Office of Research, Development, Test, and Evaluation

Stockpile Stewardship Quarterly

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Message from the Office of Research, Development, Test, and Evaluation

Dr. Ralph Schneider, Director, Office of Research and Development
and Dr. Keith LeChien, (Acting) Director, Office of Inertial Confinement Fusion

It is important to remind ourselves of the progress we have made in the past two decades. With the cessation of underground testing in 1992, it was recognized that it was important to build a sustainable science-based program that probed regions of physics that were only previously accessible through nuclear testing. It was envisioned that a "science-based stockpile stewardship program" would be able to attract, train, and retain the future stewards of the stockpile, as well as underpin the annual assessment of an aging stockpile and resolve surveillance questions. Advanced computer platforms and algorithms were needed, as were modern experimental facilities for hydrodynamic testing (Dual Axis Radiographic Hydrodynamic Test Facility), subcritical plutonium (U1a Complex), and high energy density (National Ignition Facility, Z, and Omega) research. The article by Webster, Wallin, Herrmann, Haynes, Chadwick, Wan and Sapone is an excellent summary of how far we have come in building the experimental "power tools" of stewardship. It is important to note the intimate relationship between the experimental and Advanced Simulation and Computing (ASC) program computational tools. The article by Anderson shows how the data generated in these experiments eventually end up within the libraries and algorithms contained in the modern ASC computational tools.

Now as we enter the third decade of stewardship, these power tools of stockpile stewardship must turn to a new challenge, the ability to certify the life extension activities for the stockpile, as well as the need to have a way to "train the next generation certifiers," the nuclear weapon designers whom have not had the benefit of training by underground testing. In response to these changes, the NNSA national laboratories established the Predictive Capability Framework (PCF) Council to revise the plans to align with the Directed Stockpile Work life extension plans and this new vision. The results of the PCF Council's efforts are encapsulated in the PCF revision which is described in the article by Hanrahan.

To support these new technical challenges, it was recognized by NNSA Deputy Administrator for Defense Programs Don Cook that there was an experimental capability that needed to be enhanced in order to assess the performance of aging materials and underwrite newly manufactured, reused, or repurposed component qualification and, finally, support the laboratory directors' life extension program certification. The subcritical experimental capability needed to be enhanced with new diagnostics to perform sub-scale experiments at high levels of integration. The articles by Froggett, Droemer, and Stevens describe some of the early diagnostics developed for this purpose that were applied in the Gemini series of subcritical experiments. The other enhanced capabilities needed—enhanced radiography and neutron diagnosed subcritcal experiments—are in development and are planned to be implemented before this decade is out.

The next generation of stockpile stewardship will be comprised of enduring capabilities for nuclear deterrence. These include the testing of the next generation weapons designers through integral experiments in implosion design; the validation of codes through fundamental and focused experiments in high energy density physics, dynamic material science and nuclear physics; the development of threat-relevant radiation-driven hostile environment platforms; the transition to next generation high performance computing platforms; and the strengthening of microscale and mesoscale materials science to support the evolving field of advanced manufacturing. •

Inside

Comments
The *Stockpile Stewardship Quarterly* is produced by the NNSA Office of Research, Development, Test, and Evaluation. Questions and comments regarding this publication should be directed to Terri Stone at terri.stone@nnsa.doe.gov. | Technical Editor: Dr. Joseph Kindel | Publication Editor: Millicent Mischo

The Predictive Capability Framework 2.0 *by Robert Hanrahan (National Nuclear Security Administration)*

The Predictive Capability Framework (PCF) was launched in 2006 as a mechanism for communicating the linkage of experimental, computational, and major facility milestones required to demonstrate improvement in prediction of nuclear weapons performance as the stockpile ages and evolves through life extension programs. The PCF was originally designed to map out anticipated improvements through 2020. Each major objective was represented with a pegpost representing a future level 1 or level 2 milestone. The term "pegpost" was chosen to communicate that, recognizing the difficulties in all types of prediction, the particular goals might move in time, change in significance, or be rendered obsolete by new knowledge. Over the past seven years, several major pegposts have been completed, and many more have been moved, added, or deleted. In 2013, we found ourselves halfway through the original projected timeframe of the PCF (see Figure 1) and realized that it was time to examine the entire suite of challenges facing stockpile stewardship and coordinate an update of the PCF.

Accordingly, the PCF Council undertook a "blank sheet" of paper approach to evaluating the spectrum of key technical challenges to stockpile stewardship. In July 2013, the PCF Council submitted a 35-page classified white paper to the National Nuclear Security Administration. In the white paper, the council described the identified challenges and proposed changes to the binning of the work (the "strands," the order of challenges to be addressed, and the emphasis of the pegposts). Consequently, consolidations made in the revised PCF have taken it from five to four strands (see Figure 2).

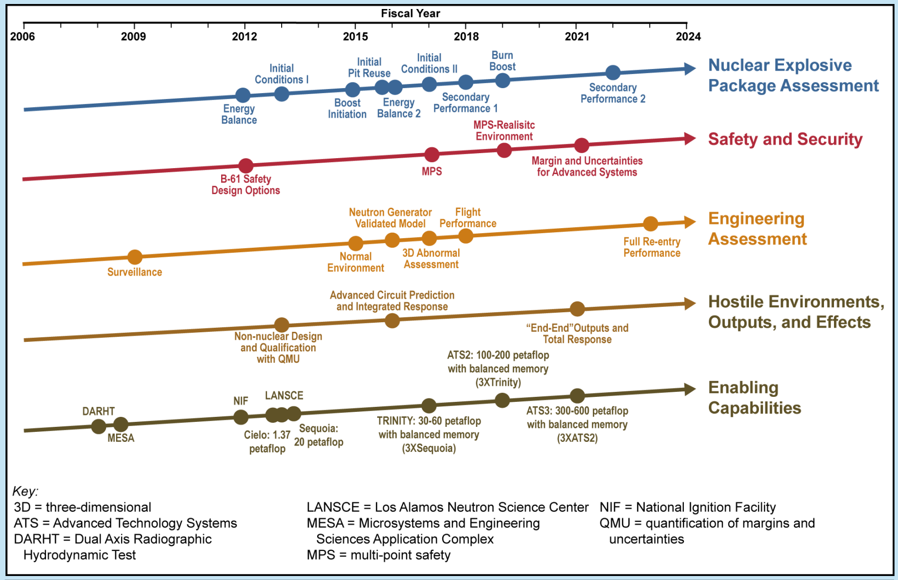


Figure 1. PCF (February 2013).

