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Message from the Assistant Deputy Administrator, Office of Stockpile Stewardship, Chris Deeney

Welcome to the first edition of the quarterly for the Office of Stockpile Stewardship, NA-11. With our newly approved reorganization, we wanted to build on the success of the *Defense Science Quarterly* and produce a newsletter that covers the breadth of NA-11. Thanks to everyone who contributes to our newsletter and to the NNSA headquarters team that publishes it.

New is an appropriate word to describe this first edition, but it really highlights all of the new technologies and science that have been developed in the Stewardship and Institutional programs. Two of our new facilities are discussed in this issue. NIF received the Project Management Institute's Project of the Year Award—well done to the Lawrence Livermore National Laboratory (LLNL) team and its host of strategic partners. The Dual Axis Radiographic Hydrodynamic Test facility really demonstrated what an exceptional new radiographic tool that it is. Four very successful shots supporting Directed Stockpile Work and Advanced Certification were conducted this year. Pulsed power is also providing a new capability to measure shear strength. All of these examples remind us that the important challenge of stewardship is to be both technically demanding and innovative. The Advanced Simulation and Computing program is a direct result of this fact.

The power of our new petaflop computing abilities was very impressively shown in tour de force calculations of laser plasma interactions (LPI) on Roadrunner. Approximately 0.4 trillion particles and 2 billion cells have enabled 3-D calculations that can model stimulated Raman scattering at scale. LPI remains an area of great interest for the National Ignition Facility and the new generation of petawatt lasers.

In support of research directions elucidated in the 2010 report, *New Worlds and New Horizons in Astronomy and Astrophysics*, the LLNL Laboratory Directed Research and Development program is capitalizing on its optics, data analysis and computing strengths to develop science and technologies in support of next generation ground-based telescopes. Space-based x-ray telescopes are also providing more insight into the evolution of our universe, SNL is exploiting its strength in z-pinch-based x-ray sources and spectroscopy to provide new methods to explore some of the oldest stars, white dwarfs.

Please enjoy reading this quarterly. Relevance and quality continue as a hallmark of our program, and the new NA-11 organization is proud and privileged to be the Washington, DC champion of this work. We are all committed to the success of stewardship, and our new office, Nuclear Experiments, headed by Dr. Robert Hanrahan, will be the champion of a better integrated and operationally more efficient hydrodynamic program across the laboratories and sites, including all our dynamic plutonium work (see page 3). Let's work together to make sure that FY 2011 is the year that sets the standard of high quality success for the new NA-11 organization!

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Understanding the Nonlinear Physics of Laser-Plasma Interaction Through "at-Scale" Plasma Kinetic Simulations on Roadrunner

by Lin Yin, Brian J. Albright, Ben Bergen, and Kevin J. Bowers (Los Alamos National Laboratory)

Inertial confinement fusion (ICF) experiments have commenced at the National Ignition Facility (NIF), launching a campaign that will extend over many years. In these experiments, over a million joules of laser energy are focused within a gas-filled hohlraum. The hohlraum walls absorb the laser energy and re-radiate it as x-rays, which are absorbed by a spherical capsule at the hohlraum center. This causes the capsule to compress, bringing the deuterium-tritium fuel to the high temperatures and pressures required for thermonuclear fusion.

To prevent the hohlraum walls from ablating during the ~10^{-8}-second laser drive, a fill gas of hydrogen or helium is used. As the laser propagates through the fill gas, laser-plasma instabilities (LPI) may arise, which scatter laser light out of the hohlraum, degrade capsule implosion symmetry, and preheat the fuel with hot electrons, making compression harder to achieve.

Stimulated Raman scattering (SRS), the resonant amplification of electron density fluctuations by a laser, is one of the LPI concerns in ICF. In ICF experiments, a roughly uniform laser intensity is maintained across the beam with random phase plates that break the beam into an ensemble of laser speckles. For the success of fusion experiments on the NIF, we must first understand the physics of onset and saturation of SRS in the fundamental building block of a NIF laser beam, a single laser speckle. In a laser speckle, SRS manifests as the amplification of a forward directed electron plasma wave (EPW) and the backward scattering of laser light. Unlike the linear growth of SRS, the nonlinear physics was not well understood until recently[1]. Simulations on the 1.4 petaflop Roadrunner supercomputer have been used to assess the impact of the nonlinear SRS physics on laser penetration and energy deposition in fusion experiments. These fully kinetic plasma simulations employ the VPIC particle-in-cell code[2] and are performed in large plasma volumes in three dimensions (3D) at an unprecedented range of time and space scales.

Until recently, it has not been possible to fully simulate the comparatively large three-dimensional (3-D) plasma volumes of laser speckles. With VPIC on Roadrunner, simulations of the NIF holhraum plasma have been done using 4096 Cell chips at a range of laser intensity values (see the Figure 1 inset). This study is only possible on a petaflop-scale supercomputer like Roadrunner, where at-scale kinetic simulations of laser-plasma interaction in 3D at realistic laser speckle and multispeckle scales can be done at unprecedented size, speed, and fidelity.

