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Message from the Assistant Deputy Administrator for Stockpile Stewardship, Dr. Chris Deeney

What do physicists and paparazzi have in common? They know that a picture is worth a thousand words! For this issue of the *Stockpile Stewardship Quarterly*, the theme is advances in imaging diagnostics. Not only do the images tell a story, as asserted in the old axiom, about the dynamics of high-explosives, laser or pulsed power-driven events, but they are also becoming very quantitative. The quantitative nature is driven by our need to compare to simulations and to achieve accuracy levels driven by our Qualification of Margins to Uncertainty methodology. Four articles in this issue demonstrate our improvements in self-emission imaging (x-rays and neutrons) plus radiography.

While there is significant scientific chatter about what may or may not yet have been observed at the Large Haldron Collider, the world's most powerful particle accelerator, the article about the new diagnostics being developed at the Los Alamos Neutron Science Center clearly highlights that even fission still has to be better understood. This article and the others underscore how scientifically we are already living NNSA Administrator Thomas P. D'Agostino's *One NNSA* vision. Every article discusses two, three or many NNSA institutions working together to achieve our stockpile stewardship goals: impact to the stockpile through excellent science, technology and engineering (ST&E).

The article about the Stewardship Science Graduate Fellowship Program highlights the excellent pipeline of talented ST&E professionals being developed and, as proof, we offer our congratulations to Dr. Dan Sinars, an alumnus of our high energy density physics center at Cornell University and now a manager at Sandia National Laboratories, for his recent selection for the prestigious DOE Office of Science FY 2011 Early Career Research Award.

The scientific opportunities of the National Ignition Facility are also being realized. Learn about them in the articles about x-ray imaging and neutron imaging, as well as the two Physical Review Letter papers summarized by Doug Drake in Publication Highlights.

I thank the whole ST&E community for your excellent work. You are making an impact, and the trust being shown by the NNSA Administrator and U.S. Congress through their support of the FY 2011 budget request is a great testament to your achievements.

The 2011 Stewardship Science Academic Alliances Symposium drew more than 250 attendees, including university and DOE/NNSA National Laboratory scientists, researchers and staff, graduate and post doctoral students, and NNSA management.

Dr. Jason Pruet Joins NNSA

The Office of Stockpile Stewardship welcomes Dr. Jason Pruet to its ranks. Jason will be a program manager focused on providing the science basis supporting maintenance of the U.S. stockpile for an indefinite future without nuclear testing. Jason will also be leading the growth of a new program to provide technical capabilities required for Intelligence Community assessments of foreign nuclear weapons activities. Prior to joining NNSA, Jason was a group leader for nuclear physics at Lawrence Livermore National Laboratory.

Comments
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Monochromatic X-ray Backlighting on the Sandia Z Facility

by Daniel B. Sinars (Sandia National Laboratories)

Backlighting is a method of actively probing dense plasmas by directing x-ray photons (usually created using a laser) through plasma and recording the resulting x-ray image of the plasma, similar to the way dentists x-ray teeth. Backlighting (radiography) is widely used because it provides a two-dimensional snapshot of fast-moving plasma, from which the plasma size, shape, symmetry, ion density, and velocity can be inferred. These are all important parameters for understanding high energy density plasmas. One of the NNSA's premiere stockpile stewardship research facilities, the Sandia Z facility, is a 26-MA, 22-MJ pulsed power machine capable of creating magnetic pressures of the order of 100 Mbar (1.45×10^9 psia) that can be used to drive a wide variety of experiments. Its capabilities are augmented by the multi-terawatt, multi-kilojoule Z-Beamlet laser, which can be used to create short-duration (~1 billionth of a second) x-ray emitting plasmas in the Z vacuum chamber. These x-ray sources, in combination with unique spherical crystal imaging optics[1], are routinely used to produce one or two radiograph images per Z experiment[1-2].

The majority of the experiments on the Z facility use z-pinch plasma implosions. The term z-pinch refers to the central axis of a cylinder, usually defined as the "z" axis. A current along the z direction at the outside edge of a cylinder creates a Lorentz (JxB) force that will implode, or "pinch" the material toward the axis of the cylinder. Z-pinches can be created many different ways. Large-diameter, low-mass z-pinches can be created using cylindrical arrays of fine wires. Small-diameter, high-mass z-pinches can be created using hollow metal tubes commonly referred to as liners. Z-pinch implosions on the Z facility occur on time scales of about 100 ns (100 billionths of a second). Thus, a backlighting x-ray source duration of 1 ns provides a stop-motion image of the imploding plasma. Z-pinch plasmas can be used to make the world's most powerful radiation sources (>300 TW, >2 MJ of 0.1-10 keV x-rays). They can also be used to directly compress matter for dynamic material property or inertial confinement fusion experiments. Regardless of the specific application, radiography is a key research tool.

Figure 1 shows radiograph images from selected z-pinch physics experiments on the Z facility. Figure 1(a) shows radiographs from copper wire array implosions. As current passes through the wires, material blows off the wire surfaces (ablates) and is pushed by the Lorentz force toward the array center (the z-axis). Eventually the wires break up into pieces and the remaining mass implodes toward the axis. The radiographs shown capture these key processes. As the wire-array mass implodes, it can be ripped apart by an instability known as the magneto-Rayleigh-Taylor (MRT) instability. Figure 1(b) shows a wire array implosion as the mass approaches the axis. In this image, >90% of the mass is in a hollow tube between 2 and 4 mm in radius[4]. The plasma that appears to show up at smaller radii in the image is also from 2-4 mm in radius—imagine looking through the middle of a drinking glass—your view passes through two thicknesses of glass even though the center of the glass is empty. The MRT instability contributes to the "clumpiness" of the plasma in this image and distributes it over a 2-mm thickness, thereby limiting the symmetry and simultaneity of the arrival of this mass on the array axis.