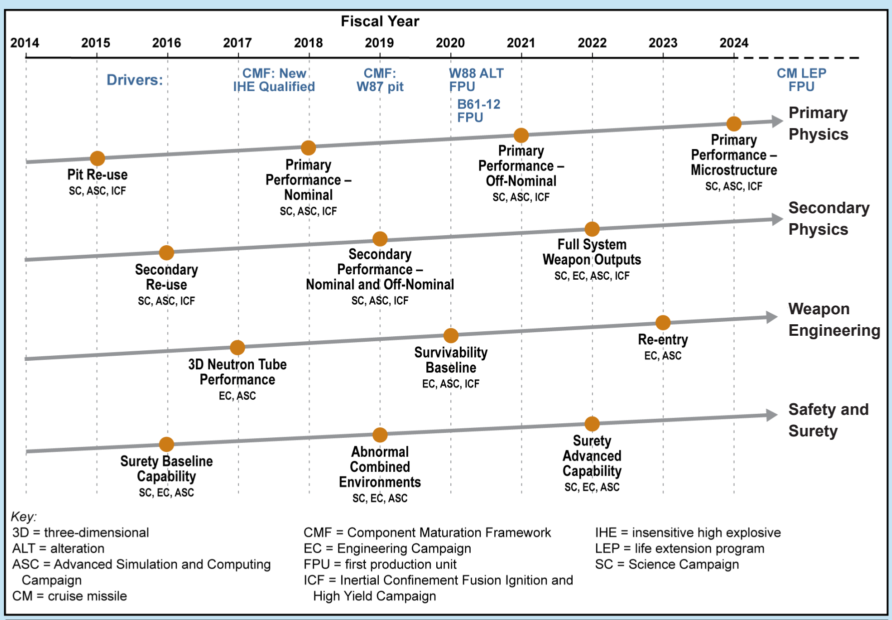


Figure 2. PCF 2.0 (December 2013).

Important near-term examples of the PCF pegposts are in 2015 and 2016 for Primary Physics and Secondary Physics assessments underwriting the reuse of nuclear components. These are driven by the need to ensure that the predictive capabilities are in place to underwrite the most likely design options that were identified by recent Life Extension Program studies for both the Long Range Standoff and Interoperable Warhead-1, including pit reuse recertification and secondary reuse. The out-year pegposts build on these capabilities by developing advanced models and methods to enable higher-fidelity assessments of the performance impacts caused by engineering, manufacturing, and aging features. Finally, the culmination of all these advances will support the ability to certify a new generation of advanced surety solutions and the delivery of high-fidelity, full-system weapon outputs along with their impact to the surrounding environment. •

A Quick Tour of the Role of Experimental Facilities in Stockpile Stewardship

by Robert Webster, Mark Chadwick, and Don Haynes (Los Alamos National Laboratory); Brad Wallin, Dan Sapone, and Alan Wan (Lawrence Livermore National Laboratory); and Mark Herrmann (Sandia National Laboratories)

The experimental facilities supported by NNSA's Office of Research, Development, Test, and Evaluation are an integral part of stockpile stewardship. While the present state of understanding of nuclear weapons performance is very good, it relies on having adequate models of the behavior of materials under extreme and highly dynamic situations typical of the interior of a functioning nuclear weapon. At present, the theoretical modeling of materials in those extreme conditions is incomplete, and we fill in the gaps in knowledge, as needed, with the strong suite of experimental capabilities that is available.

Fundamentally, we cannot perform experiments on materials that simultaneously achieve the size, density, and temperatures that are accessed within a nuclear weapon. Such experiments would require releasing an amount of energy equivalent to a weapon and cannot be achieved in the absence of nuclear testing. Instead, today's stewards rely on the development of general scalable models of material response, and test those models in different regimes, ranging from hot and dense (but of small scale) to relatively cold and large. The final evaluation of the implications of such material models is then accomplished using massive high-performance simulations.

High Energy Density Facilities

To evaluate materials that are hot and dense, we use the so called high energy density (HED) facilities: Omega, Z, and the National Ignition Facility (NIF). The Omega laser at the University of Rochester Laboratory for Laser Energetics provides shot rates that have allowed many studies, such as the development of improved models of material mixing, and the response of materials in the ensuing mixed state. These models can then be applied in weapons simulations. They have superior generality in calculating the results of underground nuclear tests over the historic method of local tuning of adjustable parameters in the weapon simulation codes. Indeed, the improved confidence that is available by underwriting our models through the use of above ground experiments has already impacted the uncertainties quoted during annual assessment of the stockpile, and has been used to clarify and reduce concerns of risk in some situations where material aging was observed during stockpile surveillance.

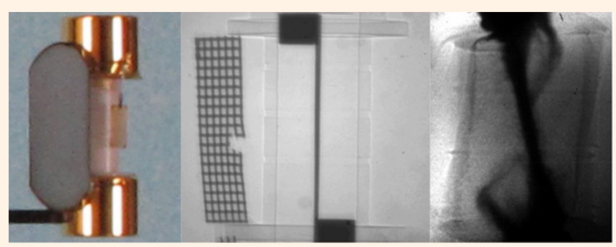
The Z facility at Sandia National Laboratories provides the capability to study unique dynamic material properties, radiation effects, and fusion experiments for materials ranging from hydrogen to plutonium. A recent focus on Z has been the study of plutonium constitutive properties in previously inaccessible regimes. These experiments are helping to refine our models of the plutonium equation of state and strength, both of which are critically important to developing a predictive capability for nuclear weapons. These data complement the data collected at the JASPER two-stage light gas gun, which is optimized to explore higher temperature states of plutonium metal.

With 1.8 MJ in 192 beams, NIF is designed to provide, in a controlled and repeatable setting, access to extreme physical conditions relevant to an operating nuclear weapon. Data collected in experiments at NIF underpin annual assessments of the current nuclear stockpile and certification of modifications made to stockpile warheads. As NIF transitions to a national user facility, a balanced program is being pursued of weapons physics experiments such as burn performance, high-pressure and high-rate material properties, radiation transport, complex hydrodynamics, and output and effects.

