Stockpile Stewardship Quarterly

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

Stockpile Stewardship Science is not for wimps, and this issue of the *Stockpile Stewardship Quarterly* (SSQ) proves it. The need for excellent science pushing the envelope of technology and understanding at extreme conditions is the heart of stewardship. It is also a fair summary of this SSQ.

NNSA has been engaged in the grand challenge of achieving ignition in the laboratory to enhance the laboratories' capabilities to steward and manage the stockpile. Ignition is definitely an exciting goal that energizes the community and drives our technology and science advances. Great progress has been made, and Bob Kauffman demonstrates this progress and describes the future work to achieve ignition. Another driver of technology is our need to conduct plutonium experiments in test area U1a. In the last five years or so, the advent of faster digitizers has enabled a technique called photonic Doppler velocimetry (PDV). PDV has started to rival VISAR as the key method to measure velocity in dynamic compression experiments. Now, amazingly, the teams at National Security Technologies, LLC, Los Alamos National Laboratory and Lawrence Livermore National Laboratory have pioneered a system to obtain more than 100 channels of PDV on an implosion experiment at U1a. This technology advance is spurring new thoughts and techniques to interpret the implosion data. Beyond this, NNSA is also promising techniques to enable higher energy radiography in the U1a complex. Linear transformer drivers, as described on page 9, offer some attractive features. The diode physics required to meet the radiographic specifications is also showing great progress. DARHT sets a very high bar for radiographic quality, but new diode strategies are getting closer by integrating new diagnostics with improved calculational tools. At the smaller scale, similar techniques and tools are being applied for developing improved understanding of neutron generators. These small accelerators must work reliably and predictably. The advances in understanding neutron tubes will reduce prototyping and testing times and will better inform lifetime extensions.

Such advances across the board will allow future stewards such as those from a Stewardship Science Graduate Fellowship class to work in a phenomenal Nuclear Security Enterprise (NSE). As we enter a new year—a year that marks stewarding the stockpile for 20 years without any new underground nuclear tests—we are all very proud of the accomplishments of the NSE, and we look forward to another exciting year. We are grateful for an appropriation, and we at headquarters have to continue to improve our advocacy for the science, technology and engineering (ST&E) that underscores an entire endeavor. That said, FY 2012 still has ST&E budgets at a higher level than that of FY 2010 so we have no financial excuses. Let's get the job done—Gemini, Sequoia and Ignition!

2012 Stewardship Science Academic Alliances (SSAA) Symposium

The Office of Stockpile Stewardship will host its annual SSAA Symposium on February 22-23, 2012, at the Grand Hyatt Washington in Washington, DC. The registration deadline for this Symposium is February 10, 2012. For more information and to register, visit http://www.orau.gov/ssaa2012/.

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Comments

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Applying Advanced Simulation Models to Neutron Tube Ion Extraction by Matthew M. Hopkins, Edward V. Barnat, Polly L. Hopkins, Lawrence C. Musson, Paul S. Crozier, and Paul A. Miller (Sandia National Laboratories)

Neutron Tubes (NTs) are critical weapon components that have been intensely studied and developed for as long as we have had a nuclear weapons stockpile. Their correct operation ensures that a weapon achieves its maximum intended yield by injecting neutrons at the optimal time during pit implosion. They are also one of the most expensive non-nuclear components within a weapon. Because they have a finite lifetime, they must be replaced periodically, which incurs even higher product and handling costs. A deeper scientific understanding of NT operation will lead to a better understanding of the design margin trade-off space, thus reducing the number of prototype NTs required to answer margin questions. It will also lead to a less expensive NT enterprise as we employ simulation as a surrogate for real NTs to address questions that arise during deployment. One such scientific investigation aimed at better understanding of NT operation and identification of important design parameters is described in this article.

NTs function as miniature particle accelerators by smashing an accelerated ion into a surface with enough energy to undergo fusion and produce neutrons. But unlike their multi-kilometer relatives in Geneva, Switzerland (European Organization for Nuclear Research, Organisation Europeenne pour la Recherche Nucleaire); Menlo Park, California (SLAC National Accelerator Laboratory); and Batavia, Illinois (Fermilab), ions are accelerated on a scale of centimeters and with relatively much smaller energies. In NTs, ions are extracted from plasma (a quasi-neutral combination of ions and electrons) by applying a strong accelerating field. This field draws positive ions out of the plasma and accelerates them through a vacuum to the fusion target, while simultaneously repelling the electrons and leaving them within the plasma. The exact location of the plasma boundary is extremely sensitive to the fields and extracted ion current. There are other peripheral phenomena at work, but primary interest is in what influences the extracted ion flux.

Studies of ion beam extraction occurred over approximately four years, iterating between experimental investigations and simulation model improvements, each informing and guiding the next stage of the other. A simple model geometry consisting of two chambers, one containing plasma and one containing vacuum and a two-dimensional detector, was used. The two chambers in the simulation were separated by a metal plate with a circular hole (see Figure 1). By holding the separation plate at ground and the detector at a large negative voltage, it was possible to effectively extract ions from the plasma through the hole and leave the electrons behind. By increasing the strength of this applied electric field (the difference of the voltages across the gap), the extracted ion beam current could be increased (up to the Child-Langmuir limit). By sufficiently reducing the strength of the electric field, the plasma could bleed through the hole, resulting in a diffuse ion beam, reminiscent more of an ion "cloud" than a sharp beam.