These simulations[3] showed that SRS reflectivity within a solitary speckle exhibits nonlinear behavior, i.e., a sharp onset at a threshold intensity, whereby reflectivity increases abruptly to a level orders of magnitude higher than linear theory predicts over a small range of intensity, with a plateau in reflectivity at higher laser intensity in which SRS non-linearly saturates. This generic behavior matches that measured in single speckle experiments at the Los Alamos National Laboratory Trident laser facility[4] with physics that cannot be captured by linear gain models of SRS growth within the speckle.

As a highlight of the unique simulations afforded by Roadrunner, the largest of these calculations was run on 16 Connected Units (CUs) using 11,520 ranks, nearly the full Roadrunner system, and employed a record 0.4 trillion particles, over 2 billion computational cells, and ran for nearly 58,160 time steps (~10^{19} floating point operations), long enough for two bursts of SRS to grow from noise to significant amplitude at a laser intensity near the SRS onset. Figure 1 shows isosurfaces of electrostatic field associated with these bursts; the wavefronts exhibit bending or "bowing," arising from nonlinear electron trapping, as well as self-focusing, which breaks up the phase fronts.

The essential nonlinear physics governing SRS saturation has now been identified. The scattering manifests as a series of pulses, each of which passes through the four distinct phases that follow. (1) SRS grows linearly from density fluctuations. (2) Electrons trapped by the EPW reduce the wave frequency and phase velocity by an amount that scales with EPW amplitude. (3) Near the speckle center, where the amplitude is highest, the EPW phase velocity is lower than at the speckle's edge; EPW phase front bending ensues as shown by the top image in Figure 2. (4) The EPW amplitude exceeds the electron trapped particle

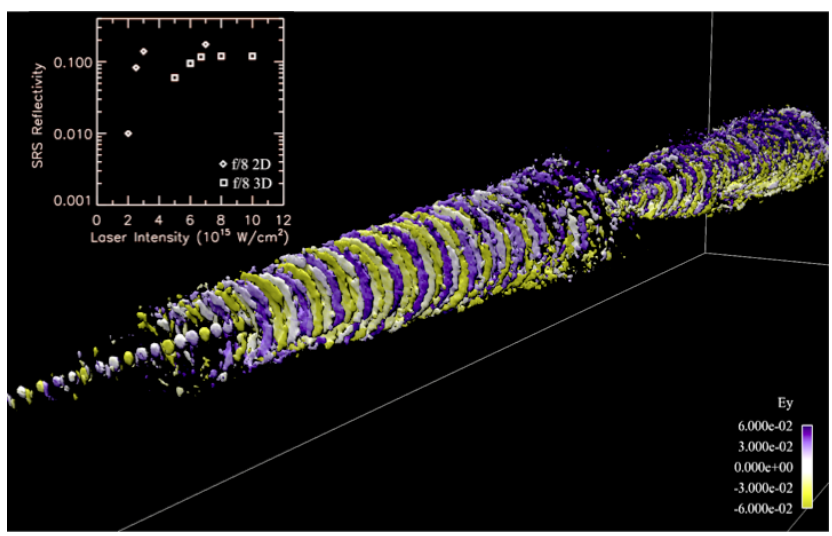

Figure 1: Single-speckle LPI calculations using 16 CUs of Roadrunner (11,520 ranks), nearly the full system; this calculation employed a record 0.4 trillion particles, >2 billion cells, and ran for nearly 58,160 time steps (~10^{19} floating point operations), long enough for two bursts of SRS to grow from noise to significant amplitude at a laser intensity near the SRS onset. The inset shows the scaling of SRS reflectivity versus laser intensity for 2-D and 3-D VPIC calculations; in 3D, the onset threshold is higher, owing to increased side loss of hot electrons from laser speckles.

modulation instability (TPMI) threshold[5]. TPMI generates waves off-axis from the laser direction and leads to EPW filamentation, self-focusing and phase front breakup, shown by the bottom image in Figure 2. Self-focusing increases transverse loss of trapped electrons and increases EPW damping.