The HED facilities are useful for characterizing materials in regimes typical of the later phases of a nuclear

HED Shock/Shear Experiments to Support the Study of Material Mixing

The HED shock/shear experiments study extreme hydrodynamic processes. The experiments, started in 2011 on the Omega laser, are currently transitioning to NIF. Greater available driving energy and longer duration laser beams will allow the NIF version of the experiment to access faster speeds, drive more dense materials, and sustain the experiment for longer periods of time.



The experiments are built with different content and geometries, depending on what hydrodynamic phenomena they are used to study. In all cases, the millimeter-scale laser-driven target (left) is irradiated on both the top and bottom, driving strong shocks into the cylindrical tube body. In the shear experiment configuration (center), the shocks, separated by a metal plate when they are launched into the tube, pass each other by at the tube center. This creates an intense velocity difference on each side of the plate, allowing researchers to study the Kelvin-Helmholtz shear instability in high-Mach-number, high-density settings. Here, the instability leads to mixing and the initially smooth plate is driven into a rough, irregular shape (right). The flow speed difference from the left of the tube to the right is in excess of 100 km/sec.

– Doss et al., Physics of Plasmas 20, 122704, 2013.

explosion, but weapon performance begins in a state closer to room temperature. Material response in this regime tends to be complex, and requires modeling material strength and damage in addition to the equation of state. The experimental facilities needed for such characterization tend to be more diverse, and vary significantly in scale. The small scale or so called “table-top” experiments consist of equipment like Hopkinson bars and Taylor anvils, used to distort material, measuring the strength, ductility and, ultimately, the failure of materials under tension or compression in dynamic regimes. These experiments return data that is useful in characterizing material models at the macroscopic or “continuum” level required for engineering analysis. From the analyzed data, we are able to evaluate the validity of theoretical models such as stress-strain relationships and models of material fracture. Once determined to be valid, these models can be used in weapon simulations to evaluate the impact of material substitutions or aging on weapon performance.

Accelerators and Light Sources

Modeling at the continuum level is critical in the assessment of material performance, but proving the validity of the continuum-based models in the extreme environments encountered in a nuclear weapon can be difficult. To get truly scalable models of materials, it is sometimes necessary to model the material at a finer scale ranging somewhere between atomic and crystal. Probing the validity of models at these scales is not always well suited to the small-scale experiments described above. Instead, the research efforts supported in NNSA’s Office of Research, Development, Test, and Evaluation reach out to various accelerators and light sources around the country.

For example, recent experiments performed using ultrafast x-ray pulses from the Linac Coherent Light Source, SLAC National Accelerator Laboratory’s x-ray free electron laser, allowed us to image shock-driven collapsing of voids in single crystal samples of PETN, an explosive whose characterization is of interest within the Stockpile Stewardship Program. The experiments showed the shock wave, the collapsing of voids, and the material flow behind the shock wave. The imaging data will help us to understand the process of void collapse in explosives, which leads to hot spot formation and the initiation of chemical reaction. The diffraction data will provide critical information for characterizing the high explosive reactants under shock compression conditions.

As another example of the recent use of accelerators and light sources, we’ve performed dynamic compression experiments at the Advanced Photon Source at Argonne National Laboratory on high density polyethylene, and polytetrafluoroethylene, both semi-crystalline polymers, using time-resolved

Carbon Deuterium (CD) Symcap Campaign: Studying Gas/Shell Atomic Mix at the National Ignition Facility

The CD Symcap campaign utilizes a CH (deuterated plastic) capsule, filled with tritium (T) gas, with a thin layer of CD placed near the gas/shell interface, to study gas shell atomic mix. These experiments are performed at the National Ignition Facility using indirect drive by illuminating a hohlraum with 1.5 MJ of laser energy to drive the capsule implosion and measuring resultant deuterium (D)T yield, TT yield, ion temperature, and emitted neutron spectrum. A schematic of the capsule is shown in Figure 1a. When the plastic ablator mixes into the core, there are DT reactions from the mixed CD with the hot T gas. Figure 1b shows an ARES simulation of the CD Sycmap implosion that was featured on the cover of January 2014 issue of Physical Review Letters[1], showing the product of the D and T fractions. This plot shows the region were D is mixing into the core and DT neutrons are produced. Simultaneously, the core implosion performance is observed by measuring the TT yield observed using highest quality observations of the emitted TT neutron spectrum to date.[2]

Figure 1. a) Schematic of the CD Symcap capsule. The capsules are filled with pure tritium gas and contain deuterated plastic layers at various distances from the gas/shell interface. b) ARES simulation of a CD symcap implosion, featured on the January 2014 cover of Physical Review Letters, showing the mix of D from the plastic ablator with the T gas core. c) Measured DT to TT neutron yield ratio for CD Symcaps, as a function of the recession depth for the CD layer from the gas/shell interface. The DT/TT yield ratio, a measure of the atomic mix in the core, decreases as a function of recession depth demonstrating sensitivity of the platform to gas/shell mix. Results from ARES simulations are also compared to the observations.

[1]V.A. Smalyuk et al., Physical Review Letters 112, 025002, 2014.
[2]D.B. Sayre et al., Physical Review Letters 111, 052501, 2013.

x-ray diffraction to measure compression of the crystalline lattice and phase transitions. Using a slow-release gas membrane controller, polymer samples in diamond anvil cells were compressed at high strain rates, to a pressure "jump" of over 10 GPa. X-ray diffraction is used to probe how dynamic compression affects phase transition pressures and rates, and investigate viscoelastic effects in the long-chain structures under rapid compression.

We also use the Los Alamos Neutron Science Center (LANSCE) to supply basic nuclear and material data ranging from improving the accuracy of neutron cross section measurements to the use of neutrons to probe structural response in new and aged materials. For example, a project within Dynamic Materials Properties (Campaign 2) of the Office of Defense Programs' science campaigns is just finishing a neutron reflectometry study on PBX 9404 with a "dirty binder." (PBX 9404 is a high explosive that is of historical interest, and better characterization of this explosive will increase the utility of some data that was collected during the days of underground testing.) These neutron scattering experiments have explored the role of chemical formulation on the HMX crystal—binder interface for a number of formulations and linked these to macroscopic observable changes in material response. The studies of PBX 9404 HMX crystal/nitrocellulose binder interfaces have revealed interface structures distinct from previous observations on other formulations.