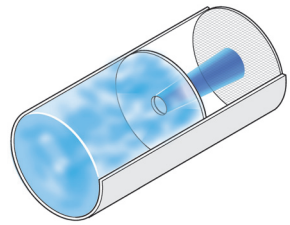

Figure 1. Schematic of ion extraction diagnostic. Plasma on left is extracted and accelerated to diagnostic on right (cross-hatched surface). An accelerating electric field is applied between the separation plate and the detector.

Real breakthroughs came when we began asking questions about which plasma characteristics influence the beam profile, as opposed to field and geometry characteristics. Our first models contained a number of assumptions that proved to be incorrect. Figure 2 shows our initial simulation prediction and how it compared with the experiment: terribly! Attempting to understand what contributed to our poor prediction and uncover poorly understood or completely unknown phenomena, iterations were made through a series of discoveries and model improvements. Initially, only the dominant ion species was used, but the real system contained multiple species. We demonstrated that our simulation was indeed sensitive to the presence of multiple species and began including them in the model with estimated relative proportions. Next, although the total ion flux through the hole to the detector is measured, it is not possible to uniquely identify specific species' number densities and drift velocities, especially in a multi-component system (the product of drift velocity and number density gives flux, but reliable measurement of either of the prior two quantities was not made).

A Thompson parabola diagnostic was developed to measure velocity distributions according to charge/mass ratios (i.e., by species). Because of the processes used to generate the plasma, velocity distributions with a mean drift energy of ~30 eV, and a temperature (spread) of approximately 1,500 K (or ~0.1 eV) were expected.

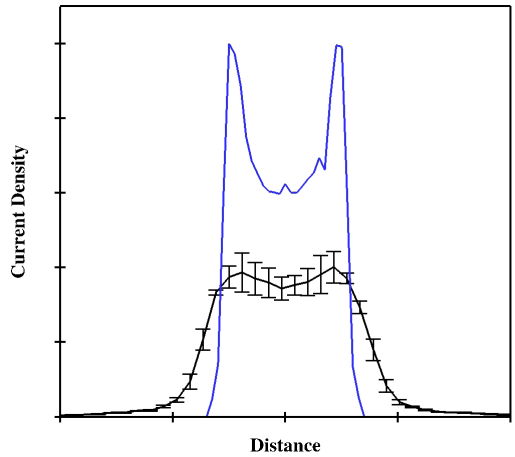

Figure 2. The current density footprint on the detector along a centerline is shown. Comparison of initial simulation results (blue curve) to experimental data (black curve with error bars).

Although an ~30 eV drift velocity was observed, the width of the measured velocity distribution was instead ~25 eV, or ~288,000 K. Using the as-measured temperatures within the simulation produced improved agreement with the experiments. The culmination of including this new knowledge in the simulation tool is seen in Figure 3, a much improved comparison. The detailed processes that drive the broad velocity distribution are not fully understood and are under further investigation.

By making better ion beam predictions and, more importantly, better understanding the key contributing phenomena to ion extraction, better control can be demonstrated over this aspect of NT operation. The sensitivity of ion extraction (and, thus, neutron output) to species densities and velocity distributions was not well understood prior to this work. Previously, NT operation questions involving ion extraction would have required extensive building of prototype NTs and subassemblies, an exercise both expensive and time-consuming. Now, a significant number of those questions are being addressed through application of these new models, and the overall NT design trade-off space is better understood.

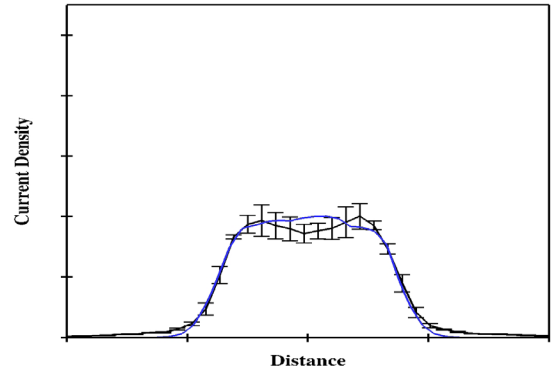

Figure 3. Comparison of latest simulation results (blue curve) to experimental data (black curve with error bars).

Advanced Optical Cavities for Subcritical and Hydrodynamic Experiments by Brent Frogget, David Esquibel, Robert Malone, Vincent Romero, Morris Kaufman, Brian Cata, and Brian Cox (National Security Technologies, LLC [NSTec]) at the Nevada National Security Site

Optical velocimetry is an important experimental diagnostic for monitoring the movement of a surface. Frequently, flat surfaces are measured; however, a new requirement is to monitor the movement of a curved imploding surface. Historically, electrical pins of various lengths time an imploding hemisphere dome under dynamic testing. Each pin provides a shorting signal when its tip comes in contact with the collapsing surface. Different lengths of pins short at different times. As an alternative, the velocity measuring technique known as photonic Doppler velocimetry (PDV) has been developed to measure a surface continuously over the length of a beam of light during the surface movement. Reflected light from each spot on the surface is Doppler-shifted with a small portion of this light propagating backwards through the lens into the launching fiber. A PDV probe uses a lens to direct light to and from a surface through the same single-mode optical fiber.

