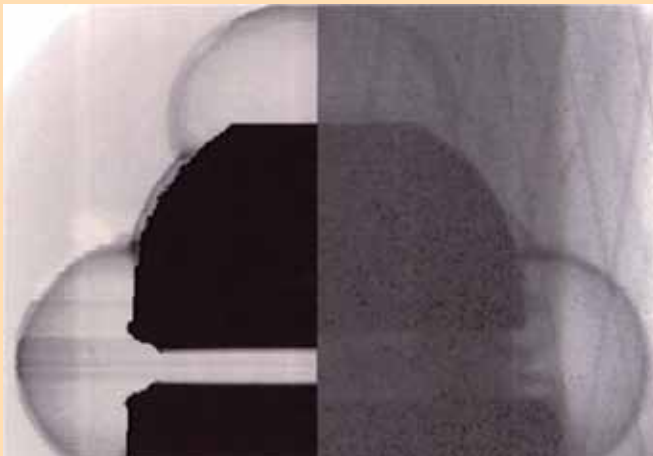
on page 9. We have validated LASNEX by comparing experimental measurements with code predictions of the evolution of the density variations.

Getting a Clear Shot of the Source

To ensure fidelity of the LASNEX simulation, the x-rays emitted by the DH source must be well-characterized. Both the temporal and spatial profiles of the x-rays delivered to the hohlraum are required so that we can uniquely compare a simulation with experimental data. To ensure that we knew these input parameters, we measured the x-ray drive with an array of x-ray diodes located some distance from the hohlraum. The diodes looked down through a hole in the x-ray transport taper shown above. The slanted cutout section of aerogel gave the diodes an unobstructed view of the x-ray source. However, the blast wave was reflected



An x-ray shadowgraph taken 14.5 ns after the DH x-rays entered the bottom of the hohlraum. Clearly visible are the blast waves ("bubbles") produced by x-rays escaping through the polar hole and the circumferential gap in the special hohlraum. Note the asymmetry of the blast wave on the left caused by the removal of a section of aerogel to give an array of x-ray diodes a clear view of the DH source. The two vertical bars visible in the gap are two of the three support struts. The slanted lines are x-ray shadows of the undisturbed part of the wires used to create the imploding wire array in the DH x-ray source, which is located below the hohlraum.



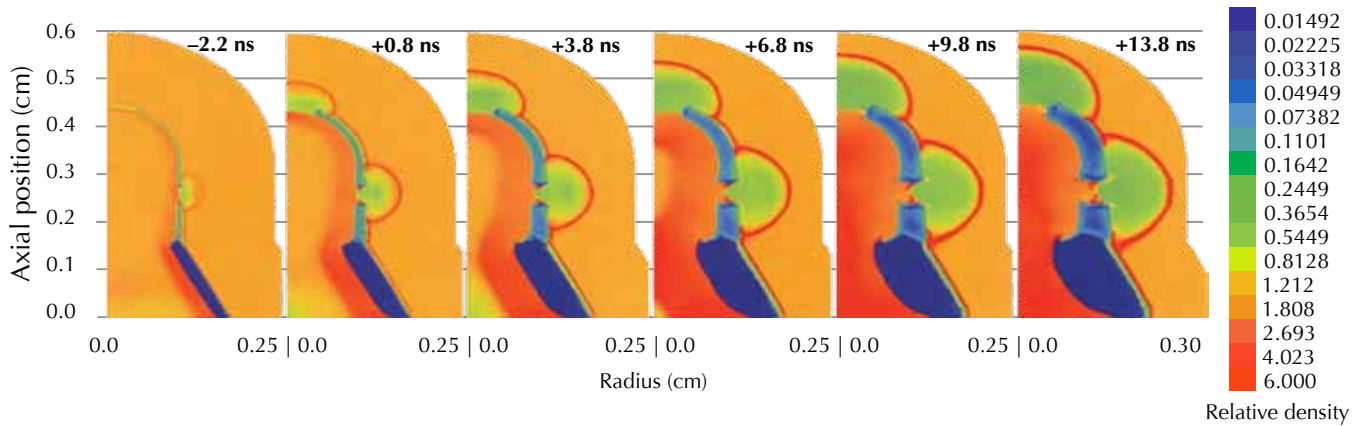
A side-by-side comparison between the synthetic shadowgraph produced from LASNEX calculations (*left*) and the experimental shadowgraph (*right*) 14.5 ns after the DH x-rays entered the hohlraum.

from the slanted surface, and the reflected shock propagated back toward the centerline of the hohlraum to produce the asymmetry seen on the left side of the experimental shadowgraph above. For this reason, we compare code results only to the right half of a shadowgraph where the cutaway and the asymmetry it produced were not present.

LASNEX's calculational space includes the hohlraum, the aerogel inside it, and the aerogel encasing the top of it. As the 200-eV x-rays travel to the top of the hohlraum through the internal aerogel, they heat the aerogel and the copper wall, which then emits x-rays. The wall-emitted x-rays combine with the DH x-rays for the duration of the DH x-ray pulse to generate the earliest blast wave when the x-rays escape through the circumferential gap (first frame in the figure on page 10) and a more delayed blast wave when they

escape through the polar hole (second frame on page 10). Both blast waves then evolve further, as seen in the later frames. The density of the copper wall changes with time from its initial value, but the wall, except for some radial inward and outward expansion, remains reasonably close to its initial location.

The aerogel inside the hohlraum tamps the radially inward motion of the wall material to some degree. If the internal aerogel was not there, the copper wall material would completely close off the inside of the hohlraum within a few nanoseconds, at which point x-rays from the DH source could no longer enter the hohlraum. (The gas in a gas-filled NIF hohlraum serves a similar purpose, that is, keeping the hohlraum open for energy delivery throughout the duration of NIF's 26-ns-duration laser drive.)



Six snapshots in time sequence from a LASNEX simulation of the evolution of the blast waves originating at the polar hole and the circumferential gap. In each snapshot, the local density is normalized to the initial density at that location to show how the material becomes more or less dense as the experiment evolves. In an experimental shadowgraph, densification produces a local increase in backlit-x-ray absorption. The same effect allows us to use the results of a LASNEX simulation to generate a synthetic shadowgraph.

Truth and Consequences

An important result of this study is that LASNEX’s predicted position of the gap’s blast wave as a function of time agrees uniquely with the measured values only when the DH x-rays’ spatial distribution and radiation temperature history, which are both input to LASNEX, agree, respectively, with the measured spatial profile from a shot without a hohlraum on top of the DH source and the actual measured temperature history on the shot being simulated.

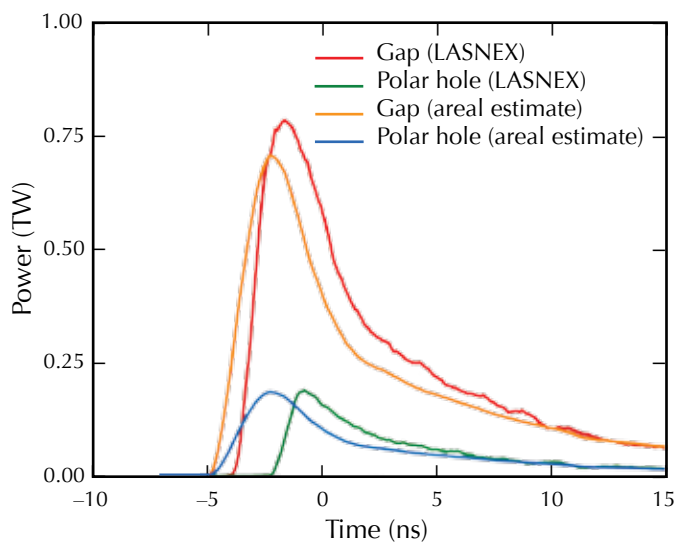
Moreover, the shadowgraphs on page 9 show that the major blast-wave features in the experimental shadowgraph are also present in the synthetic shadowgraph generated from the LASNEX calculations. There are also some obvious differences between the synthetic and experimental shadowgraphs, such as the two “smoke rings” inside the open gap, that do not appear in the synthetic shadowgraph. The rings are probably low-density material blown off the edge of the gap by x-rays, just as material is blown off the outer surface of the target capsule in a NIF experiment. We are still studying the differences between the experimental results and those of the simulations.

However, based on the analysis we have done so far, we believe that LASNEX correctly models

- the energy lost through the polar hole and the circumferential gap,
- the behavior of the blast waves resulting from that energy loss, and
- the bulk radial hydrodynamic motion of the wall.

However, as suggested by the existence of the “smoke rings,” something about modeling the metal blown off the copper wall may be wrong. Possibly the way LASNEX handles cold-metal physics could be improved.

The results in the graph below reveal another important result of the study. Typically, the designer of a fusion-hohlraum experiment will estimate the time-dependent x-ray power lost through a hole in the hohlraum’s wall by multiplying the time-dependent power delivered to the hohlraum by the ratio of the hole’s area to the total wall area.



Comparison of simple areal estimates and LASNEX’s calculations for the x-ray power lost through the polar hole and the circumferential gap. These results are for the shot that produced the shadowgraph on page 9.

The graph on page 10 shows that the power loss calculated by LASNEX is delayed compared with the power loss calculated from the areal estimates, which scale the time-dependent input power by 16.6% for the circumferential gap and 4.36% for the polar hole. The delay is caused by the silica aerogel, which delays energy delivery to the wall in a location-dependent manner. If the aerogel was not present, the x-ray loss calculated by LASNEX would essentially coincide in time with the DH x-ray drive history.