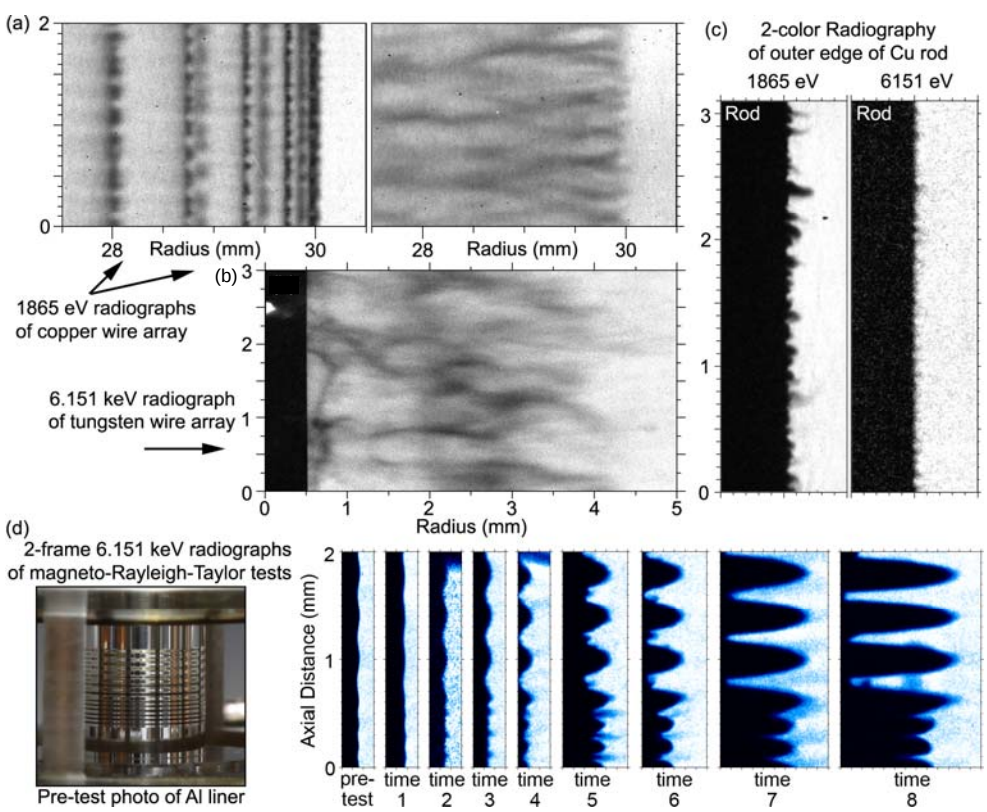

Figure 1: Example radiograph images of assorted cylindrical z-pinch experiments. The z-axis of the cylindrical pinches is always vertical and to the left side of these images, and the black regions are areas where the x-rays were completely absorbed by the pinch mass (0% transmission). (a) Radiographs of a 60-mm diameter copper wire array on Z that show the wires ablating mass radially inward and breaking apart[3]. (b) Radiograph of a 20-mm diameter tungsten wire array implosion showing the mass in flight just before it reaches the axis[4]. (c) Nearly-simultaneous images of the edge of a solid 13-mm diameter Cu rod at two different photon energies showing the development of instability growth[5]. (d) A sequence of multi-frame images showing the development of single-wavelength instabilities on the outside edge of an Al liner. The instabilities were created by slightly perturbing the outer surface as seen in the photo[6,7].

Figure 1(c) shows data from liner experiments designed to measure the plasma instabilities that affect z-pinch implosions. The figure shows near-simultaneous radiographs of the outer edge of a solid copper rod that were made using two different x-ray photon energies[5]. Lower-energy photons are more easily absorbed in copper plasmas than higher-energy photons, so that the two images are sensitive to different plasma densities. These images show more variation in the instability growth of the low-density plasma imaged at 1865 eV compared to the higher-density plasma imaged at 6151 eV. In the rod experiments, the MRT instability grows up from small imperfections in the liner surface and from "electro-thermal" heating instabilities, both of which are difficult to simulate. Additional experiments were done using aluminum liners in which the outer liner surface was slightly perturbed using small sine-wave perturbations at two different axial wavelengths, as shown in the photo in Figure 1(d). The resulting well-defined longer-wavelength MRT instability was captured using two-frame radiography to make the movie shown in the rest of Figure 1(d). These and similar measurements have been modeled successfully by analytic theory and simulations[6,7].

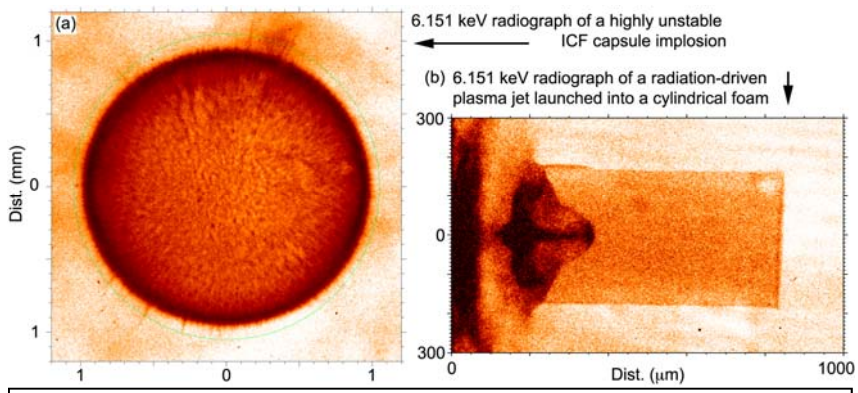

Figure 2: X-ray backlighting images of radiation-driven stockpile stewardship experiments on the Z facility. (a) Image of a highly unstable ICF capsule implosion[8]. (b) Image of a radiation-driven plasma jet experiment[9].

Figure 2 shows examples of radiation-driven experiments that use x-rays from z-pinches to create high energy density plasmas. Figure 2(a) shows an inertial confinement fusion (ICF) capsule experiment in which the plastic capsule had thousands of micron-scale surface defects and an embedded glass layer in the plastic, both of which contributed to the growth of the spikes visible in the radiograph (from the Rayleigh-Taylor instability)[8]. In Figure 2(b), z-pinch radiation was used to launch a shock in metal to create a plasma jet that propagates through foam[9]. This type of experiment is used to validate the simulation tools used by the Stockpile Stewardship Program.

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X-ray Imaging on the National Ignition Facility by Robert Kauffman and Trish Baisden (Lawrence Livermore National Laboratory)

The National Ignition Facility (NIF), located at Lawrence Livermore National Laboratory in Livermore, California, is a 192-beam laser that can focus up to 1.8 MJ of energy and 500 TW of power into a small volume of matter creating conditions of extreme temperature, pressure, and density. The study of hot dense matter is central to understanding inertial confinement fusion (ICF), high energy density (HED) science, weapons physics, and inertial fusion energy (IFE) applications. On NIF, x-ray imaging provides a powerful technique to study hot dense matter. Since hot matter radiates at x-ray wavelengths, we can either image hot dense matter by measuring its self-emission or we can use the x-rays as a source to probe or radiograph dense matter. This article presents examples of how imaging x-ray self-emission and radiography are used to understand the physics in ignition targets.