For the upcoming Gemini Subcritical Experiments (SCEs) at U1a, NSTec considered differenct probes designed to increase the number of PDV measurement points per device. Three optical probes with different features were designed: 1) the discrete PDV probe, a ball of small discrete PDV probes with one small collimator lens for each optical fiber; 2) a multifaceted prism probe, an array of seven miniature relay lenses with a multifaceted prism (several optical fibers per relay); and 3) a fisheye probe (ultimately chosen for dynamic testing). Figure 1 shows views of the discrete probe and the multifaceted prism probe; Figure 2 shows a view of the fisheye probe design.

The discrete probe design, developed by Los Alamos National Laboratory (LANL), is made up of a ball with small, discrete optical fiber collimators, each pointed to a point of interest. This LANL design was based on a previous design developed under a Site-Directed Research and Development project by NSTec's Vince Romero[1] in 2005 for a prototype optical pin dome. The multifaceted prism probe, developed at NSTec by Robert Malone,[2] relies on a multifaceted prism configuration in which seven different fiber optic arrays send light through seven miniature relay lens stacks in a six-around-one configuration. Six arrays per lens stack reflect light off a six-faceted prism. The center array/lens stack sends light through a hole in the prism. The fisheye probe is described in more detail below. Both the multifaceted prism probe and fisheye probe were completely new designs that progressed from concept to field-ready units in a very short time.

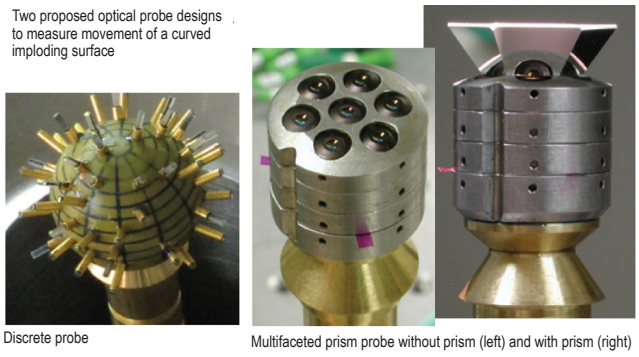

Figure 1. Two Advanced Optical Cavity (AOC) probes evaluated for the Gemini SCE series.

Fisheye Probe

Initial tests of the new PDV probes were conducted in August and September 2011. For these tests, approximately 44 points were measured for each probe. Each performed

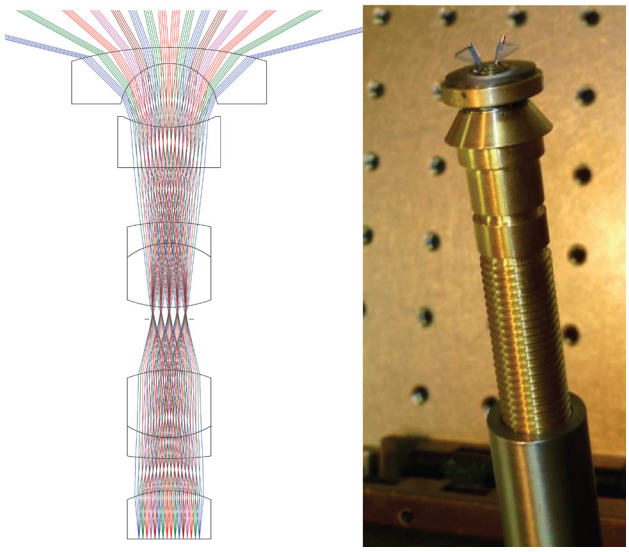

Figure 2. Left - An optical ray tracing software model of the fisheye probe. Right - Fisheye probe as fielded on the second LANL optical dome test, August 25, 2011.

well and could have many more points added. All three collected high-quality dynamic data and met the minimum physics and diagnostic requirements for the Gemini series. However, based on probe differences in physical size, achievable density of angular coverage, capability to support spare fibers aimed at regions of interest, the degree to which all rays appeared to originate from a common point, and likely robustness, the fisheye probe was chosen for use on upcoming experiments.

Some features of this probe stand out. One is that the front fisheye element does not encroach too much into the center of the imploding hemisphere. This is important because ideally experimentalists want the measurement to record data until the shock wave impacts the probe; therefore, the smaller the probe is, the better its ability to record late-time measurements. This probe also uses an index-matching gel between the fiber array and the first lens to keep all fibers at the same plane and reduce high return loss or back-reflections associated with the end of the fibers and the glass-air interface between the fiber array and the first lens. This fiber/lens assembly is assembled as one unit into a tube that is later inserted into the larger tube holding the fisheye lens. This approach allows the focus for the entire probe to be adjusted at once and optimized before final assembly.

To cover such a large angular field-of-view (greater than a hemisphere), a simple fisheye lens has some inherent distortion at the largest angles. This distortion causes these spots to become elliptical and less efficient during PDV measurements. Therefore, small prism mirrors were added for better high-angle measurement. These prism mirrors introduce some 'dead' regions that cannot be measured and are, therefore, kept small (see Figure 3).