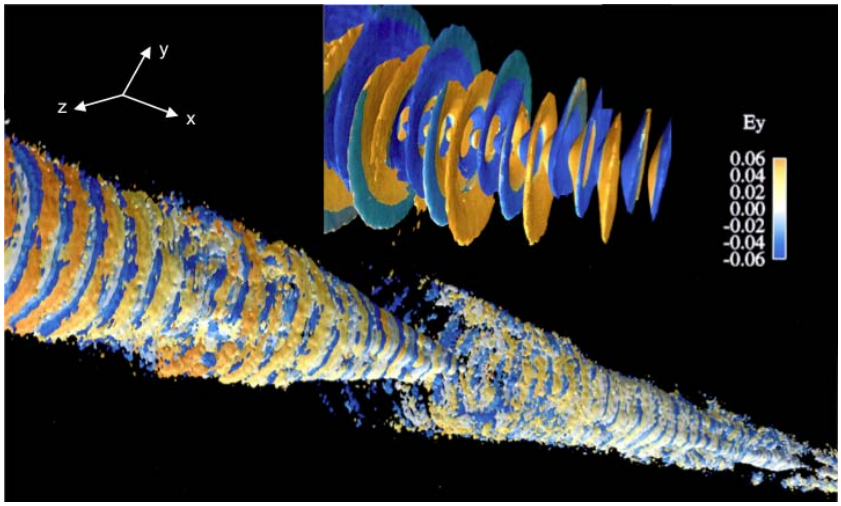

Figure 2: *Top* - A snapshot taken from a 3-D VPIC LPI simulation at SRS pulse saturation of a f/4 laser beam, showing bending of isosurfaces of EPW electric field across the speckle. The iso-surfaces are colored by the laser electric field intensity, graphically showing the source for SRS backscatter has become incoherent. *Bottom* - Self-focusing and filamentation in two bursts of SRS, a snapshot taken from a 3-D VPIC LPI simulation of an f/8 laser beam. The speckle volume is 16x larger than the f/4 simulation, permitting more transverse self-focusing modes to develop. This leads to chaotic EPW phase variation across the speckle. This further reduces SRS source coherence and increases wave damping, quenching the SRS pulse.

From these basic science simulations, researchers are now able to understand better the essential nature of LPI nonlinear onset and saturation. Current research focuses on determining whether neighboring speckles can interact via exchange of hot electrons or waves to produce higher backscatter than they would individually, the kind of study only possible on a supercomputer like Roadrunner, where "at scale" kinetic simulations of laser-plasma interaction in 3D at realistic laser speckle and multi-speckle scales can be prosecuted at unprecedented size, speed, and fidelity.

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Implosion Subcritical Experiment Planned for 2012

NNSA's Defense Programs office recently reorganized oversight of the hydrodynamic and subcritical experiments programs under a single office, Nuclear Experiments, NA-115. The intent of this office is to coordinate the long-term program of hydrodynamic experiments using surrogate materials, subcritical experiments using plutonium, along with a robust program aimed at understanding the underlying physics of the materials and components in nuclear weapons. These efforts will continue to be closely coordinated with the Boost Initiative through the Predictive Capability Framework (PCF). As one of its first actions, NA-115 has requested a JASON study. The JASON group will be asked to look at the current plans from the NNSA laboratories for hydrodynamic and subcritical experiments to make recommendations for the future efforts using all of the available experimental facilities and platforms.

The first major challenge for NA-115 is the execution of the next subcritical experiment on an accelerated schedule in order to demonstrate responsiveness and linkage to the Boost Initiative and PCF. A proposal by the Los Alamos National Laboratory has been selected for this experiment; it will be conducted at the Nevada National Security Site by September 2012. The primary diagnostic for the first shot will be photon Doppler velocimetry with the CYGNUS radiographic machine providing corollary data. The objective of this experiment is to test the predictions for the initial conditions of primary implosion. The pre-shot predictions of this experiment will be linked to a longstanding level 1 milestone for initial conditions for Boost planned through the PCF.

ASC Alliance Center Deputy Director Receives Presidential Early Career Award for Scientists and Engineers (PECASE)

The Office of Stockpile Stewardship congratulates 2009 PECASE award winner Gianluca Iaccarino, Ph.D., Deputy Center Director of the NNSA Predictive Science Academic Alliance Program (PSAAP) Center at Stanford University. Iaccarino was selected for his extensive and deep scientific contributions in the areas of turbulent flow and uncertainty quantifications and quantified margins of uncertainty, which are amplified for the NNSA community through his position of intellectual leadership at the PSAAP. He is one of 13 DOE researchers, and one of the 85 researchers supported by 10 federal departments and agencies, to receive the award for 2009. Each recipient of the once-in-a-career award received a citation and plaque and will continue to receive DOE funding for up to five years to advance his or her research. The recipient scientists and engineers received their awards at a White House ceremony on December 13, 2010.

Radiative Properties of Astrophysical Matter: A Quest to Reproduce Astrophysical Conditions on Earth

by J.E. Bailey** (Sandia National Laboratories)

Experiments in terrestrial laboratories can be used to evaluate the physical models that interpret astronomical observations. The properties of matter in astrophysical objects are essential components of these models, but terrestrial laboratories struggle to reproduce the extreme conditions that often exist. Megajoule-class DOE/NNSA facilities such as the National Ignition Facility and Z can create unprecedented amounts of matter at extreme conditions, providing new capabilities to test astrophysical models with high accuracy. Experiments at these large facilities are challenging, and access is very competitive. However, the cylindrically-symmetric Z source emits radiation in all directions, enabling multiple physics experiments to be driven with a single Z discharge (see Figure 1). This helps ameliorate access limitations. This article describes research efforts under way at Sandia National Laboratories' Z facility investigating radiation transport through stellar interior matter, population kinetics of atoms exposed to the intense radiation emitted by accretion powered objects, and spectral line formation in white dwarf (WD) photospheres.