Imaging X-ray Emissions

In ICF experiments, the NIF's high-powered lasers are used to heat the inside walls of a heavy metal cylinder, or hohlraum. This results in the production of large fluxes of thermal x-rays, which implode a spherical capsule containing the fusion fuel in the center of the hohlraum. When the capsule absorbs the thermal x-rays, the capsule material heats up and ablates. This process of ablation creates a force that drives the capsule inwards and compresses the fuel within, from a radius of a millimeter to tens of microns. At maximum compression, the fuel in the center or core reaches temperatures of millions of degrees and radiates high-energy (multi-kilovolt) x-rays on a time scale of a tenth of a nanosecond (10^{-10} seconds). Gathering data from these experiments requires diagnostics that can image x-ray emission with micron-scale and picosecond-scale resolution—spatial and time scales that push the limits of imaging technology.

Imaging the shape of the capsule at maximum compression is a principal tool for studying the quality of the implosion. The shape is a measure of the symmetry of the x-ray flux that drives the capsule to implode. A small asymmetry in the x-ray flux in the hohlraum translates to a large asymmetry in the compressed core. Recent experiments studying the effect of x-ray drive symmetry on the shape of the compressed core are shown in Figure 1. These images represent a frame of a series of time-resolved images of the self-emission of the hot

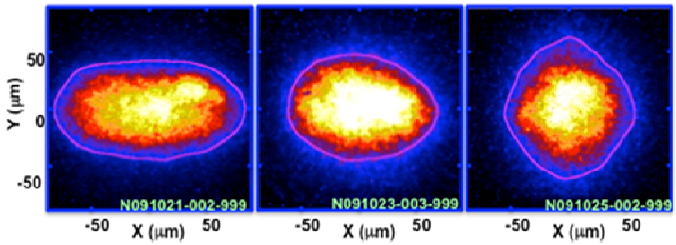

Figure 1: Time-resolved images of the compressed core from an ICF implosion. Each image is from a different shot as the laser is varied to obtain a round implosion.

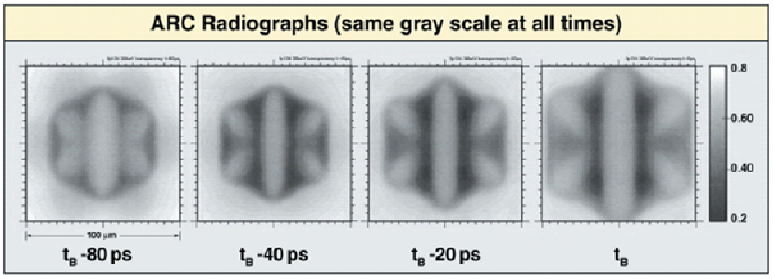

Figure 2: Simulated radiographs of an ignition implosion.

core at maximum compression. The spatial resolution of these images is ~10 microns and the time resolution is ~70 picoseconds. Initially the image is flat, or oblate, indicating that the x-ray flux was higher at the ends of the hohlraum compared to the middle. (The axis of symmetry of the hohlraum is vertical.) For the second shot, the incident laser conditions were changed to reduce the laser light near the ends of the hohlraum. Although the shape improved, the core was still somewhat oblate. Additional adjustments were made on the third shot to achieve a more spherical implosion. As the laser was adjusted to obtain a spherical implosion, important physics was demonstrated of the interaction of the laser beams as they cross and propagate in the target. This is just one example of how x-ray imaging of the compressed core is used to understand the complex physics occurring in ignition targets.

X-ray Radiography

Capsule performance can also be measured using x-ray radiography. Radiography, similar to dental imaging of teeth, images dense material using an external x-ray source. NIF beams can be used to produce an external radiation source to backlight a compressing capsule. The attenuation, or absorption, of x-rays as they pass through the imploding capsule is a direct measure of the areal density (product of the shell density times its thickness), which is a measure of the quality of the implosion. X-ray radiography is one of the few techniques that can measure areal density. Also, radiographs can measure structures in the imploding capsule that can cause mixing of the capsule material with the fusion fuel. Fuel mix is difficult to observe in self-emission because the mixing material cools the fuel reducing its self-radiation. High quality radiography requires x-ray sources with high brightness for good contrast images and short durations to reduce motion blurring as the material moves. Moreover, for ignition implosions, the source has to produce x-rays at high energy to penetrate the dense fuel (typically >20 keV). Short-pulsed lasers (<10 picoseconds) have been shown to produce high-brightness x-ray sources suitable for imaging ignition implosions. The short-pulsed laser capability planned for NIF is called the Advanced Radiographic Capability (ARC). When fully implemented, ARC will consist of four beams (NIF quad) operating in a short-pulse mode that will produce up to eight short-pulses. Multiple beams allow recording of multi-framed images of the implosion. A computer-simulated radiograph of an ignition implosion using ARC is shown in Figure 2. Images are calculated using experimentally determined x-ray fluxes from short-pulse experiments and attenuation through an imploding core. The dark portions represent high mass, high attenuation regions. The simulation has an imposed asymmetry of the drive to accentuate the type of information that can be obtained using ARC. The time history shows how the implosion asymmetry grows as the implosion converges. Note, self-emission images of the implosion show only the center core.

Imaging applications on NIF extend beyond x-ray imaging of ignition experiments. Imaging is central for HED weapons physics, fundamental science, and IFE application experiments. X-ray energies, time scales, and spatial resolution may differ depending on the application, but the basic instrument designs and tools are common to many applications. Optical and neutron imaging are also important elements of the experimental program. The velocity interferometer system for any reflector images a probe laser with an interferometer to measure shock waves traveling through materials. It provides fundamental measurements of material properties important for HED weapons physics and fundamental science, as well as ignition capsule performance. Neutron imaging is complementary to x-ray imaging for diagnosing ignition implosions and will be a valuable tool for experiments using ignition for scientific studies. All these tools are available or being developed to make NIF a more valuable and versatile experimental facility.

The ORTEGA Experiment: Radiographic and Velocimetric Damage Measurements by

Michael Furlanetto, Nicholas King, Stephen Sterbenz, the BAROLO Experimental Series Team (Los Alamos National Laboratory), Andrew Rimmer and Alan Mears (Atomic Weapons Establishment)

On July 28, 2010, a team from Los Alamos National Laboratory, Sandia National Laboratories, the United Kingdom's Atomic Weapons Establishment (AWE), and National Security Technologies successfully executed an experiment (code named ORTEGA) at the Nevada National Security Site. This was the first in a series (BAROLO) investigating material properties under dynamic shock conditions initiated by high explosives (HE). The experiment was conducted as part of an ongoing collaboration with the AWE utilizing unique facilities and capabilities to improve our collective understanding of material behavior under extreme conditions.