While developing this diagnostic, researchers learned how to maximize performance. First, good anti-reflection coatings are needed on the lenses to keep down back reflections. Second, index-matching gel helps reduce the variation in the reflection at the fiber to index-matching element interface. The fiber polishing quality at this interface is also critical. Because the lens has high magnification, focusing to best position is sensitive and best done actively using a near-IR camera. Where it is desirable to have measurement points close to each other to probe specific mechanical features, the fibers can be moved into contact with each other and smaller-diameter fibers can be used. The lens diameters have also been cut down to fit into a smaller tube. One major advantage of this probe is that the fiber bundle can be assembled to the lenses after feeding it through a blast tube used in Gemini experiments so that fiber connectors do not need to be cut off and reattached.

The fisheye probe will continue to be refined, with several small changes being made to the next iteration: the top fisheye element will be made slightly smaller in diameter and the prism mirror made longer. This will allow the prism mirrors to direct more measurement points to high angles but still allow long tracking distances. We are changing the mounting of the prism mirrors for greater robustness. More fibers will be added so that more than 100 data points can be measured. A few large core optical fibers will be included; these will monitor the condition of the static surface of the structure being explored. Finally, smaller single-mode 80-micron diameter cladding fibers will be used to measure points in very close proximity and, thus, improve angular resolution.

Optical velocimetry is advancing rapidly to make continuous surface movement measurements in an imploding geometry with many measurement points. Recent tests have taken this technology from concept to field-ready units in a very short time. By using multiplexing PDV methods to record up to eight probe signals (overlaying four signals in frequency and two signals in time) on each high-bandwidth digitizer, experiments that generate a hundred or more PDV signals now are affordable, enabling studies of much higher spatial resolution to answer performance issues of the enduring nuclear weapon stockpile. The combined advanced optical cavity and multiplexing PDV technologies may represent a major "game changer" in how future hydrodynamic experiments

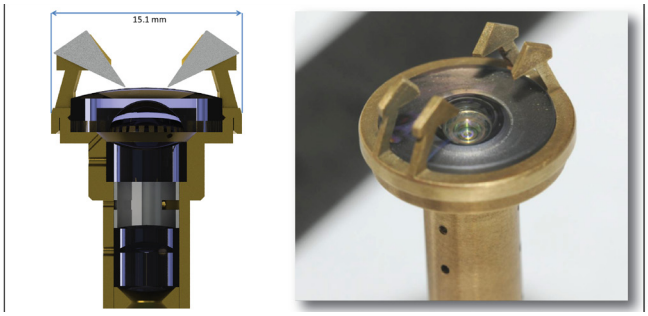

Figure 3. Improved mounting for small prism mirrors (not shown in right photo) on the fisheye probe. These mirrors provide better high-angle measurement.

are diagnosed and should enable a major increase in data captured and information gleaned from each experiment.

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Progress Toward Ignition on the National Ignition Facility by Robert Kauffman (Lawrence Livermore National Laboratory)

The National Ignition Facility (NIF) is a 192-beam laser facility at Lawrence Livermore National Laboratory (LLNL) completed in 2009. NIF is the world's most energetic laser facility for research in inertial confinement fusion (ICF), high energy density science (HEDS) and other stockpile stewardship research, advanced energy production, and basic science.[1] NIF is fully operational and has demonstrated its ability to meet its design goals of 1.8 MJ laser energy.[2] Ignition experiments are under way, and significant progress has been made toward its goal of ignition and burn in the laboratory.

The ignition research is conducted as part of the National Ignition Campaign (NIC), an enhanced management program by the NNSA. NIC is a national partnership of LLNL, Los Alamos National Laboratory, Sandia National Laboratories (SNL), the University of Rochester Laboratory for Laser Energetics (UR-LLE), General Atomics (GA) and a number of other collaborators, including Lawrence Berkeley National Laboratory, the Massachusetts Institute of Technology (MIT), the U.K. Atomic Weapons Establishment, and the French Atomic Energy Commission. The goal of the NIC program is to demonstrate a reliable and repeatable ignition platform and develop NIF as a user facility for its multiple missions. NIC encompasses all of the capabilities required for ignition experiments, including development of the diagnostics, targets, target cryogenic system, phase plates and other optics, and personnel and environmental protection equipment. Experiments on OMEGA at UR-LLE, NIF and other facilities provide the technical basis for ignition experiments.

The principal approach to ignition on NIF is indirect drive.[3] A schematic of an ignition target is shown in Figure 1. The laser beams are focused through laser entrance holes at each end of a high-Z cylindrical case, or hohlraum. The lasers irradiate the hohlraum walls producing x-rays that ablate and compress the fuel capsule in the center of the hohlraum. The hohlraum is made of Au, U, or other high-Z material. For ignition targets, the hohlraum is ~0.5 cm in diameter by ~1 cm in length. The hohlraum absorbs the incident laser energy producing x-rays for symmetrically imploding the capsule. The fuel capsule is a ~2-mm-diameter spherical shell of CH, Be, or C filled with DT fuel. The DT fuel is in the form of a cryogenic layer on the inside of the capsule. X-rays ablate the outside of the capsule, producing a spherical implosion. The imploding shell stagnates in the center, igniting the DT fuel.