Opacity quantifies the absorption of radiation by matter and strongly influences stellar structure and evolution, since radiation dominates energy transport deep inside stars. Opacity models have become highly sophisticated, but laboratory tests at the conditions existing inside stars have not been possible—until now. Z research is presently focused on measuring iron absorption at conditions relevant to the base of the solar convection zone, where the electron temperature and density are 190 eV and 9×10^{22} e/cc, respectively. Creating these conditions in a sample that is sufficiently large, long-lived, and uniform is extraordinarily challenging. A source of radiation that streams through the relatively-large samples can produce volumetric heating and thus, uniform conditions, but to achieve high temperatures a strong source is required. Z dynamic hohlraums provide such a megajoule-class source (see Figure 2). Initial Z experiments measured transmission through iron samples ionized to the same charge states that exist at the solar convection zone base (see Figure 3). The resulting data made it possible to test challenging aspects of the opacity calculations such as the ionization balance and the completeness and accuracy of the atomic energy level description. However, the density was too low to provide a definitive test of the physics at the solar convection zone base. Recent experiments have reached higher densities, and opacity model tests for stellar interiors now appear within reach.

Accretion powered objects, including active galactic nuclei, x-ray binaries, and black hole accretion disks, are the most luminous objects in the universe. Astrophysical models for these objects rely largely on comparing spectroscopic predictions with observations. A dilemma arises because the spectra originate from plasmas that are bathed in the enormous photon flux from the accretion disk and photoionization dominates the atomic ionization and energy level populations. Thus, constraining astrophysical models depends on accurate atomic models for photoionized plasmas. Unfortunately, to date the ionization in almost all laboratory experiments is collision-dominated and very few tests of photoionized plasma atomic kinetics exist. Megajoule class high-energy-density facilities can help because they generate higher x-ray fluence over larger spatial scales and longer times. Expanded iron foils and pre-filled neon gas cells have been used in experiments at Z to study photoionized atomic kinetics in two elements commonly observed in astrophysical objects. In these experiments, low density samples are exposed to a measured intense x-ray spectrum, emergent emission or absorption spectra are recorded, and the results are compared to predictions made with spectral synthesis codes used by astrophysicists. Initial experiments focused on testing models used to interpret spectra from the "warm absorber," a plasma observed in the vicinity of some active galactic nuclei. In future experiments, spectra from plasmas exposed to higher radiation intensities will be measured, possibly leading to improved understanding of the plasma in the immediate vicinity of the accretion disk.

WDs are the oldest stars and can serve as cosmic clocks, since the universe must be at least as old as the objects within it. Astrophysicists determine WD ages using stellar models

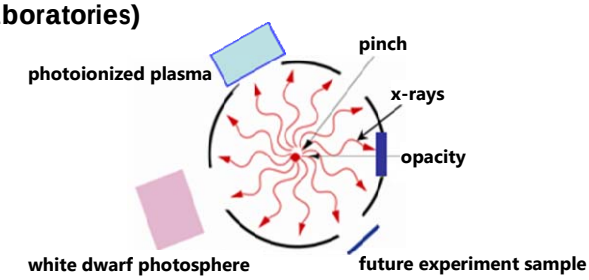


Figure 1: Top view showing multiple physics experiments conducted in a single Z discharge. An additional opacity sample is

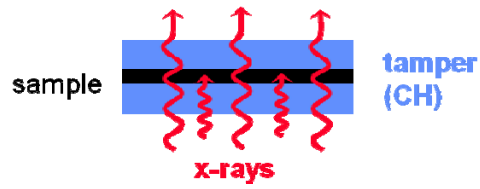


Figure 2: X-rays stream through a sample and heat it volumetrically. This improves uniformity, a key aspect of material property experiments because it enables comparison with models at a single temperature and density. For opacity experiments, the transmission is measured by positioning a backlight source below the sample and measuring the transmitted spectrum with a spectrometer positioned above the source.