At 10.5 ns after the DH x-rays entered the hohlraum, 19.24 kJ of x-ray energy had been delivered to the hohlraum. LASNEX calculated that 3.42 kJ of x-ray energy had been lost through the circumferential gap and 0.65 kJ through the polar hole, compared with areal estimates of 3.2 kJ for the gap and 0.84 kJ for the hole. So, the losses calculated by LASNEX can be larger or smaller than the simple areal estimates, depending on where a hole or gap is located.

The aerogel (or a NIF gas fill) ensures that energy can be delivered to the hohlraum for the full duration of the drive pulse, but the aerogel also introduces a complication: the energy delivered to a particular location on the hohlraum wall will depend on that location. This effect could potentially change the temporal history of the x-rays illuminating the target capsule, which could delay the implosion or produce an asymmetric implosion. Either effect could reduce the implosion's efficiency.

Although the effects of the aerogel on the peak amplitude and time history of the power lost through

the holes are relatively small, they could affect the detailed behavior of the implosion and the diagnostic setup. We therefore suggest that simple areal estimates of the x-ray power lost through holes in the hohlraum's walls can be used early in the design of an experiment. Before an actual shot, the predicted hole losses as a function of time should be studied carefully so that diagnostic instruments can be properly set up and implosion times can be accurately estimated.

Toward Viable Fusion Reactors

Controlled nuclear fusion has great potential as an economical, nonpolluting, proliferation-proof, and nearly inexhaustible source of energy. Fusion reactors could be supplying significant amounts of our energy needs by the middle of this century or earlier—but only if details such as the effects of x-ray leaks from fusion hohlraums are carefully studied and resolved. The LASNEX code-validation studies described here thus represent a necessary step to fully realizing the potential of inertial-confinement controlled nuclear fusion. **NW**

Point of contact:

Bob Watt, 505-665-2310, watt_r@lanl.gov

Other contributors to this work are George Idzorek, Tom Tierney, Randy Kanzleiter, Robert Peterson, Darrell Peterson, Bob Day, Kimberly DeFriend, the Los Alamos Target Fabrication and Assembly Team, Mike Lopez, Michael R. Jones, and the entire Z-accelerator operating crew at Sandia National Laboratories in Albuquerque, New Mexico.

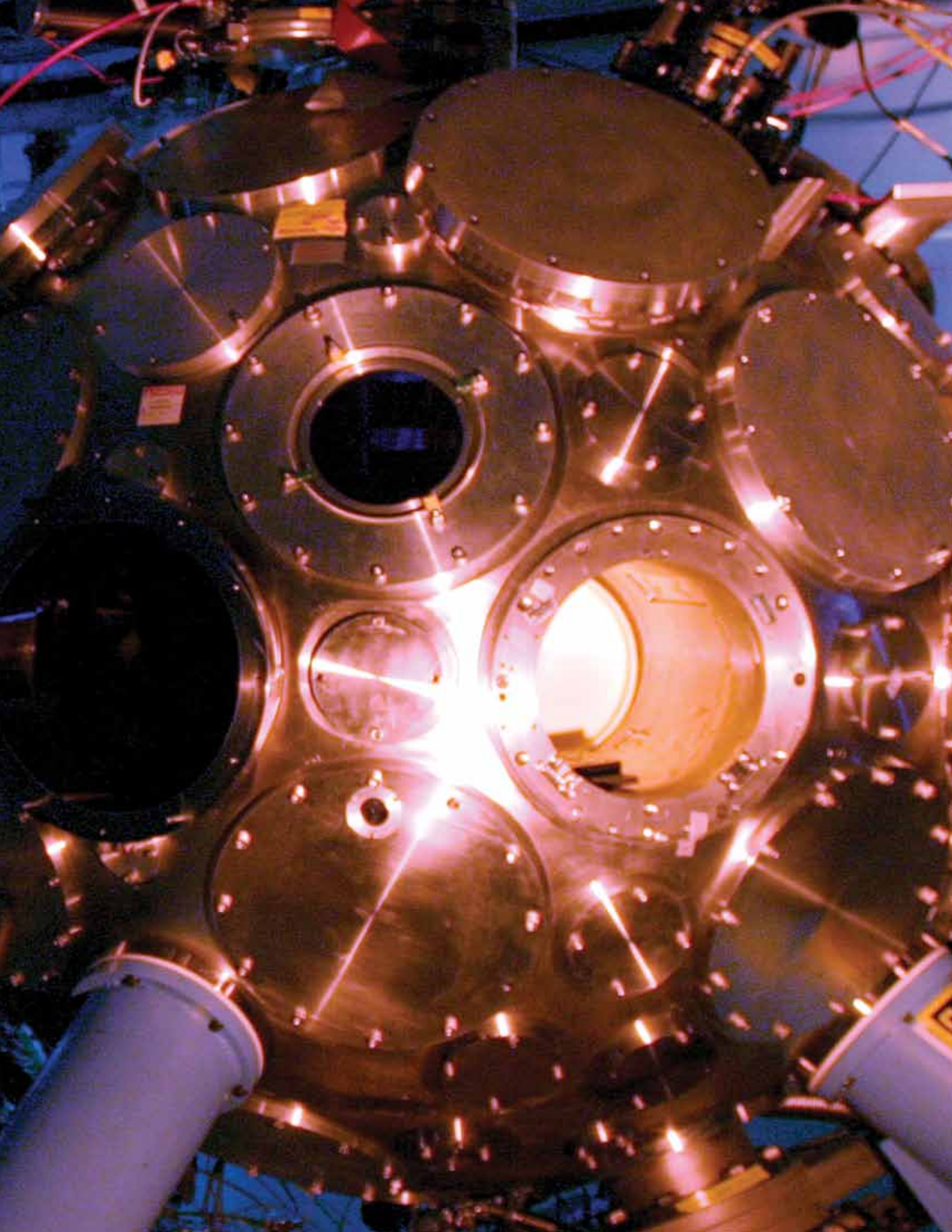
Upgrades Made to the Trident Laser Facility

Upgrades make LANL's Trident Laser Facility one of the most powerful high-energy lasers in the US.

The Trident enhancement team's first goal was to enable experiments at the Trident Laser Facility that would advance LANL's high-energy-density (HED) physics program. Also, the team had the following two primary performance objectives:

- generate 18–35 keV x-rays of sufficient dose to illuminate an x-ray detector (see Plasma Experiments and Detectors) and
- generate intense ion beams with energies greater than 1 MeV/amu.

The team's final goal was to continue to operate the facility efficiently and to increase the number of innovative scientific experiments conducted by LANL and external experimental teams.



Plasma Experiments and Detectors

In a typical Trident experiment, two laser beams strike a target material inside a vacuum chamber to generate a plasma. The third beam is shined through the plasma. As the third beam passes through the plasma, the interaction of the beam with the plasma ions generates x-rays, which are recorded with an x-ray detector.

Current detector technology uses x-ray framing cameras that are comparable to digital cameras—only instead of recording visible light, these cameras sense x-rays and then amplify and convert them into visible light. The x-ray framing camera captures a fixed number of extremely short exposures in a rapid series. Optical and particle emissions from the plasma are also recorded using various high-speed (16 billion frames/s) cameras.

Trident HED Facility

The Trident Facility is dedicated to HED physics experiments and laser technology research. This facility consists of a three-beam, high-energy laser system and experimental target chambers. The hallmark of the Trident Facility is its flexible illumination geometry, pulse lengths, and diagnostic configurations.

Trident's three infrared beams can be individually focused onto an HED target. Two beams operate in long-pulse mode, that is, they generate light pulses that last between 1 ns and 10,000 ns. The third beam can operate in either long-pulse (1–10,000 ns) or short-pulse (~0.0005 ns) mode. Flexible pulse lengths enable a wide range of experiments, including studies of radiation hydrodynamics, laser-plasma interactions, and laser-launched flyer plates for creating very high pressure and very high strain rates in material samples.

Each laser beam can be directed into either of two target chambers (a third chamber is being commissioned, see Flexible User Facility). Experiments can occur in both chambers simultaneously, alternately, or all three beams can be directed to one target chamber. Each beam can be converted with a nonlinear optical element to produce green laser light. The third beam can also be converted to ultraviolet light. The varying wavelengths of infrared, green, and ultraviolet laser light enable advanced diagnostic techniques that otherwise would not be possible.

Fundamental discoveries and first observations from Trident experiments include monoenergetic fast-ion acceleration, fluid/kinetic nonlinear behavior of plasma waves, electron-acoustic wave scattering, energetic proton acceleration well beyond the power scaling found in the literature, the first observation of the ion-acoustic decay instability, and the first observation of ion plasma waves.

Intermediate-Scale Laser Facilities

HED science has been brought to the forefront of scientific research with the completion of the National Ignition Facility (NIF) and the beginning of inertial-confinement fusion (ICF) experiments. Large-scale HED research facilities such as NIF, which has 192 converging laser beams, and the University of Rochester's Omega Laser Facility, which has 60 converging laser beams, provide researchers with the highest energy-density conditions currently possible in the laboratory.