NIC has overseen installation of all of the hardware for performing ignition experiments, including the commissioning of approximately 50 diagnostic systems in NIF. The diagnostics measure scattered optical light, x-rays from the hohlraum over the energy range from 100 eV to 500 keV, and x-rays, neutrons, and charged particles from the implosion. An example of a diagnostic is the Magnetic Recoil Spectrometer (MRS) built by a collaboration of scientists from MIT, UR-LLE, and LLNL shown in Figure 2. The MRS measures the neutron spectrum from the implosion, providing information on the neutron yield and areal density that are metrics of the quality of the implosion.

Experiments on NIF extend ICF research to unexplored regimes in target physics. NIF can produce more than 50 times the laser energy and more than 20 times the power of any previous ICF facility. Ignition scale hohlraum targets are three to four times larger than targets used at smaller facilities, and the ignition drive pulses are two to five times longer. The larger targets and longer pulse lengths produce unique plasma conditions for laser-plasma instabilities that could reduce hohlraum coupling efficiency. Initial experiments have demonstrated efficient coupling of laser energy to x-rays. X-ray drive greater than 300 eV has been measured in gas-filled ignition hohlraums and shows the expected scaling with laser energy and hohlraum scale size.[4]

Experiments are now optimizing capsule implosions for ignition. Ignition conditions require assembling the fuel with sufficient density and temperature for thermonuclear

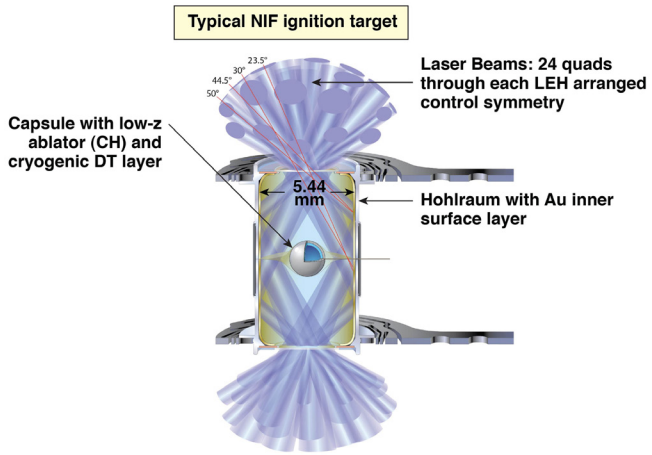

Figure 1. Schematic of a NIF indirect-drive hohlraum target. The lasers irradiate the high-Z hohlraum wall, imploding the spherical capsule in the center containing the fusion fuel.

burn. X-rays ablate the outside of the capsule, accelerating and spherically compressing the capsule for assembling the fuel. The implosion stagnates, heating the central core and producing a hot spot that ignites and burns the surrounding fuel. The four main characteristics of the implosion are shell velocity, central hot spot shape, fuel adiabat, and mix. Experiments studying these four characteristics of implosions are used to optimize the implosion.

Integrated experiments using cryogenic fuel layer experiments demonstrate the quality of the implosion as the optimization experiments progress. The final compressed fuel conditions are diagnosed by measuring the x-ray emission from the hot core and the neutrons and charged particles produced in the fusion reactions. Metrics of the quality of the implosion are the neutron yield and the shell areal density, as well as the size and shape of the core. The yield depends on the amount of fuel in the hot core and its temperature and is a gauge of the energy coupling to the fuel. The areal density (the density of the fuel times its thickness) diagnoses the fuel assembly, which is measured using the fraction of neutrons that are down scattered passing through the dense shell.

The yield and fraction of down scattered neutrons, or shell rho-r, from the cryogenic layered implosions are shown in Figure 3. The different sets of data represent results after a series of implosion optimization experiments. Both yield and areal density show significant increases as a result of the optimization. The experimental Ignition Threshold Factor (ITFX) is a measure of the progress toward ignition.[5] ITFX is analogous to the Lawson Criterion in Magnetic Fusion. Implosions have improved by more than a factor of 50 since the first cryogenic layered experiments were conducted in September 2010. This increase is a measure of the progress made toward the ignition goal in the past year. Optimization experiments are planned in the coming year for continued improvement in implosion performance to achieve the ignition goal.

In summary, NIF has made significant progress toward ignition in the approximately 30 months since project completion. Diagnostics and all of the supporting equipment are in place for ignition experiments. The NIC is under way as a national collaborative effort of all the NNSA science laboratories as well as international partners. Experiments have shown that hohlraum conditions can produce x-ray drive temperatures needed for ignition with low levels of preheat. Cryogenic implosions have shown remarkable progress during the first year of experiments, and continued improvements are planned for this year to attain the ignition goal.

Figure 2. The Magnetic Recoil Spectrometer (MRS). The MRS, fielded by a team from MIT, UR-LLE and LLNL, measures the neutron spectrum from an implosion to determine the yield and areal density.

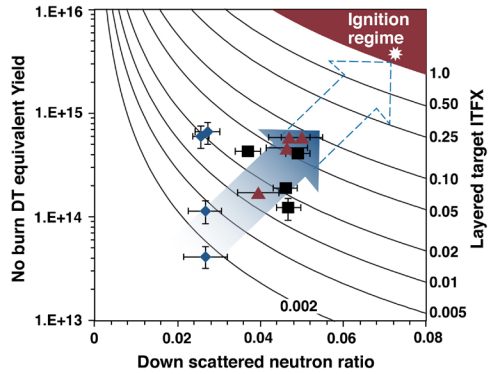

Figure 3. Results showing the neutron yield and areal density from layered cryogenic implosions. The progress toward ignition is shown by the improvement in ITFX.