The LANSCE accelerator also enables the proton radiography (pRad) diagnostic. The penetrating power of high-energy protons, like that of x-rays, makes them an excellent probe of a wide range of materials under extreme pressures, strains, and strain rates. The charge of the particles allows them to be imaged with magnetic optics that provide unique advantages for penetrating radiography, producing especially sharp images. An example of integrated testing with pRad is the Goblin experiment, which was completed on January 28, 2014. Goblin was intended to test the fidelity of weapons hydrocodes under conditions resembling those encountered in a primary implosion. The pRad team at LANSCE acquired highly resolved, time-sequenced dynamic images that revealed the detailed character of the implosion. Pre-shot predictions provided a good overall description of the data, and we anticipate that detailed comparisons of predictions against the pRad "movie" of Goblin will provide important information to improve the accuracy of our hydrodynamic modeling. Looking forward, Goblin provides a prototype for future experimental platforms that will quantify specific aspects of primary behavior that influence boost.

Integral and Subcritical Experimental Facilities

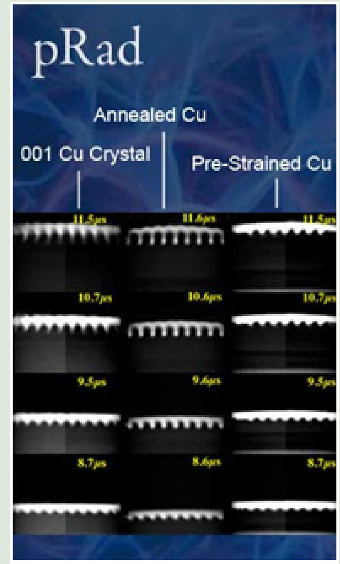
Once material models are known, the next crucial step is to evaluate that these models are all working together correctly in an integral sense. Facilities such as the Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) and Contained Firing Facility (CFF) play a vital role in establishing that the interplay is valid within the high-explosively driven regime. These facilities have an advantage of being able to operate at the actual scale of a nuclear weapon, albeit with surrogates used in place of special nuclear materials. We routinely use these facilities to address the adequacy of implosion systems in weapons under a variety of environments and in the presence of changes that are detected in the surveillance program.

During a hydrotest, scientists detonate a "mockup" of the primary stage of a nuclear weapons system. The mockup consists of actual high explosives, but not plutonium. Instead of plutonium, scientists use a non-fissile surrogate material that has similar weight, density, and other metallurgical properties so that it behaves much like the plutonium, but cannot produce nuclear reactions when the explosives are detonated.

The CFF was built at Bunker 801 at Site 300 to enable its flash x-ray accelerator (FXR)—the only wide-angle penetrating radiography accelerator in the NNSA complex—to be used in a contained environment. In addition to FXR penetrating radiography, the CFF also fields diagnostics that record arrival time of an explosively driven surface through use of pin domes and photon Doppler velocimetry (PDV) probes, a time velocity record of these surfaces using laser velocimetry, and visual records of the event using high-speed cameras. This combination of FXR, pin/PDV diagnostics, and laser velocimetry coupled with a large enclosed firing chamber provide a critical capability in the NNSA complex to obtain comprehensive data on the early phases

Proton Radiography, a Diagnostic That Spans Small-Scale and Integral Experiments

Invented at Los Alamos National Laboratory, proton radiography employs a high-energy proton beam to image the properties and behavior of materials driven by high explosives. The penetrating power of high-energy protons, like that of x-rays, makes them an excellent probe of a wide range of materials under extreme pressures, stress, and strain rates. The charge of the particles both affects scattering in interesting ways but allows them to be imaged with magnetic optics that gives them unique advantages for penetrating radiography such as very sharp images shown below. The incredible efficacy and versatility of proton radiography also stems from the ability to produce multiple proton pulses in an accelerator coupled with multiple optical viewing systems that can result in 20-40 frame movies.



of implosion for integrated weapons experiments.

DARHT consists of two linear induction accelerators that are oriented at a right angle to one another. Each electron beam is focused onto a metal target that converts the beam's kinetic energy into x-rays. Multiple x-ray pulses produce multiple-view radiographic images of a full-scale nonnuclear weapon mockup as it implodes. DARHT's two large x-ray machines produce freeze-frame radiographs—high-powered x-ray images—of materials that implode at speeds greater than 10,000 miles an hour.

The recent Gemini Experimental Series, hydrodynamic experiments at the U1a Complex at the Nevada National Security Site, has ushered in renewed interest in fielding integrated experiments with plutonium. The Gemini experiments produced an incredible amount of data through the maturation of the multi-probe PDV diagnostic. This diagnostic provided such complete coverage of the type of implosion data that it acquired, that features in the data that could have historically been attributed to noise are now recognized to be signals that warrant theoretical understanding. This data has challenged the limits of our understanding of plutonium response in certain shocked environments and further driven an increased desire for small-scale experiments as described above in order to explore the range of validity of the choice of surrogate materials used in the integral full-scale experiments at CFF and DARHT.

In the end, the goal is maintaining confidence in weapon performance and safety. Through the use of these facilities, we have been able to underwrite the essential weapon predictions through the present period of stockpile stewardship, and we've done that without the need to return to nuclear testing. The ability to achieve the size, density, and temperatures of materials for characterization that was possible with testing has been replaced by a combination of high performance computing and a broad suite of experimental facilities. Thus far, this strategy has been successful, and continues to evolve as we learn more about material response in weapon-relevant regimes. •

Developing a Predictive Capability *by Mark Anderson (Los Alamos National Laboratory)*

Stewardship of the nation's nuclear deterrent requires the ability to make defensible decisions regarding the safety, security, and reliability of the stockpile without additional nuclear testing. The inherent complexity of the nuclear weapon life cycle coupled with a stockpile that has aged and needs modernization necessitates the use of the most powerful computers available, along with models of the weapons based on the best available science and engineering knowledge. These models must be *predictive* in the sense that they need to produce accurate answers to stockpile questions for which no direct nuclear test data is available.

This predictive capability is supported by experimental science in a variety of ways. In addition to fundamental scientific theory, several classes of experiments are required:

Discovery—Experiments are required to reveal important physical phenomena that have not previously been modeled correctly or at all.

Calibration—Once a model has been proposed, experiments are necessary to identify the proper values of the parameters of the model.