Research at an intermediate-scale facility, like the Trident Facility, provides scientific foundations for national grand challenge research, e.g., fast ignition and laser-based accelerators, at large-scale facilities. Intermediate-scale facilities also allow more efficient use of large-scale facilities by providing a platform for experimental and diagnostic development using relevant plasma conditions. Because intermediate-scale facilities have versatility and flexibility not possible at large-scale facilities, they are essential to the future of HED plasma physics. Intermediate-scale facilities have flexible beam line and diagnostic configurations that enable the investigation of high-risk/high-payoff ideas—particularly in research areas that do not fit into the parameters of a large-scale facility's mission. High-risk experiments are also made possible by the high shot rate, modest costs, and HED plasma conditions relevant to those obtained at large-scale facilities. Flexibility and high shot rate also make intermediate-scale facilities ideal for developing diagnostic equipment and techniques necessary for effective experiments at the more expensive large-scale facilities.

Flexible User Facility

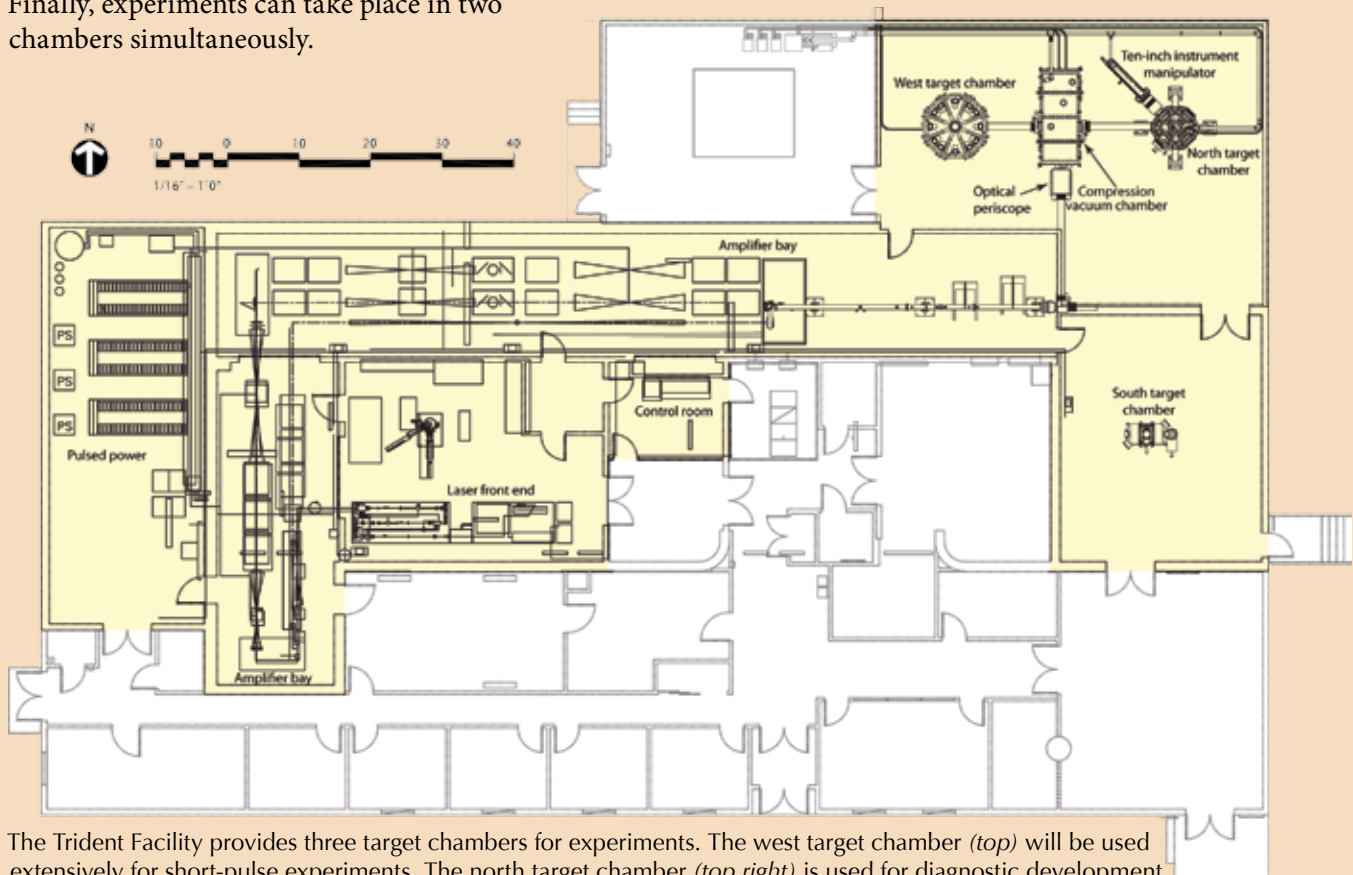
Providing flexibility, yet keeping the user interface simple, requires complex operation of Trident's laser and the experimental target areas. Each of the three laser beam lines can be directed into any one of two vacuum chambers (target chambers) where the laser will strike a target made of various shapes and materials for each experiment.

Each target chamber provides configurations, illumination geometries, and diagnostic access that can be customized for particular experiments. The south target chamber is a horizontal cylinder with a diagnostic table inside the chamber. Mirrors, spectrometers, and other diagnostic equipment can be located anywhere on this table. The laser beams can enter the target chamber through many ports. Researchers primarily use this chamber for dynamic material experiments such as laser-launched flyer plate and laser-ablation shock loading experiments. Scientists also perform laser-plasma interaction experiments such as the interaction of a short pulse (5 ps) with a gas jet formed into plasma by 1 or 2 long-pulse (1 ns) beams.

The west target chamber is being commissioned in 2010. This chamber is designed specifically for short-pulse experiments. It is a 10-sided chamber with a large optical table inside for extremely flexible experimental geometries.

The north target chamber is spherical and is used for diagnostic development and current short-pulse experiments. Attached to this target chamber is a ten-inch instrument manipulator (TIM) that transports diagnostics into and out of the vacuum chamber. This TIM is identical to the ones at the Omega Laser Facility and is compatible with the manipulators at NIF. Thus, diagnostics developed and built for Omega or NIF can be tested and qualified on Trident without using valuable time at those larger facilities.

With three target chambers to choose from, researchers can design each experiment to maximize data return and to provide data that is easily interpreted. In addition, multiple chambers increase efficiency because an experiment can be set up in one chamber while another experiment is being performed in a different chamber. Finally, experiments can take place in two chambers simultaneously.



The Trident Facility provides three target chambers for experiments. The west target chamber (*top*) will be used extensively for short-pulse experiments. The north target chamber (*top right*) is used for diagnostic development and short-pulse experiments. The large rectangular vacuum chamber contains the dielectric compression gratings that compress a laser pulse to less than 1 ps in duration. The south target chamber (*bottom*) is used extensively for materials science and laser-matter interaction experiments.

Enhancement

Trident's third beam can now produce laser pulses with peak powers of up to 0.2 PW. Reaching this power level required many component upgrades. Beginning at the front end of the laser, the enhancement team replaced the oscillator that produces the "white light" seed pulse (see Laser Beam Amplification and Compression). A pair of optical gratings increases the duration of the beam's pulse by separating it into its component wavelengths, which stretches out the pulse in time and then injects it into the amplifier chain (the next segment of the laser) where the energy of the pulse is increased.

more than 100 J from its previous limit of 30 J. Finally, in order to allow easy access to all components in the laser beam and target bays, the team elevated the beam transport system so that its components are more than 6 ft above the floor.

The laser beam enters an optical periscope where its height is lowered to 4 ft above the floor and then enters a 5 ft × 5 ft × 10 ft vacuum chamber. Within this chamber, a set of very large optical gratings (large pieces of glass that have more than 600 lines/mm etched into them) compresses the duration of the pulse

The hallmark of the Trident Facility is its flexible illumination geometry, pulse lengths, and diagnostic configurations.

To allow Trident to focus the pulse on a small spot on the target and thus increase the resolution of radiographs, the facility enhancement team placed a deformable mirror in the amplifier chain to correct distortions in the laser beam caused by thermal heating of the amplifiers. The deformable mirror is computer controlled and allows researchers to change the shape of the mirror, thereby improving the optical quality of the laser pulse. The team also incorporated additional amplifiers to increase the energy of the third beam to

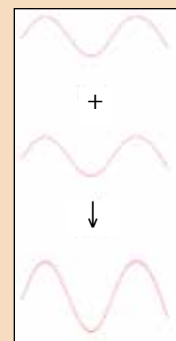
to less than 600 fs. By reversing the stretching process exactly, the various colors of the beam are recombined into the original short pulse. Because the intensity of the laser pulse will cause air breakdown (molecules of air ionize and degrade the coherence and shape of the laser pulse), the laser beam must remain in a vacuum after compression. The compressed laser pulse is then transported to a target chamber and focused onto the target by an off-axis parabolic mirror.

Laser Beam Amplification and Compression

Every laser beam starts with a low-power seed laser pulse initiated from a tabletop laser generator called a master oscillator. This seed laser pulse exhibits the general characteristics of the final laser pulse (e.g., wavelength and pulse shape), but at a much lower energy. A laser's true power is based on the fact that it produces a coherent (the light photons are correlated in space and time) beam (light waves are oriented in the same direction and do not diffuse rapidly).

The purpose of stretching and then compressing the laser beam is to prevent damaging the glass in the amplifiers. Then the laser facility amplifies the seed laser pulse to the required power level. To increase the energy in the seed pulse, it travels through several stages of amplification. Each stage consists of glass disks. In an amplifier, electrical energy is transferred to the amplifiers with flash lamps (like those on a copier machine). The light from the lamps is absorbed by glass disks and then transferred to the laser pulse as it passes through the amplifier disks.