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Z New Capability Workshop at Sandia National Laboratories (SNL)

The objective of the Z New Capability Workshop held at SNL on October 12-13, 2011 was to receive new ideas for technologies to improve the experimental platforms and diagnostics on Z. The 28 presentations given contained a wealth of capability suggestions for inertial confinement fusion, dynamic materials, radiation effects, and fundamental science experiments. The workshop, a critical step in formulating an overarching plan to improve the platforms (i.e., pulsed-power, cryogenics, containment, etc.) and the diagnostics, was attended by an advisory panel composed of internal and external scientists. That panel will provide the management team with recommendations on the relative merits of the proposed ideas, which will then feed into a multi-year plan to implement new capabilities on Z. — Greg Rochau

Commissioning the Underground Radiographic Source Accelerator (URSA Minor): The First Linear Transformer Driver (LTD)-Based Accelerator for Radiography by B.V. Oliver, J. Leckbee, T. Pointon and T. Webb (Sandia National Laboratories) and D. Droemer (National Security Technologies, LLC)

Pulsed-power-driven electron-beam diode x-ray sources have been used for radiography of hydrodynamic experiments since the 1960s,[1] when Charlie Martin first introduced the application at the Atomic Weapons Research Establishment in Aldermaston, U.K. (now the Atomic Weapons Establishment). The Advanced Radiographic Technologies Department at Sandia National Laboratories (SNL) has been conducting research and development of such systems with a long-term goal to improve and modernize the present-day capabilities. Two key areas of research are being conducted to optimize the radiographic systems: 1) development of ever brighter electron beam diode x-ray sources and 2) development of advanced accelerator architectures to drive the diodes.

In FY 2011, the small-scale URSA Minor was commissioned at SNL. This is a 21-cavity LTD accelerator built to evaluate the suitability of the LTD technology for flash x-ray radiographic applications. It is an expansion of a seven-cavity LTD that was built by the High Current Electronics Institute (HCEI) in Tomsk, Russia and was tested at SNL from 2005 to 2009.[2,3] Previous research and development had concentrated on modifications to optimize pulsed power performance (e.g., switching, reliability, etc.). Beginning in late 2009, SNL and National Security Technologies, LLC (NSTec) collaborated to manufacture and procure parts to increase the energy of the accelerator from 800 keV to 2.4 MeV. Assembly and authorization for operation occurred in late 2010 with commissioning and the fielding of radiographic diodes occurring in the summer of 2011.

A LTD is a type of inductive voltage adder (e.g., RITS-6[4,5]) where the primary energy storage is packed inside the induction cavities. Inside each cavity, the energy storage capacitors are arranged as parallel, single-stage Marx generators. Each single-stage generator contains two capacitors discharged through a spark gap switch in a low-inductance geometry commonly referred to as a LTD brick. The primary energy storage discharge circuit inductance is sufficiently low to provide the desired 50- to 100-ns electrical output pulse without the use of pulse compression stages. This fact significantly reduces the accelerator size as compared to conventional short-pulse voltage adders. The pulse shape is determined primarily by the inductance and capacitance of the individual bricks in the cavity. The voltage is defined by adding individual cavities in series.

In its present configuration, URSA Minor has 21 cavities assembled in three groups of seven, as shown in Figure 1. It is capable of producing a 100-ns electrical pulse with a peak voltage of 2.4 MV and a peak current of 80 kA. The cavities are configured to generate a negative polarity output pulse and have now been coupled to a Self-Magnetic Pinch (SMP)[5] radiographic diode load at endpoint energies between 1.5 and 2.0 MeV.

The SMP diode is a bi-polar space-charge limited diode which produces an intense (100 kA/cm^2), relativistic electron beam. The electron beam is emitted from the cathode, accelerated in an anode-cathode vacuum gap, and transported to a high atomic number target (typically Ta or W), where it is stopped and produces Bremsstrahlung radiation. The beam of electrons heats the anode to > 400°C within a few nanoseconds, enabling space charge limited ion emission from the surface. The ion space charge provides nearly complete charge neutralization of the electron beam. This causes the beam to pinch onto the converter target due to its self-magnetic field, resulting in a high-brightness (small spot) x-ray source.

Figure 2 shows results from a rolled-edge penumbral measurement to determine the source profile. The diode produced 7.3 rads, measured at one meter, with an endpoint energy of 1.7 MeV. Both the edge-spread function and its derivative (the line-spread function) are plotted. The full width at half measure of the line-spread function is 1.3 mm. Also shown in Figure 2 is an image of a resolution target and multiple step wedges taken with a radiographic magnification of 1.3. The resolution target has slits ranging from 0.1-2.5 line pairs per millimeter, and preliminary analysis indicates a resolution limit of 2.0 line pairs per millimeter. Five different step wedges are also shown in the image. From top to bottom, the four long wedges include a continuously tapered tantalum wedge and three step wedges made from aluminum, copper, and tantalum. The circular step wedge at the bottom is tungsten with a thickness of 16 mm in the center, resulting in a mass density ~30 g/cm^2.