ORTEGA consisted of two identical samples of lead driven by small charges of HE. The internal structure of the shocked lead was measured with flash x-radiographic systems. The pressure loading of the lead was determined by measuring the velocity of the leading lead surface. Detonation symmetry was monitored by electrical pins embedded in the HE.

Flash x-radiography formed the key measurement. A short pulse of x-rays "froze" the motion much like a flash camera system and thereby permitted examination of the instantaneous internal spatial density distribution of the rapidly moving material. The x-rays were produced by two independent "Cygnus" pulsed-power rod-pinch diode sources. Each produced a burst (<50 ns) of bremsstrahlung x-rays with a dose ≥4 rads at 1 meter and ~1.2 mm diameter spot with endpoint energy of 2.2 MeV. The two radiographs were taken encompassing both samples in each image and separated in time by ~4 μs to allow observation of the evolution of the samples.

X-rays transmitted through the samples were converted to visible light images by thin scintillators, relayed by optics, and recorded on charge-coupled device cameras. The images were generated through the removal of x-rays by material between the sources and the scintillators. Resolution was determined by the source spot size, scatter backgrounds of the x-rays during the removal process, and the ability of the scintillator to resolve small variations in spatially dependent material densities. The resultant resolution was ~200 microns. A simple analysis to remove distortions and scale the radiograph to a common object location is shown in Figure 1. Still ongoing are more sophisticated analysis procedures for final radiograph comparison to computer simulations.

The shock-induced damage in both samples caused failure of the still-solid material. The thin leading layer visible in the radiographs—a spall layer—became detached from the bulk material when the tension created by the shock wave reflecting off the front surface of the lead exceeded its tensile strength. Behind this initial layer, a large volume of low-density damaged lead separates the spall layer from the trailing, higher-density lead.

Two types of surface velocimetry—velocity interferometer system for any reflector and Photonic Doppler velocimetry—were used to measure the velocities of the leading layers of the lead samples as well as shock arrival at the lead surfaces. Consistency between the two techniques showed that the free surfaces of the two packages moved at over a kilometer per second. The shorting pins and the surface velocity measurements demonstrated that both HE charges behaved identically.

Preshot predictions of ORTEGA using modern Lagrangian hydrocodes matched the data quite well, as shown in Figure 2[1]. Predicted velocities are very close to those observed. The simulations also captured the initial spall layer, the trailing high-density layer, and the extensively damaged material between the two. The axisymmetric simulations will not capture detailed three-dimensional behavior, as seen in the righthand sample, but did match the two-dimensional features.

The excellent data return from the ORTEGA experiment will increase our understanding of failure in HE-driven materials and provides a benchmark against which to test the performance of our material models. Experimental observations in ORTEGA establish limits on our ability to observe differences between nominally identical HE-driven samples. These limits are important for defining future studies of differences in material properties and their impact on modeled damage mechanisms.

Reference

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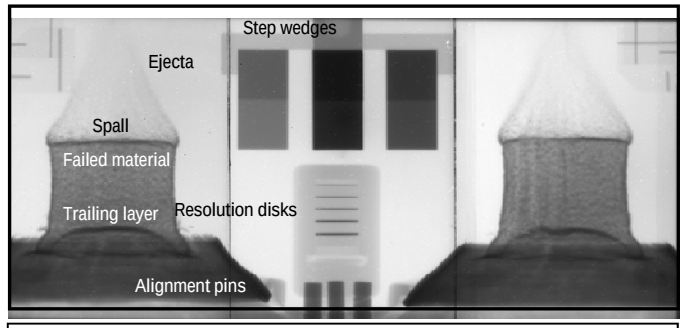

Figure 1: Processed transmission radiograph from the Cygnus 2 source. Cones of ejecta lead thin horizontal spalled layers at the top. Below those features are large volumes of failed material followed by a trailing curved layer of lead. The bottom of the image shows some of the fixtures which held the samples in place before the high explosive detonated. Also visible in the center of the image are step wedges used for density calibration, in situ resolution disks, and alignment pins. The top and bottom resolution disks are 50.8 and 304.8 microns thick, respectively.

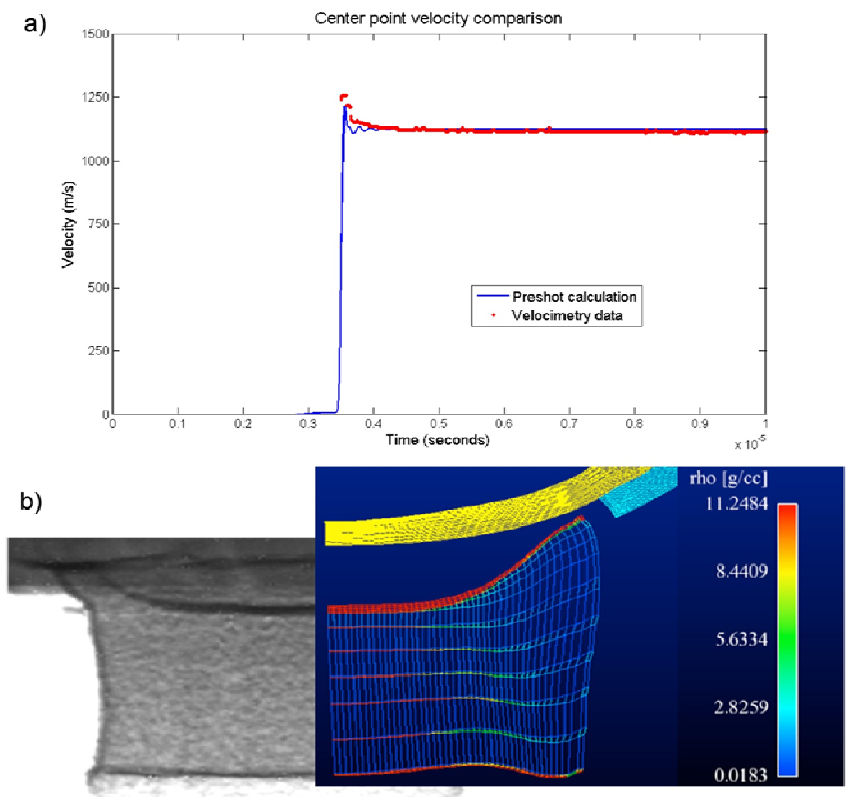

Figure 2: Comparison of pre-shot predictions and data. a) Calculated and measured surface velocities from near the axis of symmetry of one sample are shown. The calculated velocities have been time-shifted to account for some experimental details not reproduced in the simulations. b) Measured radiographic transmissions (left) and calculated densities (right) are shown, both from ~29 μs after detonation. Note that the vertical axis has been flipped with respect to Figure 1.