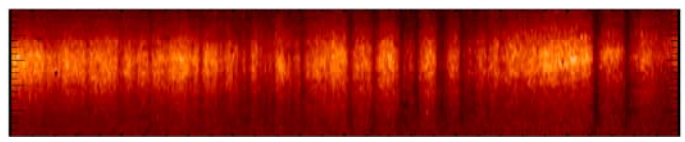


Figure 3: Transmission through iron heated to 156 eV. The x axis corresponds to photon energy and brighter parts of the image correspond to photon energies with higher transmission, or lower opacity. The dark lines are absorption by the discrete bound-bound atomic transitions prescribed by quantum mechanics.

combined with effective temperature (T_{eff}) and mass inferred from spectral observations of WD photospheres. Many line profiles in the observed spectra are dominated by Stark broadening, a process sensitive to the photosphere density and related to the total mass through the stellar model. Accurate Stark broadening theory is, therefore, critical to the precise determination of the WD properties and the inferred ages. The WD spectral interpretations are inconsistent with gravitational redshift measurements at all temperatures and break down completely at low T_{eff}, leading to unphysical results. Inaccuracy in the Stark broadening theory is currently the leading hypothesis for explaining this breakdown, which may result in significant errors to WD cosmochronology. Using Z, we are performing the first Stark broadening model tests using x-ray heated plasmas. Previous tests were quite rare and they used arc or pinch plasmas with gradients that complicated the interpretation. The advantages of these x-ray heated plasmas include uniform conditions, independent density control, adjustable path length, and freedom from turbulence. Without megajoule-class facilities, such measurements were impossible because x-ray heating of multi-centimeter-scale gas cells at the required density is inherently inefficient. Preliminary Z experiments have already provided new Stark-broadened hydrogen line spectra. Full development of this platform should provide theoretical plasma spectroscopy benchmarks as well as spectra from a variety of elements urgently needed by astrophysicists who study WD stars.

***This work was performed by a collaboration with essential contributions from G.A. Rochau, S.B. Hansen, T.J. Nash, P.W. Lake, and D.S. Nielsen (Sandia National Laboratories); C.A. Iglesias and D. Liedahl (Lawrence Livermore National Laboratory); M. Sherrill and J. Abdallah Jr. (Los Alamos National Laboratory); J.J. MacFarlane, I. Golovkin, and P. Wang (Prism Computational Sciences); I. Hall, T. Durmaz, and R.C. Mancini (University of Nevada, Reno); C. Blancard, Ph. Cosse, G. Faussurier, F. Gilleron, and J.C. Pain (CEA, France); J. MacArthur, M. Rosenberg, and D. Cohen (Swarthmore College); A.K. Pradhan, S.N. Nahar, and M. Pinsonneault (Ohio State University); R.E. Falcon, J.L. Ellis, D.E. Winget, and M.H. Montgomery (University of Texas); and M.R. Gomez (University of Michigan).*

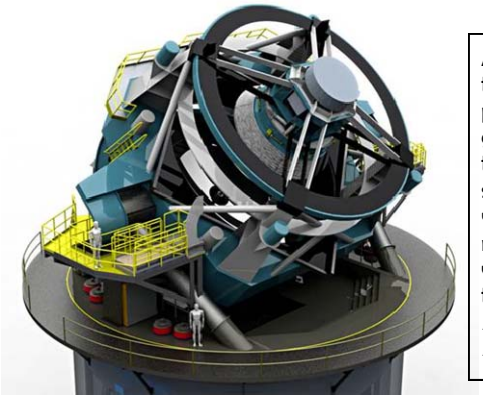
Large Synoptic Survey Telescope Ranked as Top Priority

by Anne M. Stark (Lawrence Livermore National Laboratory)

The Committee for a Decadal Survey of Astronomy and Astrophysics of the National Research Council shined a spotlight on the Large Synoptic Survey Telescope (LSST) in its August 2010 report entitled *New Worlds and New Horizons in Astronomy and Astrophysics*. It ranked LSST as its top priority for the next large ground-based astronomical facility. The committee recommended that LSST be submitted to the National Science Foundation (NSF) for Major Research Equipment and Facilities Construction in order to achieve first light before the end of the decade. The National Optical Astronomy Observatory (NOAO) will continue to have a major role in the design and development phase of the LSST project. Through at least FY 2012, NOAO will remain responsible for telescope and site design and development activities and for operations planning.

Lawrence Livermore National Laboratory (LLNL) has been one of many key players supporting LSST. Starting in FY 2004, NNSA's Livermore Site Office approved several LLNL projects that were funded under the Laboratory Directed Research and Development (LDRD) Program in support of DOE's science mission, the national security mission, and other federal agency missions (NOAO/NSF). The technologies studied under LDRD have a direct relevance to the national security enterprise by enhancing core competencies in physics, math and computing, and optics. Large telescopes and advanced optics are required for the next generation of space surveillance measurements along with high parallel computing. Algorithms and techniques developed under LDRD could enhance nonproliferation capabilities. This has been followed on by several Work for Others projects funded by NOAO.

A LLNL representative serves as the LSST project manager while other scientists helped in the development of the overall optical design, wavefront sensing and guide sensor systems, camera optics and filters. The LSST is scheduled to start



A 2010 rendering of the LSST, a proposed 8.4-meter ground-based telescope that will survey the entire visible sky deeply in multiple colors every week from a mountaintop in Chile. *Photo courtesy of LSST Corp./NOAO*

full operations six years after construction begins, and it is scheduled to be built on the Chilean mountain Cerro-Pachón near Vicuna. The LSST's primary mirror will be 8.4 meters in diameter, and the facility will have the world's largest digital camera (3.2 billion pixels). The system should be able to survey the entire visible sky every week and produce approximately 30 terabytes of data per night. It should enable scientists to view and study objects ranging from hazardous near-Earth asteroids to exploding stars (supernovae), allow them to watch the expansion of the universe, and study dark energy.