These results demonstrate the scalability of the LTD architecture to higher energy and its suitability to drive a radiographic diode. All of which has been accomplished at a greatly reduced footprint compared to present-day radiographic systems.

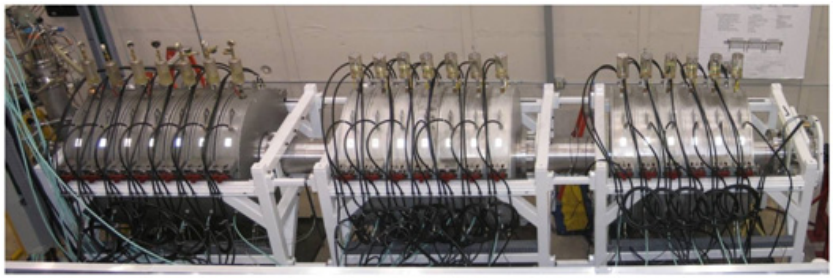

Figure 1. Photograph of the 21-cavity URSA Minor LTD system with one cavity removed. The electron beam load (not shown) is to the left of the accelerator in this photo.

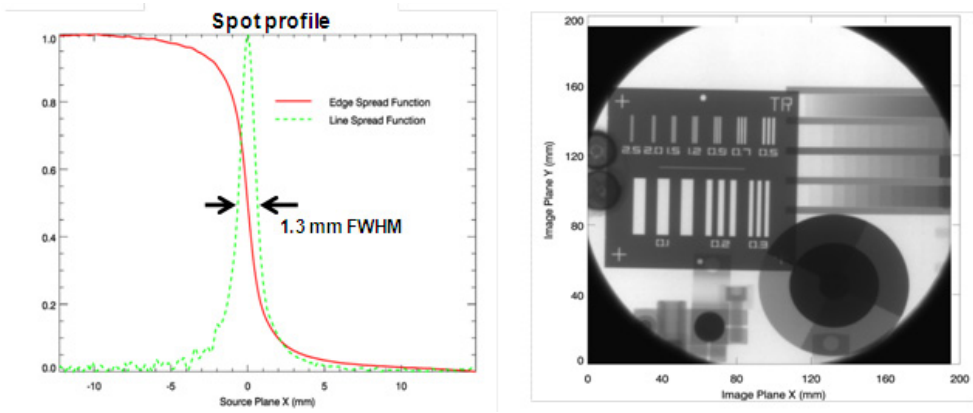

Figure 2. Left - The edge-spread function (red line) and line-spread function (green line) of a SMP x-ray diode fielded on URSA Minor. Right - A radiograph of a resolution target and step-wedges.

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Publication Highlights by Christopher Werner

This section highlights a recent publication in a high-impact scientific journal of research supported by the NNSA Office of Stockpile Stewardship.

Measurements of the Differential Cross Sections for the Elastic n-^{3}H and n-^{2}H Scattering at 14.1 MeV by Using an Inertial Confinement Facility,

J.A. Frenje et al., Phys. Rev. Lttrs. 107, p. 122502, 2011.

Researchers typically probe nuclear reactions using conventional accelerators. In a unique experiment published in Physical Review Letters (Sept. 16, 2011, Vol. 107), Johan Frenje and fellow researchers from the Massachusetts Institute of Technology, Lawrence Livermore National Laboratory, and the University of Rochester Laboratory for Laser Energetics used the Omega Laser Facility to make precise measurements of the elastic scattering of neutrons off deuterium (D) and tritium (T). This is the first time that fundamental nuclear physics results have been obtained using a high energy density laser facility.

In this work, the research team created hot, dense plasma, a condition where the electrons are stripped off their parent atoms creating an interpenetrating gas or "soup" of positive and negative charges. To achieve this plasma condition on OMEGA, all 60 of its laser beams strike the outer surface of a 1 mm-diameter glass capsule that is filled with D-T (see Figure 1). The laser beams generate a rapidly expanding high-temperature plasma gas on the surface of the capsule, causing the capsule to implode. This implosion creates a 108 K plasma of D-T ions and electrons inside the capsule. A small fraction of these D-T ions fuse together, generating energetic 14.1-million-electron-volt neutrons that travel at 1/6 the speed of light. In contrast, an ordinary chemical reaction—the burning of wood—generates about 1 electron volt of energy. As these energetic neutrons race

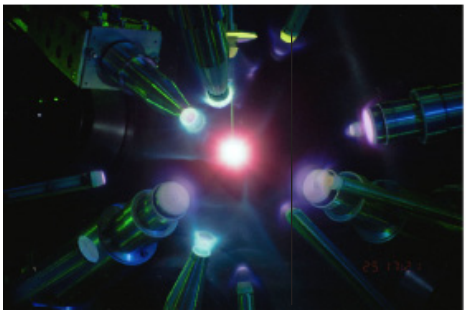

Figure 1. The Omega chamber seen during an implosion. Several diagnostics are illuminated by the impinging laser light. The horizontal distance in the picture is about 2 meters across. (*Photo by Eugene Kowaluk*)

out of the imploding capsule, a small fraction collide and scatter off the surrounding D and T ions. From these rare collisions, and from the corresponding transfer of energy from the neutrons to these D and T ions, a highly accurate measurement of this nuclear collision process is obtained. Using accelerator-based measurements to normalize the absolute cross-section, the shape of the low-energy cross section is obtained with much more accuracy than possible with accelerators. Importantly, the experimental results match ab initio calculations well, providing not only a boost to nuclear theory but also data on reactions of crucial importance to nuclear astrophysics and to fusion energy research.