Amplification increases the energy contained in the beam that is delivered to the target. Compression increases its intensity by delivering all of that energy in a much shorter time.



The combination of the deformable mirror and a high-quality focusing mirror produces a laser spot on the target that is $\sim 13 \mu\text{m}$ in diameter, which is 5 to 10 times smaller than the laser spots produced by the Omega or NIF lasers. During commissioning, Trident produced pulses as short as 550 fs that were amplified to 100 J. Since completion of the upgrade, scientists routinely produce pulses greater than 0.2 PW once an hour.

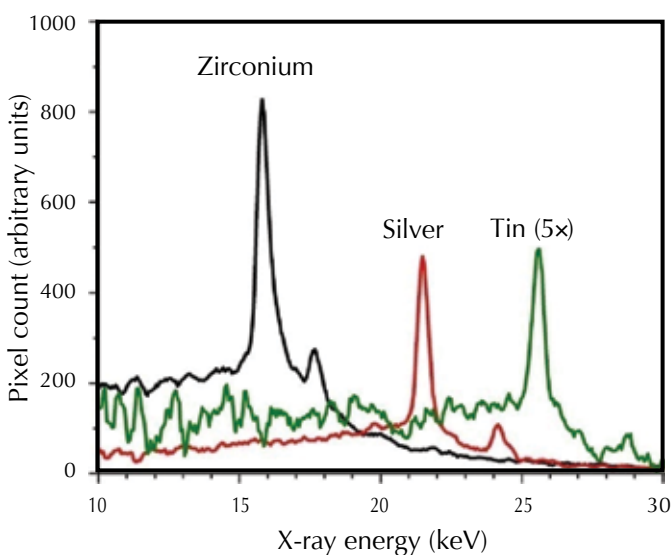
Experiments Prove Enhancements' Value

After enhancements were completed, the Trident Facility met the experimental objectives for x-ray backlighting (i.e., radiographing an object to determine the position of shock waves) and producing intense high-energy ion beams in the first month of operation. These objectives are discussed in the next two subsections.

Energetic X-rays Probe HED Phenomena

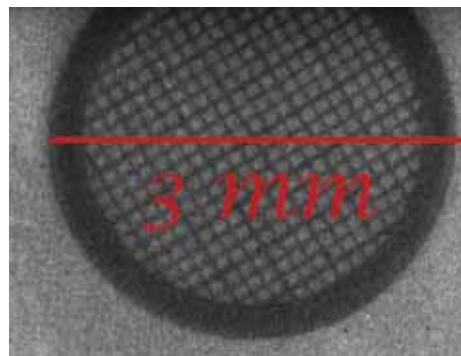
When the laser strikes a flat or curved thin foil, atoms in the focal plane of the 0.2-PW laser are exposed to a 3000-V-per-atomic-diameter electric field. Such an extreme environment rips the electrons from the atoms and accelerates them almost to the speed of light in a short time and distance. When these electrons strike nearby material, they produce x-rays—each with the characteristic signature of the native atom.

These x-rays are useful as researchers examine hydrodynamic effects (called hydrodynamic because the materials flow like a fluid) in experiments involving



Signature spectra of zirconium, silver, and tin excited by laser-driven electrons that approach the speed of light. A monochromatic (consisting of electromagnetic radiation that has an extremely small range of wavelengths) x-ray source (e.g., the signature spectra of tin, 26 keV) simplifies measuring the density of materials in physics experiments.

High-energy photon (22 keV) radiography using Trident's third laser beam in short-pulse mode. High-energy photons are needed to penetrate very dense objects. This radiograph of a gold grid shows excellent spatial resolution ($\sim 10 \mu\text{m}$). The ability to make small features within the plasma visible and distinct is critical to validate physical models.



dense materials. Such experiments are now possible because Trident is a petawatt-class laser capable of creating a sufficient flux of energetic x-rays. The experiments require short x-ray exposures because the 1-ns hydrodynamic phenomena occur on nanosecond time scales. Because the x-ray burst is shorter—approximately 1 ps—the laser-generated x-ray flux is ideal for penetrating extremely dense materials and eliminating motion blur from radiographic images.

Researchers obtained a proof-of-principle x-ray pinhole camera radiograph of a gold grid with 22-keV x-rays produced from a silver target. The excellent spatial resolution ($\sim 10 \mu\text{m}$) is due to the small size ($\sim 13\text{-}\mu\text{m}$ diameter) of the Trident laser focal spot. This x-ray backlighting capability is one of the key strengths of the Trident Facility.

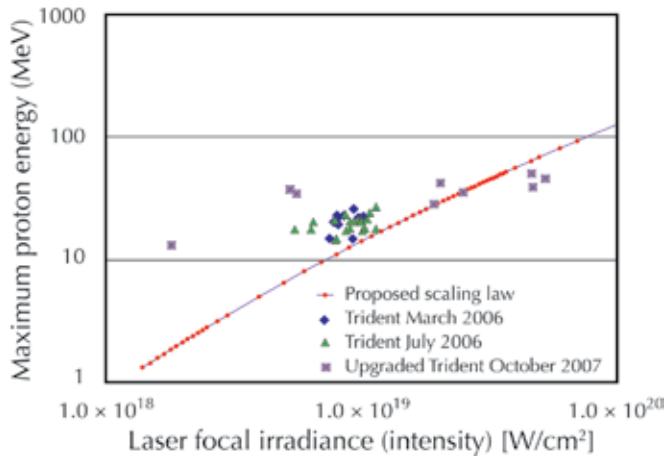
Energetic Proton Beams Produced

The Trident short-pulse enhancement permits irradiation of targets with up to 10^{20} W/cm^2 of laser light because of the beam's

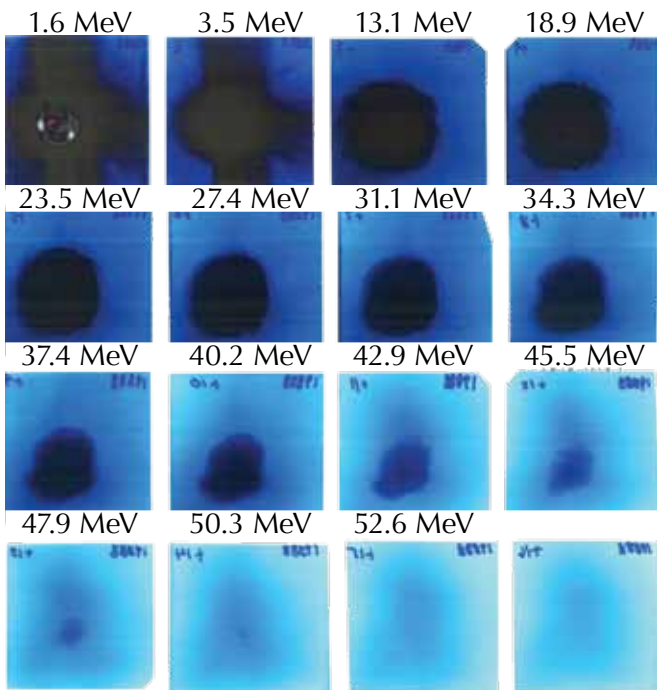
- high energy (100 J),
- short pulse width (550 fs), and
- small focal spot ($\sim 13\text{-}\mu\text{m}$ diameter).

This capability enables a solid target to emit very energetic protons.

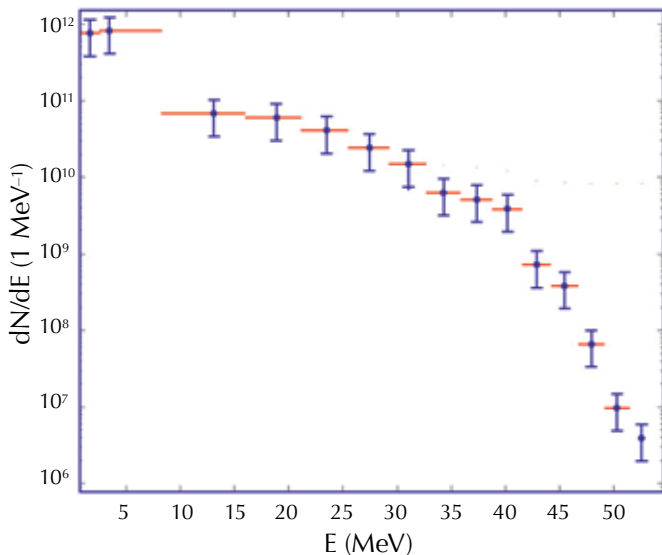
In the first experiment designed to produce a proton beam on the enhanced Trident, many more protons with higher energies were produced than expected. Higher energies will allow additional physics to be explored (e.g., fast ignition) using the highest powers available; they will also allow experiments at smaller laser facilities to access HED regimes not previously thought possible. The proton energies measured exceed a recently proposed scaling law by a factor of 10 below $1 \times 10^{19} \text{ W/cm}^2$ and exceed those of similar laser systems above $1 \times 10^{19} \text{ W/cm}^2$.



Proton energies achieved at Trident (the data points) exceed the recently proposed scaling law (solid line) at lower laser intensities. Improvements in the facility, including lower prepulse levels, enable higher-energy protons to be produced at lower laser intensities. This increased efficiency opens new opportunities for physics research in biomedical applications, weapons physics, and fast ignition.