Update: BAROLO Experimental Series Completion

The dynamic high-explosive-driven BAROLO experiments, along with the necessary x-ray calibration shots including a plutonium step wedge, concluded on March 24, 2011. The dynamic experiments included both Pu and surrogate experiments. The dynamic plutonium experiments were BACCHUS, BAROLO A and BAROLO B. The surrogate experiments were conducted at the proton radiography facility at the Los Alamos Neutron Science Center, an experiment was conducted at the Eenie firing site at Los Alamos National Laboratory, and the confirmatory experiments for BAROLO A and B and for BACCHUS (named ORTEGA) were conducted in U1a. The ORTEGA and BACCHUS experiments used configurations that differed from those used for BAROLO A and B, requiring different mounting in the experimental package as well as changes to the diagnostic configurations. For the BAROLO A and B experiments, the diagnostic measurements included radiography, high explosive electrical pins, Photon Doppler velocimetry pins, the velocity interferometer system for any reflector, and optical shadowgraphy. All of the data return (100%) was realized for the confirmatories and Pu experiments. In-depth analysis of the data is the next step. For more information, contact Jeff Paisner, Los Alamos National Laboratory, or Robert Hanrahan, NNSA (NA-115).

Neutron Imaging at the National Ignition Facility (NIF) by Frank Merrill (Los Alamos National Laboratory)

The technique of neutron imaging was developed in the 1970s to diagnose underground nuclear tests. A new diagnostic, employing the principles of this technique and developed by a Los Alamos National Laboratory-Lawrence Livermore National Laboratory team using the OMEGA laser at the University of Rochester's Laboratory for Laser Energetics, has been adapted for the diagnosis of inertial confinement fusion experiments performed at NIF.

The principles behind this imaging technique are similar to the principles behind standard pinhole cameras that are common within the world of photography. The major difference lies in the penetrating ability of 14 MeV neutrons, which are generated in deuterium-tritium fusion. The "pinholes" used to form neutron images are small tapered apertures machined in ~20 cm of gold or tungsten. The thick gold or tungsten is required to remove neutrons and the tapered aperture is designed to provide a "sharp" edge for the neutron aperture. The pinhole is located close to the source and the image is measured far from the source. At NIF, this geometry generates a magnification factor of ~100, allowing the imaging system to collect images of very small neutron sources, <100 μm in diameter.

In a conventional pinhole camera, film is used to detect the light forming the image, but neutron pinhole imaging requires a significantly more complicated detector system. Because of the unique non-interacting nature of the ~14 MeV neutrons, the detector array must be relatively thick (~5 cm of plastic scintillator). With this thickness, the probability of a neutron interaction is ~40%. A fast-gated charge-coupled device camera system is used to detect the light generated from the neutron interactions within the detector. With this system, two independently timed images can be collected during a single experiment. Because of the time-of-flight differences of neutrons of different energies, this system can collect neutron images at two energies. This data provides the information required to understand the shape of the burning core as well as measuring the distribution of the cold fuel surrounding the core.

The installation of this system was completed at NIF in early 2011 in preparation for the first measurement, which was collected on February 17. For this measurement, the target

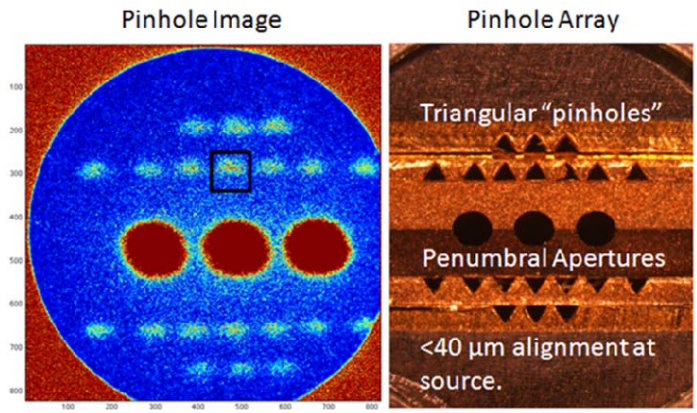

Figure 1: Left - First neutron image from the exploding pusher. Right - Microscope view of the pinhole array. The triangular "pinholes" form the pinhole images, while the penumbral apertures also provide information on the source distribution.

was a deuterium/tritium-filled, directly driven glass microballoon with a measured yield of $2x10^{14}$ neutrons. The collection of this measurement completed the operational qualification of this diagnostic. Figure 1 shows images collected with this system. On the left are images formed by the pinhole array and on the right is a microscope photograph of the gold pinhole array. Because each pinhole in the array points at a slightly different location at the target chamber center, the neutron intensity through each pinhole was used to estimate the pointing of the pinhole array. This preliminary analysis has revealed that the pinhole within the black box was pointed closest to the source and that the center of the black box in Figure 2 is centered on the pinhole field of view. This region of the image was extracted for further analysis to reconstruct the neutron source distribution.

The results of this reconstruction are shown in Figure 2. The results show an oblate source, as expected in polar-driven capsules. Because NIF is configured for hohlraum-driven implosions, the lasers are directed along the polar axes of the target vessel. In this drive configuration, the compressed core is expected to be oblate, because of the increased drive at the poles of the capsule. This result agrees well within expectations of the capsule implosion and agrees well with

the x-ray images of the same experiment. However, the x-ray images show different source distribution than the neutron images, as one would expect because the physics processes generating the x-rays differs from the processes generating the neutrons. Figure 2 shows the neutron source overlayed on the x-ray source distribution, demonstrating how the x-ray source surrounds the neutron source. The combination of x-ray images with neutron images provides complement ary information, which will be useful in fully diagnosing NIF implosions.

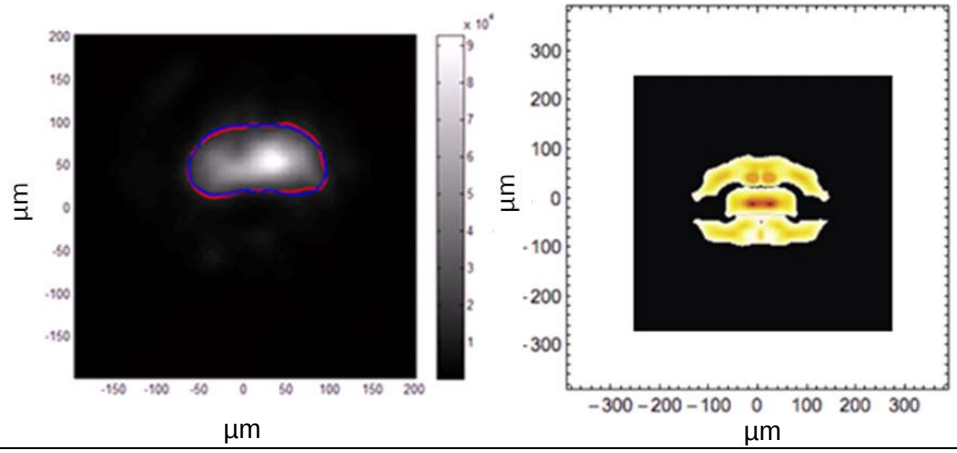

Figure 2: Left - Reconstructed neutron source. The oblate shape of the neutron source is expected from polar direct-drive capsules. Right - An Abel inversion of the neutron source is overlaid on the x-ray source distribution. This analysis clearly shows the difference between the x-ray images and neutron images from these experiments. The combination of the two measurements will be required to fully diagnose NIF implosions.