Validation—After a model has been implemented in software, simulation results using that model must be compared with experimental data to ensure that those results accurately reflect physical reality.

Confirmation—Finally, once an engineered system has been manufactured, engineering qualification and nuclear performance testing are used to confirm (or refute) the predictions made during its development.

Many experiments have aspects of one or more of these classes. The only constraint is that experiments used for calibration of a specific model may not be used for validation of the same model. Confirmation experiments for integrated nuclear performance are precisely those experiments that are precluded by national policy. Consequently, a complete array of physics-based and empirical models accompanied by a comprehensive set of discovery, calibration, and validation experiments are vitally important in underwriting the predictive capability used for stockpile assessment.

These experiments represent a coordinated effort by the Advanced Simulation and Computing (ASC) program, the Science and Engineering Campaigns, and the Inertial Confinement Fusion (ICF) program. An array of experimental platforms and experiments are being developed and performed to support this joint effort. Examples of such experiments range from small-scale hydrodynamic instability experiments to full-scale weapon-like implosion experiments. In the following paragraphs, we will describe a few of these experiments designed to support a predictive capability.

Modeling the formation of micron- and submicron-scale material ejected from a shocked metal interface is one current focus. The complex physics of this process depends on the nature of the metal released state (solid, fluid or mixed-phase), the nature of the second medium (vacuum or shocked gas), and the topography of the interface inhomogeneities. Proton radiography (pRad), which uses a high energy proton beam to image the behavior of materials, provides an exquisite microscope for observing the temporal evolution of such interfaces from the incidence of a shockwave through the growth of surface Richtmyer-Meshkov instabilities (RMI) to their breakup and subsequent evolution. Recent double-shock pRad experiments have provided detailed information for current models of breakup. Tin, with a surface, characterized by two-dimensional sinusoidal inhomogeneities, $y = h_0 \sin(kx)$, of wavelength $\lambda = 900$ µm and amplitudes $kh_0 = 1/16$, 1/8, and 1/4, was shocked to pressures of order 24 GPa. One of the results of current models for the breakup of the evolving unstable fluid sheets produced is that the time to breakup is given by

$$t_{bu} = C_{bu} \frac{1}{\rho_{gas}} \frac{1}{(\Delta v)^2} \sqrt{\rho_{liq} h \sigma}$$

where ρ_{gas} is the shocked gas density, ρ_{liq} the sheet density, h the sheet thickness, σ the liquid metal surface tension and Δv the velocity of the sheet tip relative to the free surface. C_{bu} is a numerical constant. The images shown in Figure 1 dramatically validate the gas density dependence in this expression for Sn/He, Sn/Ne, and Sn/Ar interfaces. The details of shock growth are also providing critical data for validation of multi-shock ejecta models.

Another set of experiments looks at a very different regime. These experiments are used to validate models in the presence of pure shear. Shock-shear experiments at the National Ignition Facility (NIF) explore the growth of Kelvin-Helmhotz instability growth into a turbulent shear layer. Here, the flow is in a plasma state. These experiments investigate the ability of these models to de-mix upon a strong rarefaction that occurs later in time. The de-mix phenomenon is approximately the same as what would happen if you first turn a glass of water upside down then quickly turn it right side up; the flow at the start quickly becomes turbulent and the water and air mix only after the process is reversed and the flow de-mixes. The test article, firing point configuration, and images of experimental results for the shock-shear experiment are illustrated in Figure 2.

Integral validation experiments include hydrodynamic experiments, of imploding weapon assemblies using surrogate materials. These experiments are used to validate the set of models in the codes used to simulate implosion up to the time that nuclear processes would become dominant in a real weapon. The Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) is used to diagnose so-called "core punch" tests of weapon-like assemblies. DARHT is the world's largest, most powerful x-ray facility and is capable of looking inside an imploding assembly to reveal the configuration of assembly components during implosion. Figure 3 shows the DARHT facility and linear accelerator.

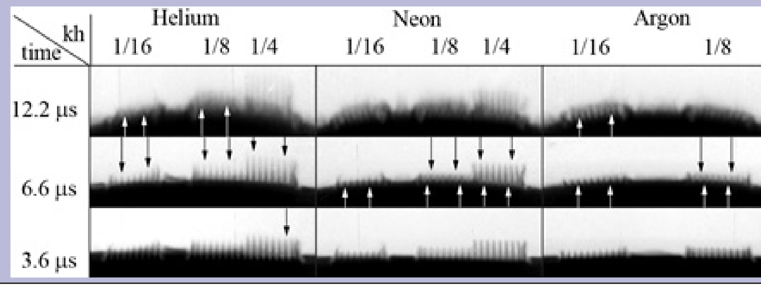


Figure 1. Double-shock RMI sheet transport at pRad. The lower images show only first-shock RMI (the second shock occurs at ≈4 µs). In the subsequent images, the white arrows indicate locations of RMI subsequent to the second shock (where we see them), and the black arrows indicate locations of the first shock instabilities. Of note: (1) the unperturbed flat interfaces between the perturbed regions are seen to ejecta quite a lot of mass at the second shock, (2) the second shock RMI grow fastest for the $kh_0 = 1/16$, and (3) the $kh = 1/8$ perturbations break up quickest in Ar, then Ne, and then He.

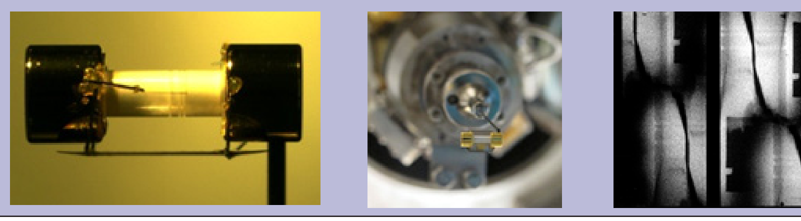


Figure 2. Shock-shear Kelvin-Helmholtz experiments at NIF. The image on the left shows the test object. The test object installed at the facility firing point is depicted in the center image. The right hand image is a composite of radiographs of the test showing the resulting shock waves.

Figure 3. The DARHT facility is shown in the left image. A portion of the accelerator beam line is shown at the lower left.