A 50.3-MeV proton beam imaged on a radiochromic film stack produced from a 10- μm -thick molybdenum foil target irradiated at $4.6 \times 10^{19} \text{ W/cm}^2$. Each layer of film stops protons of lower energy. For example, any protons reaching the 14th piece of film must have an energy of at least 50.3 MeV. The next film is at beam energy of 52.6 MeV; thus the final energy is known only to the certainty of 2.3 MeV (i.e., the beam energy was less than 52.6 MeV and greater than 50.3 MeV). The size of the spot (well-defined dark area) shows the divergence of the proton beam. (The more diffuse background shaded area is the contribution from hot electrons [1–10 MeV].) At very high energies, the spot is small—showing that the higher-energy protons are well collimated.



The angle- and time-integrated energy spectrum of the beam can also be determined from radiochromic film stack data. The darkness of each piece of film indicates the total number of protons at each energy. (Horizontal red lines are error bars. Data are binned into 3-MeV intervals.) A material will stop and absorb a proton at a certain distance that is a function of both the material's properties and the energy of the proton. A broad spectrum of protons means that the energy in the beam will be absorbed over a large depth in the material. If the beam was monoenergetic, i.e., having essentially a single energy, the beam would be absorbed in a very small volume of the target material. Tailoring where the energy is deposited by choosing the proton energy and the spectrum of the beam is essential for medical applications such as tumor treatment.

It is important to measure the properties of the proton beam to optimize production of the beam and to aid in modeling and predicting interaction of the beam with a target material. A stack of radiochromic films is the primary instrument used to measure the beam's properties. In this example, 16 pieces of film show a proton beam created from the interaction of the short-pulse laser with a molybdenum foil target. From these data, researchers determine the maximum energy of the laser and the number of protons created. The energy spectrum of the protons is derived using data obtained from the film images. The beam contains approximately 3.5 J of energy in protons above 4 MeV, i.e., approximately 4% of the total laser energy, which is a very high efficiency. In comparison, the efficiency of generating x-rays from such foils, as discussed in the previous section, is of the order of 1% or less.

The highest recorded proton beam energy obtained at Trident, 50.3 MeV, rivals the highest previously recorded energy obtained at LLNL's Nova Petawatt Laser Facility (now decommissioned), which reported 58 MeV, but required 5 times the laser energy and intensity on target. Trident's conversion efficiency is 2 to 8 times higher than similar laser systems at this laser intensity with 3 times greater proton-beam energy.

Trident provides a flexible experimental facility for the study of newly conceived HED physics such as x-ray Thomson scattering to determine the characteristics of warm dense matter. The superior performance of the Trident laser system can be attributed to low laser prepulse that creates a small plasma at the surface of the target before the main pulse reaches it. By measuring the seed laser pulse before amplification, the contrast between the main laser pulse and any precursor pulses is inferred to be greater than 10^7 . The Trident laser's pulse duration, spectrum, near-field pattern, and far-field pattern are measured and recorded for each shot. Rapid computer analysis of these laser system performance data makes the Trident Facility one of the best diagnosed high-energy, short-pulse systems in the world and allows facility staff to maximize laser performance by making slight corrections to those parameters before every shot.

WWW

Points of contact:

Randy Johnson, 505-665-5089, rpjohnson@lanl.gov

David Montgomery, 505-665-7994, montgomery@lanl.gov



Fogbank: Lost Knowledge Regained

During Japan's Muromachi period (1392–1573), swordsmiths developed the katana, often called the samurai sword, which was fabricated from special steel. Secret techniques in quenching, tempering, and polishing made the sword one of the deadliest on any battlefield.

In the 16th century, firearms were introduced to Japan. Expert swordsmiths, whose skills had been acquired from previous generations, were no longer needed. Thus, the skills associated with making such deadly blades were lost.

Today, the science of metallurgy is advanced enough so that researchers understand the processing variables that gave the katana its distinct properties. Moreover, scientists can replicate the processes to a great extent by using modern methods.

Like the katana, a material known as Fogbank has undergone a similar sequence. Produced by skilled hands during the 1980s, Fogbank is an essential material in the W76 warhead. During the mid-1990s, Fogbank production ceased and the manufacturing facility was dismantled. As time passed, the precise techniques used to manufacture Fogbank were forgotten.

When it came time to refurbish the W76, Fogbank had to be remanufactured or replaced. In 2000, NNSA decided to reestablish the manufacture of Fogbank. Officials chose to manufacture Fogbank instead of replacing it with an alternate material because Fogbank had been successfully manufactured and historical records of the production process were available. Moreover, Los Alamos computer simulations at that time were not sophisticated enough to determine conclusively that an alternate material would function as effectively as Fogbank.

Although Fogbank is a difficult material to manufacture, scientists soon discovered that restoring the manufacturing capability would prove an even greater challenge. Scientists faced two major challenges:

- most personnel involved with the original production process were no longer available, and
- a new facility had to be constructed, one that met modern health and safety requirements.

Despite efforts to ensure the new facility was equivalent to the original one, the resultant equipment and processing methods failed to produce equivalent Fogbank. The final product simply did not meet quality requirements.

Personnel took a more careful look at the design of the new facility, comparing it closely with the old one. They discovered that some of the historical design records were vague and that some of the new equipment was equivalent, but not identical, to the old equipment. Differences that seemed small during the design phase became more significant once the new facility began to produce material. The situation was exacerbated by construction delays, which put the project a year behind schedule.

As the original deadline quickly approached in March 2007, many additional resources were engaged when an emergency condition was established for Fogbank production. Personnel made multiple changes to multiple processes simultaneously. The result was production of equivalent Fogbank and recertification of the production process in 2008.

Despite this success, personnel still did not know the root cause of the manufacturing problems. In fact, they did not know which process changes were responsible for fixing the problem. After production was reestablished, personnel implemented process studies in an attempt to determine the root cause. These studies proved daunting because

- the processes are complex and depend on each other, and
- the material characteristics that control quality of the final product were not understood.

Personnel formed a hypothesis for the root cause of the manufacturing problems by combining results from recent studies with information gathered from historical records. Historical information indicated that occasionally there were production problems with Fogbank for which the root cause could not be satisfactorily resolved. The historical production problems were similar to those observed when reestablishing production.

When investigating historical records with respect to impurity levels during the Fogbank purification process, personnel discovered that in some cases the current impurity levels were much lower than historical values. Typically, lower impurity levels lead to better product quality. For Fogbank, however, the presence of a specific impurity is essential.

Laboratory data show that the presence of one particular impurity in the Fogbank purification process plays an important role in the quality of the final material. The impurity's presence in sufficient quantity results in a different morphology (form and structure) of the material. Although the change in morphology is relatively small, it appears to play an important role in the downstream processes. A review of the development records for the original production process revealed that downstream processes had been implicitly based on that morphology.

However, historical records lacked any process controls designed to

- ensure that the purification process produced the impurity morphology or
- evaluate the success of some of the important processes.

Currently, personnel are proposing additional process controls designed to check both morphology of the material and the effectiveness of the downstream processes.

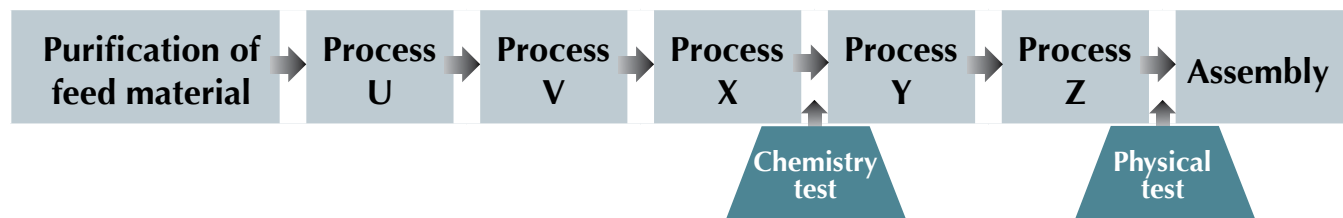
Further analyses of the restart activities revealed that there was a small variation in the feed material used in the purification process. This variation led to the change in impurity content and thus the resultant change in morphology. Scientists found that modern cleaning processes, used in the manufacture of the feed material, clean it better than the historical processes; the improved cleaning removes an essential chemical.

Historically, it was this chemical that reacted during purification of the feed material to produce the impurity necessary for proper morphology. The historical Fogbank production process was unknowingly based on this essential chemical being present in the feed material. As a result, only a maximum concentration was established for the chemical and the resulting impurity. Now the chemical is added separately, and the impurity concentration and Fogbank morphology are managed.

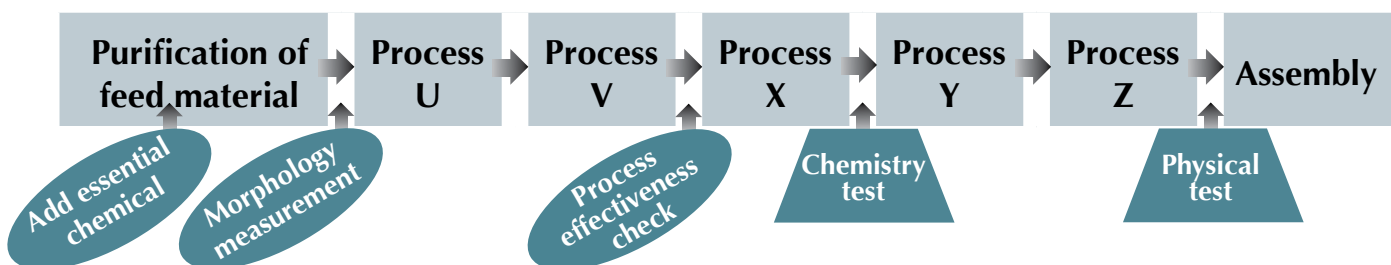
Just as modern scientists unraveled the secrets behind the production of the Japanese katana, materials scientists managed to remanufacture Fogbank so that modern methods can be used to control its required characteristics. As a result, Fogbank will continue to play its critical role in the refurbished W76 warhead. [NWJ](#)

Point of contact:
Jennifer Lillard, 505-665-8171, jlillard@lanl.gov

Reconstructed Process



Adjusted Process



To fabricate new Fogbank, modern scientists reconstructed the historical manufacturing process (*top*). However, when the resultant Fogbank assembly did not meet quality requirements, scientists analyzed the historical manufacturing process and discovered one minor difference that, when adjusted properly (*bottom*), yielded quality Fogbank.