Fission: One of Nuclear Science's Grandest Challenges

by D. Brown, M. Heffner, T. Luu, D. McNabb, N. Schunck, R. Vogt, C.Y. Wu, and W. Younes (Lawrence Livermore National Laboratory)*

Nuclear fission plays an essential role in understanding the dynamics of energy production in nuclear weapons and reactors. The production of actinide isotopes and their fission fragments in high energy density (HED) environments constrains multi-physics simulations that we use to understand, quantify, and predict performance. Nuclear fission applications rely on similar data in areas related to nonproliferation and detection, threat reduction and forensics, and next-generation nuclear reactors and safeguards. However, even with 70+ years of fission research to rely on, there are still many unanswered questions related to fission that have profound implications on stockpile stewardship science. Developing a fundamentally motivated computational capability to calculate nuclear fission and its properties with quantified uncertainties is at the heart of science-based stockpile stewardship and uncertainty quantification.

A fissioning nucleus represents a complex, self-bound, quantum mechanical system of many neutrons and protons. Developing a truly *ab initio* theory of fission that incorporates the exact many-body quantum nature of systems of neutrons and protons and describes its wealth of physical phenomena, from cold fission to non-adiabatic behaviors such as quasi-particle excitations (all important to the fission process), is daunting. Aside from being radioactively 'hot' and the dangers that this entails, experiments that measure fission properties are confounded by the abundance of concurrent nuclear reactions. Consequently, the signal of interest is drowned out by the multitude of other nuclear phenomena. As such, it comes as no surprise that understanding the physics of fission at the microscopic level is one of nuclear science's grandest challenges[1].

Drawing on technology from high-energy experimental physics, a Lawrence Livermore National Laboratory (LLNL)-led team spearheaded by M. Heffner recently designed and fielded a prototype fission time-projection chamber (TPC) at the Los Alamos Neutron Science Center (LANSCE) (see left panel of Figure 1). The *production* TPC, currently in development, will yield fission cross-section measurements with unprecedented precision and accuracy (at the ~1-2% level). As part of the Chi-Nu effort to measure the neutron fission spectrum and fission γ-rays, LLNL scientist C.Y. Wu and his collaborators have designed a fission counter with nano-second timing resolution. Such resolution provides the requisite quality of the data to extract the neutron spectrum at low (<1 MeV) and high (>10 MeV) energies. Sample data from the counter is shown in the right panel of Figure 1. Both experiments play an integral role in stockpile stewardship science, as the former directly impacts energy production

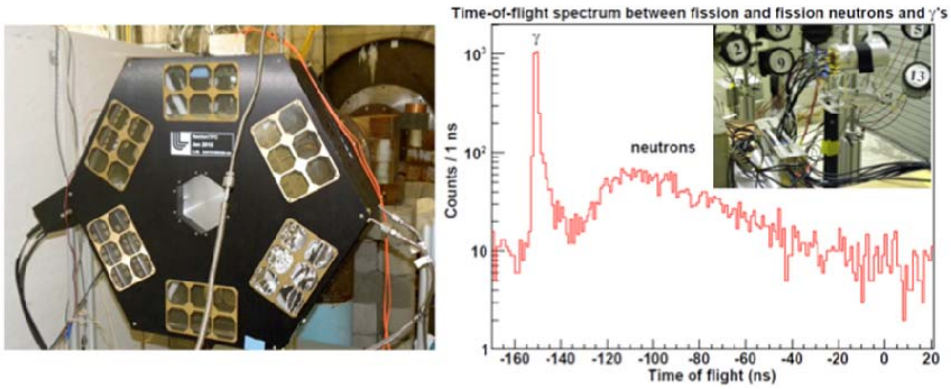

Figure 1: Left - The prototype fission TPC recently tested at LANSCE. Right - Time-of-flight data taken with the fission counter and Chi-Nu scintillator arrays at LANSCE, showing the clear separation between γ-ray events and subsequent neutrons. Right inset shows the fission counter apparatus.

and the latter provides valuable information related to neutron multiplicities and partitioning of fission energy. The high fidelity data coming from these experiments will enhance the predictive capability of advanced simulation and computing (ASC) codes.

Complementing these experimental efforts are theoretical efforts at LLNL that seek to provide reliable predictions of fission-fragment properties, such as yields and their energy dependence, through the development of microscopic, time-dependent descriptions of fission. The Hartree-Fock code HFODD[2], being developed by LLNL scientist N. Schunck and collaborators, utilizes modern nuclear density functional theory to describe the complex many-body fissioning nucleus and its interactions in a systematic, quantum-mechanically consistent manner. LLNL scientist W. Younes and collaborators are formulating the time-dependent description of fission through wave-packet analysis and its evolution, all within a quantum-mechanical framework[3]. Together, their studies, which utilized high-performance computing resources, have provided the first calculations of ^{239}Pu neutron-induced fission and its fragment yields (see Figure 2). These microscopic calculations provide input to accurate phenomenological models of fission fragment decay, like the stochastic event-by-event FREYA code developed by LLNL scientist R. Vogt and collaborators[4], which in turn calculate the fission-neutron spectrum. Future efforts along these lines will include implementing in-line capability within ASC codes for modeling fission fragments. These studies will address issues related to the fission yield basis and impact our interpretation of underground testing diagnostics.