Other universities and laboratories supporting LSST are Brookhaven National Laboratory, the California Institute of Technology, Carnegie Mellon University, Cornell University, George Mason University, Harvard's Smithsonian Center for Astrophysics, Johns Hopkins University, Stanford University, Los Alamos National Laboratory, Princeton University, Texas A&M University, Pennsylvania State University, University of Arizona, University of California Davis, University of California Irvine, and the University of Michigan. For more information, contact Carol Morreira at (925) 422-2265 or Jamileh Mogin at (202) 586-2104.

Dual Axis Radiographic Hydrodynamic Test Facility: A Critical Component of Stockpile Stewardship by David Funk and Octavio Ramos (Los Alamos National Laboratory)

The Nuclear Weapons Program at Los Alamos National Laboratory (LANL) is focused on ensuring the safety, reliability, and performance of nuclear weapons in our nation's enduring stockpile. One critical contributor to this mission is the Dual-Axis Radiographic Hydrodynamic Test facility (DARHT): two large x-ray machines that produce freeze-frame radiographs (high-powered x-ray images) of materials that implode at speeds greater than 10,000 mph.

Ten years ago, LANL personnel brought DARHT's first axis online, but it was not until December 2009 that DARHT achieved its first dual-axis, multiframe hydrodynamic test (hydrotest). "You could say that in Fiscal Year 2010, we finally put the 'D' in DARHT," said Mary Hockaday, LANL Deputy Associate Director for Weapons, emphasizing that now the facility has achieved dual-axis, multiframe operation, yielding five radiographs of an imploding mock nuclear device.

During a hydrotest, a "mockup" of the primary stage of a nuclear weapons system is detonated. The mockup consists of actual high explosives and most other components, except for plutonium. Instead, a nonfissile substitute material is used that has similar weight, density, and other metallurgical properties so that it behaves much like the plutonium.

DARHT completed a second successful two-axis, multi-frame hydrotest in July. It was followed by a third test designed by Lawrence Livermore National Laboratory in August and another LANL test in late September.

After the first successful dual-axis test and prior to the next three, DARHT was shut down to complete a months-long maintenance and upgrade project. For example, workers refurbished the second axis injector's 88-stage Marx bank, which consists of a series of 88 large capacitors that can be charged in parallel but are discharged in series, thus yielding extremely high voltage pulses. DARHT's accelerator and execution control rooms also underwent extensive upgrades; workers built a fiber-optic timing and firing communication system which greatly improved reliability. In addition, the facility incorporated energy-efficient, high-definition video monitors.

During a hydrotest, DARHT takes four sequential radiographs on one axis and one radiograph along a perpendicular axis, providing the first-ever simultaneous views of an implosion from two directions. The exposure time of such radiographs—60 billionths of a second—freezes the action of an imploding mockup to much less than a millimeter. To determine the exposure time, scientists take into consideration the radiograph's spatial resolution and the implosion speed.

Along with other tools such as advanced laser interferometers and electronic position indicators, DARHT produces data sets during these hydrotests that are used to verify computer codes for nuclear weapons. The data sets of full-scale implosions are compared to simulations derived from the computer codes. Such comparisons are key in certifying the U.S. nuclear deterrent, thus enabling the United States to certify the stockpile without recourse to underground nuclear testing. The data also helps scientists address the safety, security, and performance of nuclear weapons.

With DARHT fully operational and producing successful dual-axis hydrotests, we can now study full-scale mockups of how nuclear primaries explode. The results of these studies will help improve and verify computer models, which in the absence of actual nuclear testing are critical in assessing the effects of aging and remanufactured nuclear weapons. DARHT and its data-rich radiographs supply real-world validation for the codes and, thus, effectively enhance the confidence and credibility of stewardship efforts designed to ensure the national security of the United States.

NNSA National Labs Win 15 R&D 100 Awards

R&D Magazine presented R&D 100 Awards to Lawrence Livermore National Laboratory (6), Los Alamos National Laboratory (5), Sandia National Laboratories (4), and Y-12 National Security Complex (1) in November. Sometimes referred to as the "Nobel Prizes of technology," the R&D 100 Awards recognize the best technical advances at universities, private corporations, and national laboratories around the world.

2010 Most Promising Engineer/Scientist Award

Dr. Angel Urbina of Sandia National Laboratories is the recipient of the 2010 Hispanic Engineer National Achievement Awards Corporation (HENAAC) Award for Most Promising Engineer/Scientist, Graduate Degree. For the past 12 years, Dr. Urbina has developed modeling and algorithm processes for validating predictive accuracy and uncertainty in computational simulation, particularly focusing on problems in structural dynamics for program mission areas such as nuclear weapons.