The Los Alamos Branch of the Glenn T. Seaborg Institute for Transactinium Science

The transactinium elements—which include actinium through lawrencium (the actinides) and rutherfordium through the most recently discovered element with atomic number 118 (the transactinides)—comprise approximately 24% of all elements in the periodic table. Most of the transactinium elements are manmade and all are radioactive, making their study a challenging and highly specialized field of science.

Three transactinium elements—uranium, neptunium, and plutonium—have always been particularly important at Los Alamos, beginning with the

Manhattan Project and continuing to the present day. Over the years, fundamental transactinium science has been used to chemically process and separate these materials, manipulate their physical properties, characterize them, and detect them in support of many Los Alamos mission areas, most recently including stockpile stewardship, environmental stewardship, homeland security, and energy security.

Realizing the importance of the transactinium elements to a variety of national security missions, a group of US scientists established the Glenn T. Seaborg

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112	113	114	115	116		118 118

*Lanthanides

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

**Actinides

The modern periodic table of the elements. Actinium (element 89) through lawrencium (element 103) are the actinide elements. Rutherfordium (element 104) through the most recently discovered element (element 118) are the transactinide elements. Transactinium elements include the actinide and transactinide elements.

Institute for Transactinium Science at LLNL in 1991 (see the *Actinide Research Quarterly* 2nd quarter 2009, online at <http://arq.llnl.gov>). The Los Alamos branch of the Seaborg Institute was chartered in 1997, and a third branch was established at Lawrence Berkeley National Laboratory in 1999.

The purpose of the Institute is to provide a focus for transactinium science, to develop and maintain US preeminence in transactinium science and technology, and to help provide an adequate pool of scientists and engineers with expertise in transactinium science. With NNSA's recent designation of LANL as a "plutonium center of excellence," extensive coordination and leadership in transactinium science, engineering, and manufacturing are urgently needed. The Los Alamos branch of the Seaborg Institute has been tasked with providing much of this coordination and leadership.

Beginnings of the Seaborg Institute

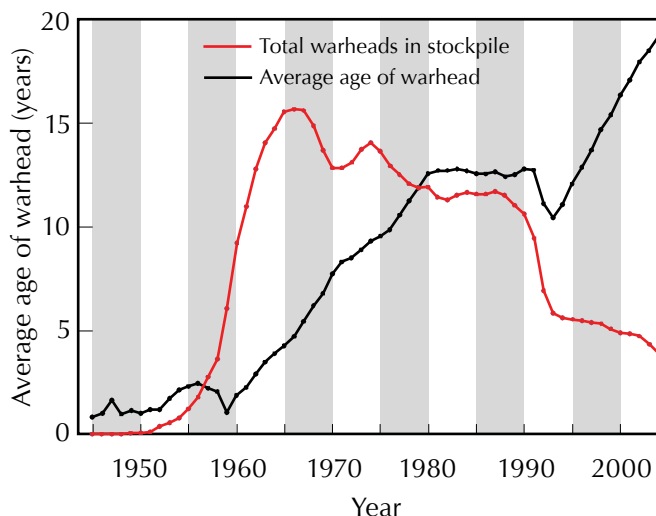
The Los Alamos Seaborg Institute integrates research programs on the chemical, physical, nuclear, and metallurgical properties of the light-actinide elements (i.e., thorium through curium), with a special emphasis on plutonium, as well as their applications in nuclear weapons, nuclear energy, nuclear forensics, nuclear safeguards, nuclear-waste management, and environmental stewardship.

The Institute provides a unique focus and mechanism for cooperation and collaboration among the national laboratories, universities, and the national and international actinide-science community. The Institute fosters closer ties with the outside community and the world through an extensive visitor program, workshops, and conferences. Additionally, the Institute encourages graduate students, postdoctoral candidates, university faculty, and other collaborators to perform research at the Laboratory.

The Los Alamos Seaborg Institute has managed and developed a variety of Laboratory programs and has offered scientific leadership, coordination, and mentoring for many programmatic activities. A few representative examples are discussed in this article.

Plutonium Aging and the Enhanced Surveillance Campaign

Since shortly after its establishment at Los Alamos, the Seaborg Institute played a central role in plutonium-aging and pit-lifetime assessments (see the *Actinide Research Quarterly* 1st quarter 2001).



The number of weapons in the stockpile is decreasing, and in another decade, the ages of most weapons will be well beyond their original design lifetimes.

The Enhanced Surveillance Campaign (ESC) was tasked with providing diagnostic tools for early detection of potential age-induced defects in nuclear weapons' components. This campaign supported many of the critical skills and much of the expertise in materials science for the weapons complex. Changes in weapons performance that result from aging represent the end of a series of events that began years or decades earlier. Changes occur first in the atomic-scale properties of the materials within the weapons—properties such as composition, crystal structure, and chemical potential. Changes are observed later in the materials' large-scale properties that are important to applications—properties such as density, compressibility, strength, and chemical reaction rates.

The ESC contributes to the scientific and technical bases for the annual assessment of aged components and for refurbishment decisions and schedules. Under the auspices of the Institute, the program successfully replicated the Rocky Flats wrought process for plutonium pits and cast several kilograms of accelerated-aged plutonium alloy that achieved a 60-year equivalent age in less than 4 years (see the *Actinide Research Quarterly* 2nd quarter 2002).

The Institute also organized a series of pit-lifetime workshops and program reviews between LANL and LLNL. The pit-lifetime workshops spanned a 5-year period and provided a forum in which to discuss all relevant LANL and LLNL data, to involve a wider

intellectual community in the discussion, and to help establish an official LANL position on the minimum pit lifetime based on sound scientific understanding. These workshops laid the groundwork for the joint 2006 lifetime assessment submitted by the two labs.



An induction furnace that might be used to heat a plutonium alloy.

The pit-lifetime assessment has been used to make national policy decisions on pit reuse, pit-fabrication facilities, and the Reliable Replacement Warhead. The assessment contributed to NNSA's decision to forego construction of a modern pit facility and designate Los Alamos as the "preferred alternative" for maintaining a small-capacity pit-manufacturing capability.

Plutonium Oxides and Disposition of Weapons-Usable Plutonium

Binary actinide oxides such as PuO_2 are of tremendous technological importance with

widespread application as nuclear fuels, long-term storage forms of surplus weapons materials, and power generators (plutonium-238) for interplanetary exploration. They are also of great importance in corrosion reactions (uranium and plutonium) in nuclear weapons and in the migration behavior of plutonium in the environment.

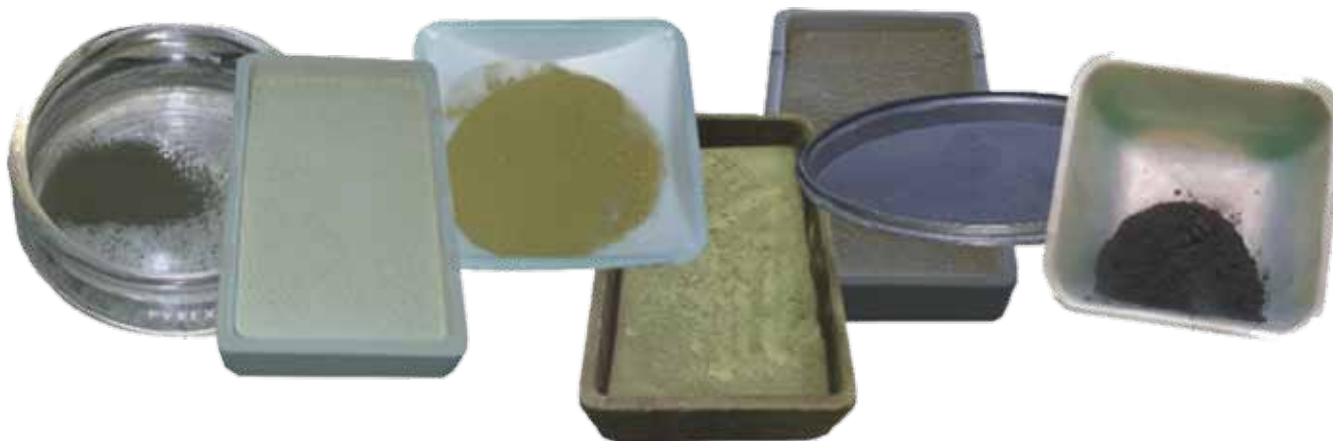
Scientists widely held that oxidation of plutonium to compositions with an atomic oxygen to plutonium ratio higher than 2.0 was not possible. Therefore, PuO_2 became the generally accepted chemical form for long-term storage of excess weapons plutonium and the established form of plutonium in the environment. This belief was shaken when Los Alamos scientists reported the formation of $\text{PuO}_{2.25}$ through the reaction of PuO_2 with water vapor in 2000. This reaction was accompanied by evolution of H_2 gas, which initiated intense interest surrounding gas generation during storage and transport of excess weapons plutonium.