References

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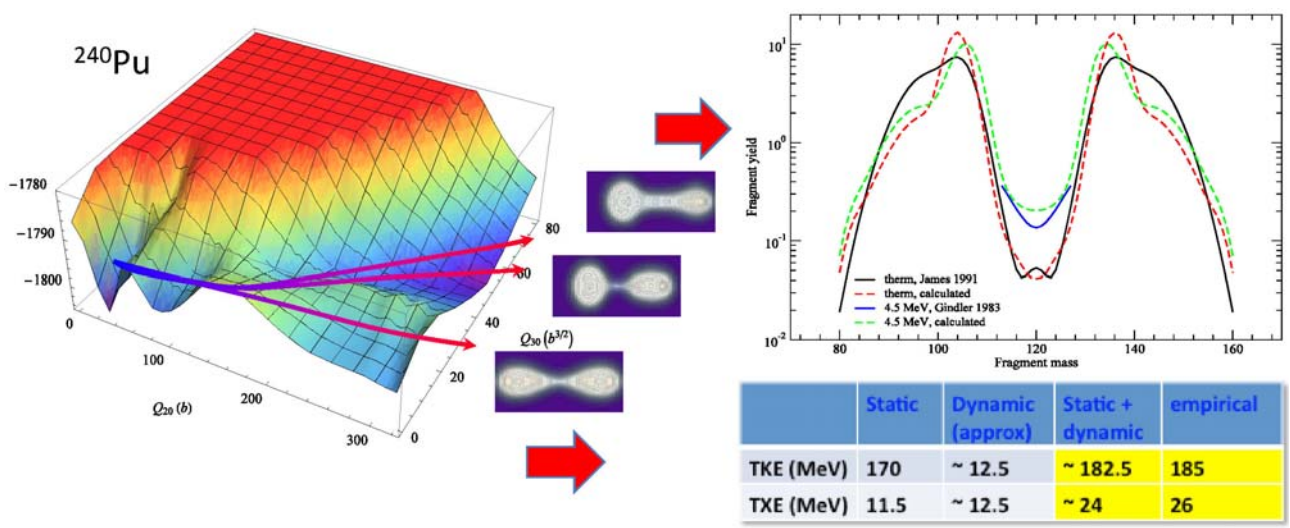
** This work was performed in collaboration with Los Alamos National Laboratory (LANL), Idaho National Laboratory, Pacific Northwest National Laboratory, Georgia Institute of Mines, Ohio University, and Idaho State University for TPC; LANL for Chi-Nu; and Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, and LANL for Fission Theory.*



	Static	Dynamic (approx)	Static + dynamic	empirical
TKE (MeV)	170	~ 12.5	~ 182.5	185
TXE (MeV)	11.5	~ 12.5	~ 24	26

Figure 2: Summary of microscopic fission calculations. Top left - The potential energy surface for ^{240}Pu along with three sample nuclear-density distributions corresponding to surface trajectory. Right - The calculated (dashed lines) fragment mass yields are compared to data-based evaluations (solid lines) for thermal and 4.5-MeV fission. The table compares the calculated (next-to-last column) and empirical (last column) values for the total kinetic (TKE) and total excitation (TXE) energies for the most likely fragmentation.

Second Plutonium Shot on the Refurbished Z

The excellent data acquired on the second shot address the NNSA Stockpile Stewardship Program's priority to obtain Pu dynamic material response data. Staging of the hardware for the second shot began on March 14, with preparation of the accelerator, diagnostics, and load hardware for the second Pu series beginning March 18, following the completion of an experiment for an Engineering Campaign customer on the previous day. The readiness shot, a dry run of the planned shot conducted without plutonium, was conducted on March 24, followed by post-shot activities on March 24 and 28. The accelerator, diagnostics, and load hardware preparations for the Pu shot were then conducted on March 29 and 30, and the second Pu shot was conducted on the morning of March 31. The experiment was performed in collaboration with Los Alamos National Laboratory (LANL). Initial indications are that Z and the containment hardware functioned as expected and quality data were obtained on the three LANL-supplied plutonium samples. The first Pu shot on Z since the 2007 refurbishment had been conducted November 18, 2010.

— SNL/LANL/SSO/NSTec Plutonium Team

Stewardship Science Graduate Fellowship Program by the Krell Institute

NNSA welcomed five impressive doctoral candidates into its Stewardship Science Graduate Fellowship (SSGF) Program last fall. The program supports students pursuing doctorates in areas of interest to stewardship science, including high energy density physics, nuclear science, or materials under extreme conditions and hydrodynamics. The fellowship covers all tuition and fees and provides a $36,000 annual stipend, $1,000 annual allowance for research and professional development, 12-week research practicum at a NNSA National Laboratory, and travel to the annual conference. Currently, there are 20 students in the program; read about the newest fellows below.

Evan Davis, a Massachusetts Institute of Technology doctoral candidate studying plasma physics and fusion, will focus on plasma turbulence, with an emphasis on models capable of spanning disparate spatial and temporal scales and of uniting a fusion reactor's interacting physical processes. Such integrated models could help development, optimization and analysis of burning plasma reactors like the International Thermonuclear Experimental Reactor and enhance understanding of plasma behavior, including turbulence, transport and other qualities. Davis also plans to experimentally characterize plasma turbulence with several diagnostics, primarily phase contrast imaging. The experimental data will help validate and improve existing and future first-principles models. B.S., Physics and Applied Mathematics, University of California, Riverside, 2010.

Michael Hay, a Princeton University doctoral student studying plasma physics under Nathaniel Fisch, will focus on the fundamental physics behind the generation and manipulation of wave packets in high energy density plasmas, such as the deuterium-tritium plasmas being researched at the National Ignition Facility. Certain types of waves may undergo adiabatic compression as they propagate through these rapidly densifying plasmas. Researchers believe excess wave energy could be used to alter the thermal distribution of ions in phase space. Hay will investigate how waves amplified during sub-nanosecond compression times could create hot ion modes, increasing fusion reactivity and thermonuclear yield. B.S., Nuclear Engineering, University of California, Berkeley, 2010.

Stephanie Lyons, University of Notre Dame, is pursuing a doctoral degree in nuclear physics. Under advisor Michael Wiescher, Lyons is working on the ^{20}Ne(p,γ) and ^{22}Ne(p,γ) reaction experiment, comparing results from using both natural and implanted targets. She is studying the data to understand the efficiency of gamma detectors and the resonance structure and reaction rates for these two reactions. Lyons also is involved in design work for Notre Dame's St. George Recoil Mass Separator, which will be used to analyze rare, low-energy reactions using inverse kinematics. She's focusing on slits that will be part of the mass separator beam line and a program to automatically change magnets for various isotope beams. B.S., Physics, Randolph College, 2009.

Elizabeth Miller, a doctoral student in materials science and engineering, is studying with Scott Barnett at Northwestern University. Her research will focus on solid oxide fuel cells for energy storage, including ceramic processing, materials development and characterization and optimizing conditions of temperature and pressure to create the best conditions for the most efficient energy storage. B.S., Materials Science and Engineering, Pennsylvania State University, 2010.