National Ignition Facility Pushes Beyond the State of the Art by Trish Baisden and Rose Hansen (Lawrence Livermore National Laboratory)

Lawrence Livermore National Laboratory's (LLNL) National Ignition Facility (NIF), the world's largest and most energetic laser facility, received worldwide recognition for excellence in project management when the Project Management Institute (PMI) presented NIF with the prestigious 2010 Project of the Year award in October. This international award recognizes the year's most innovative and successful project. PMI cited NIF's groundbreaking technical achievement and exemplary management in its award decision.

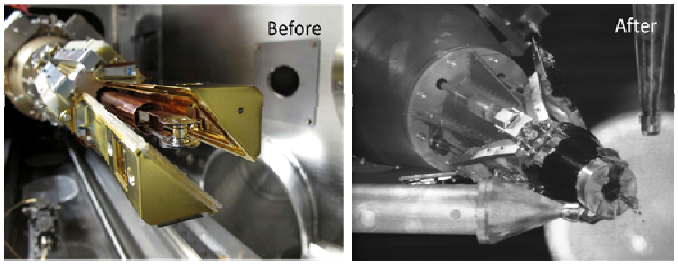
Each year, PMI selects three finalists for the award. Other 2010 finalists were the Dallas Cowboys Stadium (Arlington, Texas) and the state-of-the-art Norton Brownsboro Hospital (Louisville, Kentucky)—chosen from worldwide nominees to recognize for exemplary project management. However, only one finalist is designated "Project of the Year." Past winners have included such diverse projects as the Salt Lake City 2002 Olympic Games, the Mars Pathfinder, and expansion of the Los Angeles International Airport.

Partnerships Made the NIF Project Possible

As the 2010 recipient, NIF was honored as a facility "pushing beyond the state of the art," bringing together scientists, engineers, construction workers and contractors, vendors, safety technicians, systems managers, and administrators to successfully complete the $3.5 billion project. "The NIF project was accomplished by a worldwide partnership among governments, academia, and our many industrial partners," said LLNL Director George Miller. "NIF's success can be attributed to its excellent team of scientists, engineers, technicians and support personnel; to the rigorous application of best-practice project management standards, processes, and techniques; and to highly productive teamwork with the National Nuclear Security Administration, the Department of Energy, and our partners."

NIF was built as a part of the NNSA's program to ensure the safety, security, and effectiveness of the nuclear weapons stockpile without underground testing. With NIF, scientists will be able to evaluate key scientific assumptions, obtain previously unavailable data on how materials behave at temperatures and pressures like those in the center of a star, and help validate NNSA's supercomputer simulations by comparing code predictions against laboratory observations. Other missions include advancements in fusion energy and enabling scientists to better understand the makeup of stars in the universe and planets both within and outside of our solar system.

LLNL Director George Miller (left) and NIF Principal Associate Director Ed Moses (center), with DOE Deputy Secretary Daniel Poneman (right), receive the 2010 Project Management Institute Project of the Year award on October 9, 2010.



The first layered cryogenic target before and after being shot at the National Ignition Facility.

On the Path Towards Fusion Ignition

NIF began full operations in March 2009 and has been ramping up laser power and experiment complexity ever since. NIF reached a major milestone on September 29, 2010 with the completion of its first integrated ignition experiment. This launched a series of laser shots that will lead up to conducting full-scale ignition experiments—that is, fusion with energy gain. All 192 laser beams fired 1 megajoule of laser energy into the first cryogenically layered capsule. This capsule used a mixture of tritium, hydrogen, and deuterium tailored to enable the most comprehensive physics results in a necessary step towards demonstrating fusion ignition. All systems operated successfully, and 26 target diagnostics participated in the shot. These diagnostics captured valuable data necessary to support successive shots planned in the phased ignition program. From a system integration point of view, the experiment met all objectives, and the preliminary results of the target performance were encouraging.

Using layered targets also represents significant progress in NIF's ability to field complex experiments in support of its missions. This achievement was a direct result of the collaborative effort among LLNL's National Ignition Campaign partners—the Laboratory for Laser Energetics at the University of Rochester, Los Alamos National Laboratory, Sandia National Laboratories, and General Atomics—as well as contributions from institutions and organizations such as the Massachusetts Institute of Technology, the Atomic Weapons Establishment in the United Kingdom, and the Commissariat à l'Energie Atomique in France.

Plutonium Experiment on Z

On November 18, Sandia National Laboratories (SNL), along with Los Alamos National Laboratory, performed the first plutonium experiment on the Z machine in four years. The experiment is a continuation of studies performed at SNL prior to the major refurbishment of the Z machine to increase the output of electrical energy.