The Los Alamos Seaborg Institute organized a series of workshops to discuss the status of the structure, properties, and reactivity of PuO_2 and other oxides. Subsequent workshops discussed how the new data and a strong technical understanding ensure the safe and proper stewardship of actinide oxide materials. Although originally controversial, the formation of PuO_{2+x} is now widely accepted by the international actinide-science community, and its formation is included in modern thermodynamic models. The structural arrangement of atoms, the role of impurities in gas generation, and the role of radiolysis are still important topics under study today. A summary of important findings is described in the *Actinide Research Quarterly* 2nd and 3rd quarters 2004.

Postdoctoral Fellows Program

The Institute's Postdoctoral Fellows Program provides a broad intellectual community for actinide science in support of Laboratory missions and creates a mechanism to attract and retain a future generation of actinide scientists and engineers. The program also fosters sustained excellence and enhanced external visibility in actinide science.

Seaborg postdoctoral fellows perform research that supports new actinide science at the single-investigator or small-team level in the areas of actinide physics, chemistry, metallurgy, sample production, experimental-technique development, theory, and modeling. Funded by the Laboratory Directed Research and Development Program,



These photos show a wide variability in color and general appearance for samples of plutonium dioxide. This variability in the appearance of plutonium dioxide samples is well known, and while the material is normally olive green, samples of yellow, buff, khaki, tan, slate, and black are also common. It is generally believed that the color is a function of chemical purity, stoichiometry, particle size, and method of purification.

Seaborg postdoctoral fellows are selected in a highly competitive process and are supported half time by the Institute and half time by program support provided by their mentors.

Recent Seaborg postdoctoral fellows have conducted research in several LANL divisions, including Materials Science and Technology, Earth and Environmental Science, Theoretical, Chemistry, Nuclear Materials Technology, and Materials Physics and Applications. Their research has included studies of electron correlations in neptunium, the synthesis of actinide organometallic compounds (compounds with metal-carbon bonds), phase transformations and energetics in plutonium, covalency within *f*-element complexes, radiation-damage effects in uranium-bearing delta-phase oxides, thermodynamic measurements of actinides, and structure and property relationships in actinide intermetallic alloys (alloys with a super-lattice crystal structure, unlike conventional alloys).

Heavy Element Chemistry

The Institute leads the DOE Office of Basic Energy Sciences Heavy Element Chemistry Program at Los Alamos. The central goal of this program is to advance the understanding of fundamental structure and bonding in actinide materials.

The actinide series marks the emergence of *5f* electrons in the valence shell. Whether the *5f* electrons in actinide molecules, compounds, metals, and some alloys are involved in bonding has been the central and integrating focus for the fields of actinide chemistry and physics. In the pure elements, those to the left of plutonium in the periodic table have delocalized (bonding) electrons and elements to the right of plutonium are localized (non-bonding). Plutonium is trapped in the middle, and for the delta-phase metal, the electrons are in an exotic state of being neither fully bonding nor localized, which leads to

The purpose of the Institute is to provide a focus for transactinium science, to develop and maintain US preeminence in transactinium science and technology, and to help provide an adequate pool of scientists and engineers with expertise in transactinium science.

novel electronic interactions and unusual physical and chemical behavior. The issues surrounding localized or delocalized *5f* electrons pervade the bonding descriptions of many actinide molecules and compounds, and the degree to which *5f* electrons participate in chemical bonding in molecular compounds is unclear. In the normal nomenclature of chemistry, the delocalized electrons are those involved in covalent bonding, while the localized electrons give rise to ionic behavior.

The Los Alamos approach to understanding covalency and electron correlation in actinide molecules and materials is to combine synthetic chemistry, sophisticated spectroscopic characterization, and advanced theory and modeling to understand and predict the chemical and physical properties of actinide materials. This multidisciplinary approach is an established strength at Los Alamos and provides the scientific means to formulate rational approaches to solve complex actinide problems in a wide variety of environments.



Seaborg points to the element 106, seaborgium, on the periodic table of the elements. He is the only person to have a chemical element named for him during his lifetime.

Nuclear Energy

Plutonium is the linchpin of any future nuclear-energy strategy. It is a byproduct from “burning” uranium in a nuclear reactor. Next-generation nuclear fuel cycles are designed to safely use and recycle nuclear fuels to enhance energy recovery and dispose of waste more efficiently. Safety and waste management, as well as robust safeguards to limit proliferation, are issues that will be addressed internationally to enable long-term sustainability of nuclear power. A combination

of technologies is currently being developed to achieve these long-term goals, and further efforts are required in fundamental research, particularly in the scientific fields related to the light-actinide elements, which make up the first half of the actinide series.

The Seaborg Institute has formally contributed to the development of nuclear-energy programs at Los Alamos and nationally since 2001.

The Future of Los Alamos as a Center of Excellence

Los Alamos will remain the center of excellence for nuclear-weapons design and engineering as well as plutonium research, development, and manufacturing under NNSA’s complex transformation. As NNSA’s weapons-complex transformation reduces the size of the nuclear-weapons program, the Laboratory must maintain the breadth of capabilities that support stockpile stewardship and nuclear deterrence. At the same time, Los Alamos must also produce innovative discoveries that will lead to new missions in plutonium science and engineering and provide the capabilities to address future technological challenges. **NW**

Points of contact:

David L. Clark, 505-665-6690, dlclark@lanl.gov

Gordon D. Jarvinen, 505-665-0822, gjarvinen@lanl.gov

Albert Migliori, 505-667-2515, migliori@lanl.gov

Glenn T. Seaborg

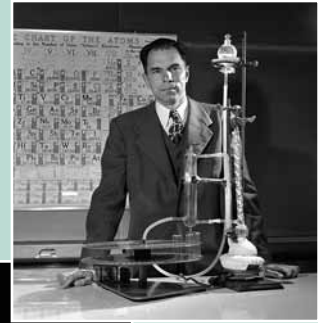
The 1930s and early 1940s were exciting times on the University of California's Berkeley campus. Ernest O. Lawrence and M. Stanley Livingston invented the cyclotron there in 1931, giving researchers a tool with which to bombard various elements with intense, high-energy beams of neutrons or deuterons in order to produce nuclear reactions. Before the cyclotron was invented, only very weak beams of subatomic particles—produced by natural sources, e.g., radium—were available for such research.

The nuclear reactions produced by the cyclotron's intense beams produced many new elements and isotopes. Nearly all were radioactive.

Glenn T. Seaborg was inspired to enter the new field of transuranium elements—whose purview is elements heavier than the heaviest known natural element, uranium (atomic number 92)—soon after he arrived at Berkeley for graduate studies and heard of Enrico Fermi's 1934 experiments in Rome in which uranium was bombarded with a weak beam of high-energy neutrons. Fermi's group thought the radioactive products of these experiments were isotopes of transuranium elements, which had never been seen before. In 1939, Otto Hahn and Fritz Strassman showed that the products were in fact two approximately equal-sized nuclear fragments, certainly not transuranium elements. These German scientists provided the first experimental evidence that these nuclear fragments were instead the result of nuclear fission—and reason to think an atomic bomb could be built.

Seaborg received his doctorate in chemistry from Berkeley in 1937 at age 25. His thesis experiment provided what was probably the first unequivocal evidence that neutrons could lose energy when they scattered from atomic nuclei. Remaining at Berkeley as Gilbert Lewis' laboratory assistant, Seaborg collaborated with physicists Jack Livingood and Emilio Segre to discover several radioactive isotopes used by other researchers to perform groundbreaking biological and medical studies shortly after the new isotopes were discovered.

A portrait of Seaborg in his laboratory at Berkeley.



Seaborg and Segre present the one-half-microgram sample of plutonium to the Smithsonian Institution in 1966.

Meanwhile, Lawrence had been steadily making bigger and bigger cyclotrons to increase their beam energy. The first working cyclotron, which produced 80-keV protons, was 4 inches in diameter. The 60-inch-diameter cyclotron, which began routine operation in February 1939, produced 16-MeV deuterons. (A deuteron consists of a proton bound with a neutron.) The 60-inch cyclotron was used to make the first two transuranium elements—neptunium and plutonium.

In 1940, Edwin McMillan and Philip Abelson bombarded natural uranium—which is mostly uranium-238—with neutrons from the 60-inch Berkeley cyclotron. One product of these experiments was an isotope with atomic number 93, atomic mass 239, and a half-life of 2.5 days (later revised to 2.356 days). When an atom of uranium-238 was bombarded with the cyclotron's neutrons, it sometimes absorbed one of them to become uranium-239, which then decayed, with a half-life of 23.45 minutes, by emitting an electron to become the first known transuranium element. McMillan named it neptunium, because Neptune is the next planet after Uranus, after which uranium had been named 150 years earlier.

McMillan then began looking for the decay product of neptunium-239. According to calculations, it would be an isotope with atomic

number 94 and atomic mass 239. He didn't find anything, so he assumed (correctly) that the half-life of the decay product he sought must be very long. Hoping to find a short-lived isotope with atomic number 94, McMillan began bombarding uranium with deuterons from the 60-inch cyclotron instead of neutrons. The experiment was cut short when he was called to the Massachusetts Institute of Technology to work on wartime radar.