2010 SSGF Fellows, left to right: Stephanie Lyons, Michael Hay, Evan Davis, Elizabeth Miller, and Thomas Saller

Thomas Saller is a first-year doctoral student in nuclear engineering at the University of Michigan under advisor Thomas Downar. Saller researches designs for generation-IV nuclear reactors, using upgraded modules in the SCALE6 software tool for evaluation of nuclear fuel facility and package design. He's focusing on obtaining homogenized cross sections for the High Temperature Test Reactor prismatic reactor for use in the Purdue Advanced Reactor Core Simulator (PARCS). Surface discontinuity factors, similar to assembly discontinuity factors used in light water reactor codes, must be taken into account to ensure the cross sections incorporate proper boundary effects. Saller is working on generating these discontinuity factors and implementing a newly developed triangle-based nodal solver into PARCS. Improved models are necessary to advance the development of more efficient, safer and less wasteful next-generation reactor designs. B.S., Mechanical Engineering, University of Texas, 2009.

2011 SSGF Annual Meeting

The SSGF Annual Meeting will be held July 21-22 at the Crystal Gateway Marriott in Arlington, VA. For more information, visit www.krellinst.org/conf/ssgf/2011/.

DOE Office of Science FY 2011 Early Career Research Award

Dr. Daniel Sinars of Sandia National Laboratories was selected to receive a DOE Office of Science FY 2011 Early Career Research Program award. Chosen for his proposal entitled *Fundamental Instability Measurements in Magnetically Driven Z-Pinch Liner Explosions*, he will receive $2.5 million over five years for his research. Sinars and the other 64 award recipients were selected from a pool of approximately 1,150 applicants. The Early Career Research Awards are designed to bolster the nation's scientific workforce by providing support to exceptional researchers during the crucial early career years, when many scientists do some of their most formative work.

Publication Highlights by Douglas Drake

This section highlights recent publications in high-impact scientific journals of research supported by the NNSA Office of Stockpile Stewardship.

Observation of High Soft X-Ray Drive in Large-Scale Hohlraums at the National Ignition Facility, J.L. Kline et al., Phys. Rev. Letters 106, February 2011

Researchers report encouraging results in a recent series of experiments with vacuum hohlraums at the National Ignition Facility (NIF). The data concerning material equations of state, hydrodynamic instabilities, radiation transport, etc., that can be acquired in this way is of potentially high value to the national weapons program. The degree to which this potential will be realized is dependent on the efficiency with which the laser light can be converted to x-rays, and also on the accuracy of the physical models that enable researchers to correctly interpret the results of experiments.

Earlier experiments at the facility raised the concern that the efficiency of x-ray conversion might be impaired by backscatter of the laser light due to laser-plasma instabilities. The observed backscatter reported in the more recent experiments was less than 2% of the total incident energy. Although the hohlraums used in the earlier experiments where somewhat different, in that they were gas-filled and included small targets mounted inside the hohlraums, this is still positive news. Measured levels of x-ray flux provided further grounds for optimism. Computer models benchmarked by results from the smaller hohlraums fielded on the Omega and Nova facilities were found to significantly underestimate actual radiation flux levels. In fact, observed levels were 20% to 30% higher than expected based on a model with a conservative atomic physics package (XSN) that agreed with experimental results at the smaller facilities. The observed results turned out to agree much better with a code using a less conservative atomic physics model (DCA), which includes two electron processes, as well as more accurate treatment of the rate equations that account for radiation emission and absorption.

It was also found that a simple model of radiation flow agreed very well with the observed results as long as a term known as the flux limiter was chosen correctly. The radiation transport equation describing radiation flow can be expanded in an infinite series of angular moments. In the simplest models, only the first term in this expansion is retained. Such models are much cheaper to run in terms of computational resources than models that retain higher order angular moments. However, they can occasionally predict unphysically high levels of radiation flow. A so-called "flux limiter" term is used in the models to prevent this from happening. It was found that, for an appropriate choice of flux limiter, a simple model worked very well as long as electronic processes were correctly modeled as described previously.

Demonstration of Ignition Radiation Temperatures in Indirect-Drive Inertial Confinement Fusion Hohlraums, S.H. Glenzer et al., Phys. Rev. Lttrs. 106, February 2011

As its title implies, this paper documents the experimental demonstration of radiation temperatures in NIF hohlraums sufficiently high to achieve fusion ignition. However, that is not the only piece of encouraging news reported by the more than 400 authors listed under the title. In the recent series of NIF experiments described in the paper, conducted with ignition-scale hohlraums, they also demonstrated that worrisome levels of laser energy loss due to backscatter induced by laser-plasma interactions (LPI) can be controlled by adjusting the amount of helium in the gas filling the hohlraums. Further reductions in LPI were achieved by optimizing the polarization of the beams in the critical inner beam cones, resulting in coupling efficiencies of around 90%, deemed high enough to achieve ignition. In addition, the observed symmetry of the x-ray radiation flux at the capsule surface was consistently high, a key requirement for achieving the highly uniform implosions needed to achieve ignition. Finally, these observed results were found to be in good agreement with the predictions of computational models. These results represent impressive progress towards the ultimate goal of fusion ignition.

Future studies will explore further improvements in hohlraum drive, including experiments with optimized wall areas and hohlraum fill densities as well as hohlraums with higher-Z wall materials and higher wall opacities.

Total Yield Nuclear Activation Diagnostic Operational on the National Ignition Facility (NIF)

The diagnostics that Sandia National Laboratories designed, fabricated and delivered to the National Ignition Facility include a copper nuclear activation diagnostic (NAD20). The diagnostic measures the total deuterium-tritium (DT) neutron yield on NIF experiments in support of the national objective to achieve ignition in a DT fuel capsule on Lawrence Livermore National Laboratory's 192-beam neodynium glass laser. The NAD20 has been used on DT exploding pusher shots and on cryogenic-layered tritium-rich THD capsule shots. In the first quarter of FY 2011, SNL designed and installed a second nuclear activation diagnostic at 19 meters from a NIF target (i.e., in front of the neutron time-of-flight diagnostic) to reduce attenuation and scattering effects associated with the original 29-meter location. An additional NAD was also fielded at the equator for one shot in order to compare with the neutron time-of-flight yield measurements at that location. We are obtaining high-quality total neutron yield data at all the NAD locations. The yield measurements at multiple locations are consistent, giving high confidence that the diagnostics are well understood. Record-breaking neutron yields of approximately 2×10^{14} have been measured for DT exploding pusher shots. SNL is preparing to calibrate the NAD20 system at SNL's Ion Beam Laboratory, and an engineering design is nearly complete for these third quarter FY 2011 calibration experiments. In addition, a new line-of-sight for the NAD20 diagnostics on NIF is expected to be implemented during the third quarter.