Improved High-Angle Efficiency of Optical Dome Probes for Implosion Experiments

by Brent Frogget (National Security Technologies, LLC)

National Security Technologies, LLC continues to develop optical dome probes for imploding geometries used in dynamic material experiments, recently making improvements to the high-angle efficiency of the probes. The new, sophisticated geometries used in the experiments collect data from large numbers of data points, and using photonic Doppler velocimetry (PDV) optical technology greatly increases position and velocity data return. In fact, using these new technologies, more data were recorded on the recent Gemini Scaled Subcritical Experiment Series than had ever been collected previously on similar experiments. The data richness provided by this transformative diagnostic continues to enlighten predictive modeling of weapon behavior in supporting the assessment and certification processes.

The optical dome probe used in recent experiments has a fisheye lens design whose function is illustrated in Figure 1. This design takes up minimal space in the imploding system being characterized, can direct a multitude of beams across a large range of angles, and collects enough return light from the surface to give usable velocimetry traces. In addition, the use of an index-matching element allows a flat fiber plane with relatively little back reflection into the fibers. This design has worked well and generated many ideas for future experimental configurations.

The next-generation probes being developed have been named NX1 and NX2. The larger size of the NX2 probe will enable it to collect data at farther distances and will have application for viewing realistic weapon geometries at larger scale than current experiments.

Fiber angular spacing verses angle from the lens axis shows that the reduced distortion design has greatly flattened and reduced the fiber-to-fiber angular spacing.

Fiber angular spacing is important for getting good data yields. For example, larger angles (those near 90° to the lens axis) have inherent distortion, resulting in inefficient return signals and larger point spacing, resulting in fewer data points being recorded. Notice how the angular spacing near 90° is much higher than that near zero for the NX1 probe, as shown in Figure 2. To improve efficiency, small mirrors were added that direct less steep angles to problem areas. However, these small mirrors can block some of the surface coverage. A change in the lens design has greatly reduced high-angle distortion (from 23% to 5%) and reduced the need for small mirrors. Compare the two upper curves in Figure 2 (the NX1 probe verses the NX1 redesigned probe).

The high-angle efficiency of the probes has also been increased by using high-angle anti-reflection coatings. These have the added benefit of reducing back reflections at each lens element surface.

The fisheye lens probe size determines signal efficiency. As the probe size is reduced, less light can be collected from more distant surfaces but the time record for capturing velocity data can be extended slightly until the smaller probe is crushed by imploding material. Size also affects magnification or angular spacing between measure-ment points; the smaller the probe, the larger the

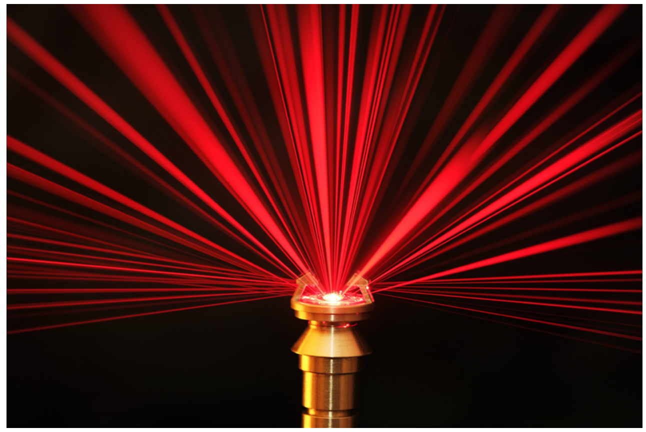


Figure 1. Fisheye Lens Probe demonstrating redirection of multiple laser beams.

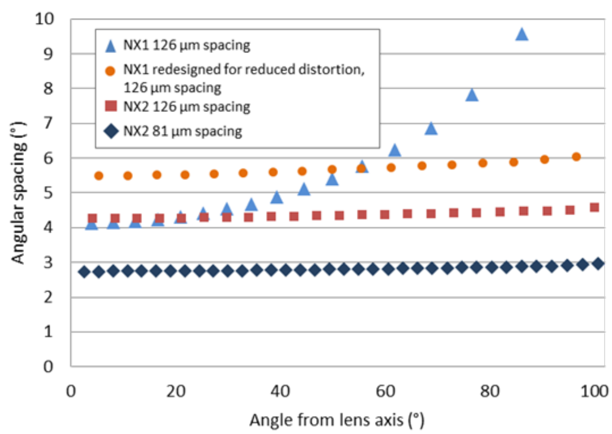


Figure 2. Angular Spacing is shown: original in comparison to improved designs.

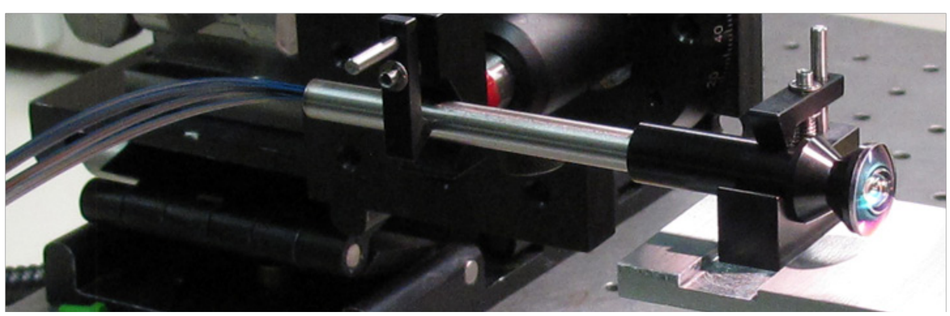


Figure 3. An assembled NX2 probe in test fixture. The fisheye lens is pictured at the right with the lens housing (black); the ribbon fibers are on the left.

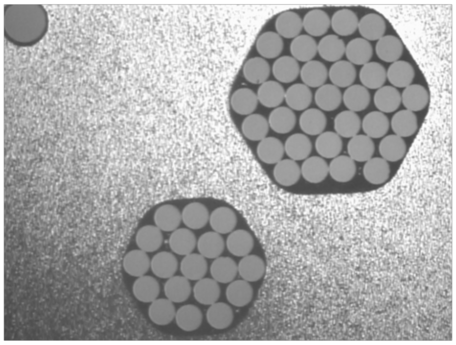


Figure 4. The orderly 'hex' pattern in a 'hex'-drilled hole using the smaller 80 µm cladding diameter fibers (bottom center). Notice the size difference of the standard size 125 µm diameter fiber in the upper left.

angular spacing between measurement points. Figure 2 shows the angular spacing change between the redesigned NX1 probe and the larger NX2 probe, which is shown in Figure 3.