Seaborg continued McMillan's experiment, along with Arthur C. Wahl, one of Seaborg's two graduate students, and Joseph W. Kennedy, a fellow Berkeley instructor. The team soon tentatively identified an isotope with atomic number 94, atomic mass 238, and a half-life of approximately 50 years (later revised to 87.74 years), but felt they didn't have enough proof to announce the discovery of another new element. However, in an experiment that began the night of February 23, 1941, and ran well into the next morning, Wahl confirmed that the isotope's atomic number was in fact 94. A second transuranium element had been found.

Thinking they'd reached the end of the periodic table (which turned out to be false), Seaborg's team considered naming the new element "extremium" or "ultimum," but then decided to follow McMillan's lead and call it plutonium, for Pluto, which at the time was thought to be the next planet after Neptune. They chose "Pu" for the new element's symbol—for its obvious olfactory allusion—although this prank later got much less of a rise from their fellow scientists than they had hoped.

Plutonium-238 decays by emitting alpha particles, which are self-absorbed by the plutonium-238 and heat it, making it an excellent heat source. Plutonium-238 is commonly used to heat a thermoelectric element, which converts heat to electricity used to power equipment onboard spacecraft. For example, the electrical equipment on the two Mars Rovers is powered

by thermoelectric generators heated by plutonium-238 produced at Los Alamos. However, plutonium-238 cannot easily be made to fission and therefore cannot produce the nuclear chain reaction required for a power reactor or a bomb.

But Seaborg and his team also discovered another plutonium isotope. Neptunium-239 decays by emitting an electron to become plutonium-239, whose half-life of 24,100 years explained McMillan's failure to detect it. Early in 1941, Kennedy, Seaborg, Segre, and Wahl found that plutonium-239 fissions when bombarded by neutrons, like uranium-235 does. Thus, plutonium-239 and uranium-235 could potentially be used to make atomic bombs.

Seaborg's team submitted their results to *Physical Review* at the end of May 1941. Because of the war effort, however, the paper was not published until 1946.

During World War II, Berkeley gave Seaborg a leave of absence from his job as a chemistry professor to work at the University of Chicago Metallurgical Laboratory. Seaborg led the group of scientists that developed the chemical extraction process to produce plutonium for the Manhattan Project. The Manhattan Project secretly produced enough uranium-235 and plutonium-239 to make the world's first atomic bombs.

After World War II, Seaborg codiscovered americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, nobelium, and seaborgium. He is the only person for whom a chemical element was named during his lifetime. McMillan and Seaborg shared the 1951 Nobel Prize in Chemistry for discovering the first two transuranium elements.



This cigar box held a one-half-microgram sample of plutonium that Seaborg produced at Berkeley in 1941. Seaborg and Segre presented the sample and its carrier to the Smithsonian Institution.



Backward Glance

During the Manhattan Project, the US Army Corps of Engineers provided all support services, including maintenance and utilities, for the laboratory and the townsite. In 1946, President Truman signed the Atomic Energy Act, which established the Atomic Energy Commission (AEC), a civilian agency. Under the terms of the 1946 act, the AEC was to be the “exclusive owner” of production facilities, but could let contracts to operate those facilities. At midnight on December 31, 1946, Manhattan Project assets transferred to the AEC. In 1947, the AEC began oversight of the Los Alamos Scientific Laboratory and the closed town of Los Alamos.

When the Zia Company was organized in April 1946 to assume support operations for Los Alamos, security was still very tight. Not only were badges required for all office and laboratory workers, but every resident, including children, needed a pass to get through the main gate (formerly a restaurant named Philomena’s and now De Colores on Route 502).

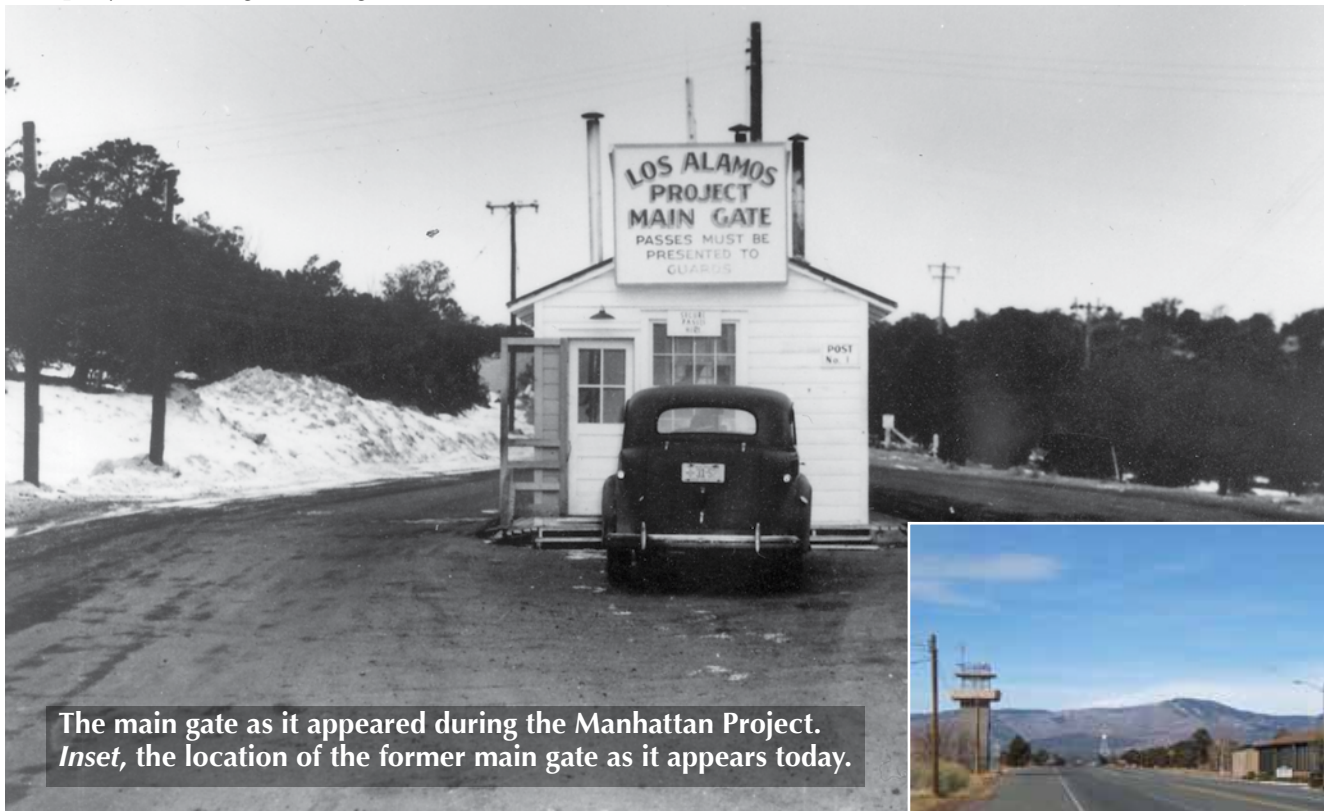
AEC officials decreed that employees of the new Zia Company would be given badge numbers with the

The Origin of the Z Number

prefix “Z.” Until then, everyone had US Army security credentials. The protective force badge office slipped the letter Z and the number 00001 into its camera and the word went out to the Zia office for employees to report to the badge office and receive a new badge. When US Army numbers were dropped, other Los Alamos residents were given “Z” numbers too.

As the property management agent for the AEC, the Zia Company furnished plumbers and other craftsmen around the clock to repair furnaces, roof leaks, or whatever else might go wrong. Among other services, Zia workers installed clotheslines, planted trees, painted rooms, and changed light bulbs. In 1966, all residences were sold and then Los Alamos residents had to do their own maintenance or call commercial craftsmen.

Los Alamos National Laboratory still assigns Z numbers to employees. A “Z” number is a permanent employee number assigned to only one person. This number identifies the employee throughout his or her career at the Laboratory and is the same number even if the employee should return decades later. *NWJ*



The main gate as it appeared during the Manhattan Project. *Inset*, the location of the former main gate as it appears today.



Presorted Standard
U.S. Postage Paid
Albuquerque, NM
Permit No. 532

Nuclear Weapons Journal
PO Box 1663
Mail Stop A142
Los Alamos, NM 87545

Issue 2 2009 LALP-10-001

Nuclear Weapons Journal highlights ongoing work in the nuclear weapons programs at Los Alamos National Laboratory. *NWJ* is an unclassified publication funded by the Weapons Programs Directorate.

Managing Editor-Science Writer
Margaret Burgess

Editorial Advisor
Jonathan Ventura

Send inquiries, comments, subscription requests,
or address changes to nwpub@lanl.gov or to the

Designer-Illustrator
Jean Butterworth

Technical Advisor
Sieg Shalles

Nuclear Weapons Journal
Los Alamos National Laboratory
Mail Stop A142
Los Alamos, NM 87545

Science Writers
Brian Fishbine
Octavio Ramos

Printing Coordinator
Lupe Archuleta

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Los Alamos National Security, LLC, for the National Nuclear Security Administration of the US Department of Energy under contract DE-AC52-06NA25396.



This publication was prepared as an account of work sponsored by an agency of the US Government. Neither Los Alamos National Security, LLC, the US Government nor any agency thereof, nor any of their employees make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by Los Alamos National Security, LLC, the US Government, or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of Los Alamos National Security, LLC, the US Government, or any agency thereof. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.