The researchers believe that important variations of this technique will soon be realized leading to innovative experiments of other fundamental nuclear processes. One such experiment is the fusion of ^{3}He and ^{3}He ions, important because it is the dominant energy producing step by which our sun generates its energy. With this class of experiments imminent, a new and exciting field of research is ushered in, Plasma Nuclear Science, that blends together the separate disciplines of plasma and nuclear physics.

2011 NNSA Stewardship Science Graduate Fellowship Class

Six new doctoral candidates became the latest NNSA Stewardship Science Graduate Fellowship (SSGF) class this past fall. The program supports 20 students researching areas of interest to stewardship science, including high energy density physics, nuclear science, and materials under extreme conditions and hydrodynamics. The fellowship covers all tuition and fees and provides a $36,000 annual stipend, a $1,000 annual allowance for research or professional development, a 12-week research practicum at a NNSA national laboratory, and travel to an annual conference in Washington, D.C. The newest fellows are introduced below.

2011 NNSA SSGF Class (L-R): Christopher Young, Walter Pettus, Jennifer Shusterman, Adam Cahill, Geoffrey Main, and John Gibbs.

Adam Cahill studies plasma physics under David Hammer at Cornell University. His research focuses on the physics of z-pinches, especially the growth and early time development of instabilities found in tungsten plasma as it accelerates toward the wire array central axis. The instabilities cause material to nonuniformly collect on the axis, reducing the z-pinch x-ray output, Cahill says. Previous research has focused on saturation of the instability's wavelength in late time. M. Eng., University of Louisville, 2004.

John Gibbs' research under Peter Voorhees at Northwestern University looks at the process of coarsening: particles in a multi-phase material grow in size but decline in number density. Coarsening occurs in many kinds of materials, including oil and water emulsions and mixtures of liquid and solid metals, where it plays a major role in microstructure development and affects the material's final properties. Gibbs plans to implement a phase field simulation of the coarsening rate in liquid-solid metal mixtures. He expects to validate the model with comparisons to coarsening measured experimentally with in-situ x-ray tomography. B.S., 2008, and M.S., 2009, Metallurgical and Materials Engineering, Colorado School of Mines.

Geoffrey Main works with Charbel Farhat at Stanford University to simulate compressible multi-material flows and their interactions with flexible structures, with an emphasis on the extreme pressures and velocities found in underwater implosions and explosions. Computational tools for single-medium flows are well developed, but algorithms for multi-medium flows are less mature. Fast, accurate and robust simulations of problems involving materials under extreme conditions are problematic, Main says. He has already developed implicit integrators for multifluid and multistructure problems and demonstrated an implicit integrator that maintains the same accuracy as an explicit integrator while demonstrating a 19-fold speedup on a multifluid air-water problem. Applying the schemes to fluid-structure problems has yielded 40-fold speedups. Main believes larger speedups are still possible. B.S., Mech. Engr., University of Virginia, 2009.

Walter Pettus studies dark matter with Karsten Heeger at the University of Wisconsin, Madison. Pettus has been involved with planning and deploying DM-Ice, a direct detection dark matter experiment at the South Pole, through planning and prototype development. He now works on running and planning the full-scale experiment. DM-Ice will use low-background thallium-doped sodium iodide scintillating crystals to measure the expected annual modulation in the dark matter signal. The detectors will be frozen 2,450 meters deep in the polar ice. Pettus works to characterize properties of, and address concerns with, the NaI (Tl) detector configuration, including the low energy threshold, temperature dependence of the light response and calibration of a remotely operated detector. B.A., Physics, Hillsdale College, 2009.

Jennifer Shusterman uses time-resolved laser fluorescence spectroscopy (TRLFS) to examine actinides and their behavior in the environment in her research under Heino Nitsche at the University of California, Berkeley. Results could lead to more precise predictions of actinide behavior in the environment and to better stewardship of nuclear materials. Highly mobile oxidized actinide species in oxic environments have the potential to leach into groundwater from nuclear wastes. Shusterman studies the solubility and sorption behavior of these species, focusing TRLFS on curium as a test case. She seeks thermodynamic stability constants and information about curium's oxidation state in a given environment, providing clues to immobilizing it. B.S., ACS-Certified Chemistry/Engineering Science, Tufts University, 2010.

Christopher Young studies plasma physics and thermo-sciences under Mark Cappelli at Stanford University. His focus is on aspects of a cylindrical plasma accelerator that he designed and built while a Stanford undergraduate. Such accelerators could be used to propel small satellites or space vehicles; but to improve their performance and lifetime, it's necessary to understand the interactions between charged particles and applied fields and to accurately resolve the propellant ionization process. Young focuses on incorporating measured plasma potential data into a kinetic electron simulation that attempts to explain how electron transport to the propellant channel occurs across strong magnetic cusps. Later, he may investigate ion dynamics in the plasma sheaths formed at the channel wall near strong magnetic cusps. B.S., Engineering Physics, Stanford University, 2010.