Angular spacing has been reduced by using optical fibers with smaller cladding; the result is shown in the two lower curves of Figure 2. There has been success in splicing 80-µm-diameter cladding fibers to standard single-mode fibers to get regions of closer angular-spaced measurement points. Even smaller cladding diameter fibers will be tried when they become available. There has also been success in improving fiber positions in close angular-spaced areas by using 'hex'-shaped holes drilled into the fiber ferrules, shown in Figure 4.

As part of the Office of Research, Development, Test, and Evaluation Nuclear Experiments and Dynamic Materials subprograms, these probes will continue to be modified to keep pace with improvements to measurement techniques and with diagnostic advancements for implosion experiments. •

Cygnus Radiography Enhancements Utilize New Zoom Lens, Shielding, and Collimation Improvements *by Darryl Droemer (National Security Technologies, LLC)*

The great success of the Gemini Subcritical Experimental Series at the U1a Complex at the Nevada National Security Site (NNSS) proved again the value of the Cygnus x-ray sources by generating a sequence of very high quality radiographs. In the spirit of continuous improvement, the radiographic team at National Security Technologies, LLC (NSTec) in collaboration with their colleagues at Los Alamos National Laboratory has now again raised the bar in the quality of radiographs achievable from the Cygnus sources. Efforts were applied to improvements in the imaging optics and in reductions in the x-ray scatter background.

To address the optics issue (described below), a new, sophisticated eleven-element telecentric zoom lens system (see Figure 1) was developed, tested, and installed in the U1a Complex. Two new zoom lens systems (ZLS) are in place recording radiographs on the Cygnus 1 and Cygnus 2 x-ray machines. The U1a zero room went through a major reconfiguration from the Fiscal Year (FY) 2013 Gemini experimental configuration in preparation for the Leda experiment, scheduled later in FY 2014 and for subsequent subcritical experiments (SCEs). The reconfiguration included removal of the radiography camera housing and the fixed conjugate lens/camera system that recorded radiographs on all previous Cygnus SCEs, beginning with the Stallion/Armando experiment in 2004.

The new Cygnus zoom lenses allow radiographic and imaging magnification to be optimized for different physics experiment object sizes. The ZLS accommodates a larger field of view than the previous lens system and can be zoomed with remote motor control to optimize field of view, scene contrast, and resolution for smaller objects. Camera focusing also is controlled remotely, positioning the camera with micron resolution. The camera focus control is a large improvement in camera setup operations over the previous manually adjusted focus for each camera position.

The previous Linos lens used on the Gemini series was optimized for blue light applications and worked very well for x-ray to blue light converting

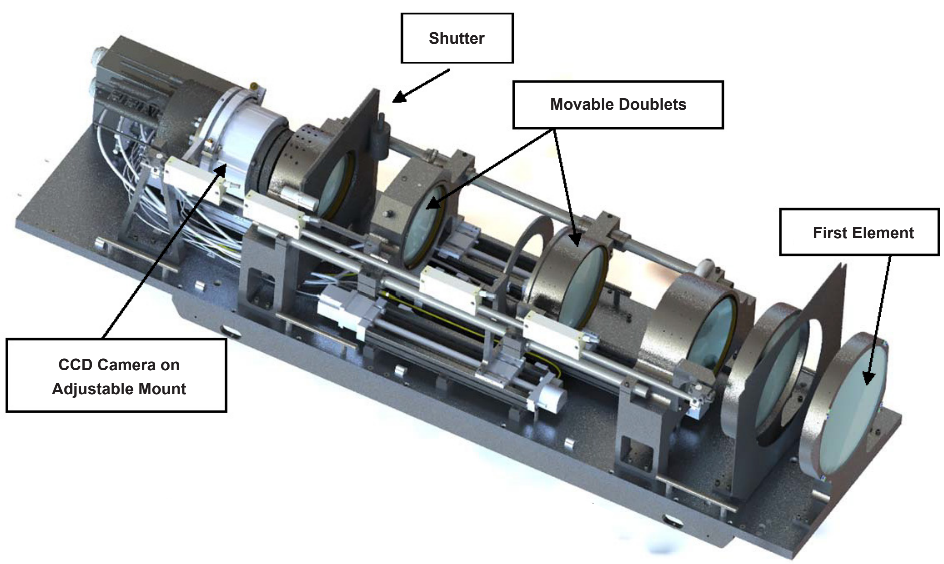


Figure 1. Telecentric Zoom Lens System illustrating placement of elements in the complex optical chain. The movable doublets provide magnification changes.

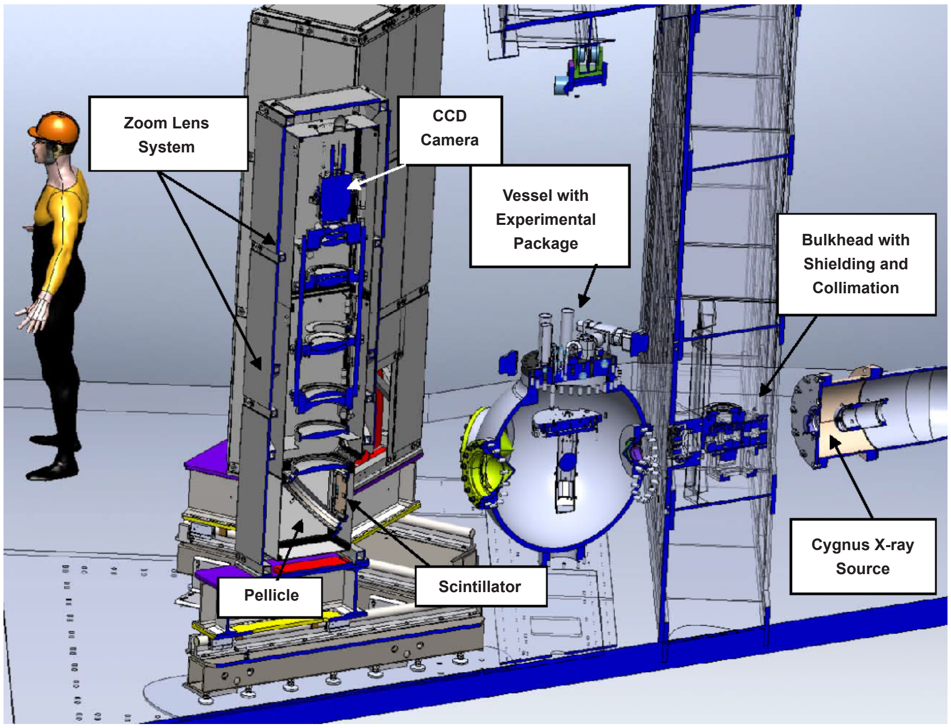


Figure 2. Illustration of ZLS installed within the U1a Complex Zero Room. Point x-ray sources from the Cygnus flash radiographic machines (right) pass through the Zero Room barrier and entrance port of the spherical confinement vessel, are partially attenuated by the experimental package being radiographed, exit the vessel port, and within the ZLS are converted via a scintillator to an optical image that is transmitted upwards to the CCD camera for post shot analysis.