Publication Highlights by Douglas Drake

This section summarizes recent publications in high-impact scientific journals of research that are supported by the NNSA Science Campaigns.

***Design of a Rayleigh-Taylor Experiment to Measure Strength at High Pressures*,** K. McKaelian, Lawrence Livermore National Laboratory, Physics of Plasmas 17, September 2010

The author proposes a method for conducting experiments designed to measure the strength of a metal at extreme conditions using the Rayleigh-Taylor instability. He notes that the mechanical properties of materials at extremely high pressures are difficult to measure using static techniques such as diamond anvil cells, which become theoretically impractical above about 5 Mbar, and are usually not implemented in experiments at pressures greater than approximately 1 Mbar. Measurements at significantly higher pressure would be useful for a number of industrial applications, and for planetary and geophysical research, and are also of interest to the weapons science community. A dynamic measurement technique is proposed that could be implemented on the NIF. Such techniques are more difficult to apply because samples must be compressed while their properties are interrogated simultaneously. However, they have already been implemented successfully in magnetic compression experiments on Z and in isentropic compression experiments on OMEGA and Z to study the strength and equation of state of a range of materials, including beryllium, vanadium, tantalum and diamond. In the proposed experimental design, x-rays would be absorbed in a high-Z-doped ablator, generated by a laser pulse temporally shaped to drive a series of shocks into the sample. Strength would be measured by the growth of Rayleigh-Taylor driven perturbations. The method would have the advantage of using exactly the same pulse intended for the first series of ignition experiments out to a time of about 16 ns, allowing experiments to "piggyback" the experience gained in ignition shots. However, radiation temperatures would be constrained to 140 eV as opposed to around 300 eV for ignition shots, making the target design somewhat more challenging but allowing use of a canonical ignition pulse as is. A novel experimental approach is suggested that would not require machining of the target surface with precise perturbations. Instead, it could be left flat, allowing experiments with crystalline materials, and surfaces on which machining might be too damaging or too invasive.

***Multi-keV X-ray Source Development Experiments on the National Ignition Facility*,** K.B. Fournier et. al., Lawrence Livermore National Laboratory, Gray Research Inc., and Defense Threat Reduction Agency, Phys. of Plasmas 17, August 2010

The authors note that bright, multi-keV x-ray sources are needed for imaging and radiography applications. Large, homogeneous sources are useful for area backlighters, and very bright sources can be apertured for point-projection backlighters. Maximizing the laser to x-ray conversion efficiency and tuning the spectral content of the x-ray source are crucial to satisfying the requirements of any backlighter or material-interaction application. They report on the results of a five-shot campaign carried out with Ar-Xe gas-filled targets at the National Ignition Facility (NIF), carried out at about 350 kJ of 3ω light per shot. The results were encouraging. A laser-to-x-ray conversion efficiency of 13 ± 1.3% was observed for isotropic x-rays with energies greater than 3 keV. Laser energy reflected by the target plasma was measured for both the inner and outer cone beams, and found to be small, at between 1% and 4% of the drive energy. Two-dimensional imaging of the target plasma during the laser pulse confirmed a fast, volumetric heating of the entire target, resulting in the efficient laser-to-x-ray conversion noted above. Post-shot simulations with a two-dimensional radiation-hydrodynamics code reproduced well the observed x-ray flux and fluence, backscattered light and bulk target motion. Of significance in these results is confirmation of the prediction that enhanced conversion efficiencies in the double-digit region could be achieved at very high laser powers. The multi-keV x-ray yields from these shots confirmed that the NIF could provide access to this new regime of high conversion efficiency.

***Design, Implementation and Testing of a Cryogenic Loading Capability on an Engineering Neutron Diffractometer*,** T.R. Woodruff et. al., Review of Scientific Instruments 81, June 2010

A novel capability was designed, implemented and tested for *in situ* neutron diffraction measurements at Los Alamos National Laboratory (LANL) under increasing loads at cryogenic temperatures. This capability allowed for the application of dynamic compressive forces of up to 250 kN on standard samples controlled at temperatures from 300 to 90 K. The authors note that diffraction based techniques for microstructural and micromechanical characterization typically use electrons and x-rays from laboratory sources and, hence, are limited to probing depths of several microns (at most) below the sample surface. Neutrons, on the other hand, can penetrate several millimeters (and even centimeters in some cases) enabling measurement from polycrystalline samples that are representative of bulk behavior. While the capability to mechanically load, heat and diffract has existed at various neutron sources, the ability to implement neutron diffraction during cooling and loading had not yet been demonstrated. This paper reports on what is believed to be the first successful implementation of such a capability. An immediate goal of the work was to study residual stress on a flow liner used in the space shuttle. However, the technique is broadly applicable to study such phenomena as deformation processes in exotic materials, transformation-induced plasticity, and temperature-induced phase transformations and twinning, which become increasingly dominant at lower temperatures, and can hence be conveniently probed *in situ*.