scintillators, but it is not suited to work at other wavelengths. The ZLS is optically designed to focus with either blue or green light. This will allow utilization of high efficiency green scintillators which may perform better on certain experiments.

The Cygnus ZLS (see Figure 2) delivers improvements in sensitivity and provides high resolution over a large field of view compared to the Linos system. The telecentric lens characteristic may better accommodate focusing in thicker scintillators which could provide radiographs on thick object experiments. A new cryogenic cooled astronomy-class charge coupled device (CCD) camera was installed on the ZLS in January 2014. Laboratory tests show that cryogenically cooled CCDs provide significant sensitivity improvements with reduced noise performance. This is expected to provide better radiographic detail on Leda and future SCEs.

To complement the optical imaging improvements, source blur, scattering, and radiographic post processing also were addressed. Shielding improvements were accomplished first through Monte Carlo N-Particle eXtended (MCNPX) modeling analysis. Shielding configurations were evaluated to identify the most effective configurations suitable for actual testing in the Cygnus beam lines. The results of the data analysis provided a configuration that, utilizing strategically placed shielding components, resulted in a three times improvement of signal to noise ratio and a 30 percent reduction of starring effects in an adjacent camera. Collimation near the Cygnus x-ray sources reduced the effect of off-axis x-rays which are produced at the base of the rod pinch diode and are a source of blur in the radiographs. This combination of shielding and collimation has the effect of significantly enhancing the fidelity of radiographs and of improving sensitivity for high areal density objects.

The radiography team will continue to enhance the quality of Cygnus radiographs as requirements for future experiments and will continue to challenge the capabilities of both the Cygnus sources and the radiographic chain. Figure 1 shows a drawing of the ZLS without shielding components.

In summary, the ZLS is a carefully optimized system of 11 lens elements on several remotely adjustable stages that couple the light from an x-ray imager at one end to a CCD camera at the other. This new system can easily be adjusted to optimize performance for each U1a experiment that uses flash radiography to detect the position of structures within the experimental package. •

Academic Alliance Program Graduate to Receive PECASE Award

Lawrence Livermore National Laboratory physicist **Miguel Morales** has been selected for a 2014 Presidential Early Career Award for Science and Engineering for his leading edge research in condensed matter physics. Morales, a graduate of the NNSA Stewardship Science Graduate Fellowship Program, studies materials at extreme pressure and temperature on some of the world's most powerful supercomputers. He uses advanced computational techniques such as density functional theory and quantum Monte Carlo. His work is important to stockpile stewardship and it also provides planetary scientists with a better understanding of planet formation. Established by President Clinton in 1996, the early career presidential awards are the highest honor bestowed by the U.S. government on science and engineering professionals in the early stages of their independent research careers.

Contact Us

What do you think about this issue of the *Stockpile Stewardship Quarterly*? We want to know. Please send your comments and suggestions for future issues to Terri Stone at terri.stone@nnsa.doe.gov. Requests to be added to our mailing list should include your full name, email address, and affiliation/organization.

Dynamic Temperature Measurements Systems *by Gerald Stevens (National Security Technologies, LLC)*

Over the past 15 years, National Securities Technologies (NSTec) has been supporting all three labs in the National Security Enterprise (NSE) in their shared goal of obtaining highly accurate temperature measurements of shock compressed materials. Temperature measurements in shock experiments are a vital, yet elusive, part of developing and validating improved multi-phase equation of state models in weapons codes. This validation results in a deeper understanding of weapon behavior. The most successful temperature measurements of shocked materials have involved optical reflectance and pyrometry. Optical reflectance is the ratio of reflected light to incident light. A pyrometer is a device that measures thermal radiation as a way to get a temperature measurement.

NSTec has designed and built portable 7-channel optical bandpass-filtered optical pyrometers, shown in Figure 1, fielded on numerous experiments at facilities such as Los Alamos National Laboratory (LANL) Chamber 9 and Ancho Canyon, Lawrence Livermore National Laboratory (LLNL) High Explosives Application Facility (HEAF), and the Nevada National Security Site (NNSS) Joint Actinide Shock Physics Experimental Research (JASPER) gas gun.

These pyrometers have nanosecond response times and are capable of recording calibrated radiance from metals at shocktemperatures ranging from around 1,000ºC to over 4,000ºC. A compact version of the pyrometer is being built for installation at TA-55, in collaboration with LANL. NSTec is also teaming with LLNL to build a 7-channel pyrometer to measure temperature on a 2 stage gas-gun experiment at HEAF in support of an LLNL FY 2014 Level 2 milestone.

Working towards the goal of less than 1 percent uncertainty in temperature measurements, NSTec recently published details[1] of a technique developed in partnership with LANL used to measure the dynamic reflectance (emissivity) of shocked metals. This technique uses an integrating sphere illuminator with a built in flashlamp to measure light reflected from a shocked metal/window interface. The sphere's illumination removes many of the geometric problems encountered in such a measurement, such as samples tilting, bowing or moving. The measured emissivity or electromagnetic energy emitted is combined with the pyrometric measurements of radiance to obtain temperatures with less than 2 percent uncertainties, shown in Figure 2. Work on extensions and modifications to the technique continue with the goal of integration into the JASPER diagnostic suite.

Figure 1. Bob Corrow, Adam Iverson, and Tom Graves with the latest portable seven channel pyrometer system ready for delivery to LLNL for use at HEAF. The inset image shows an individual photomultiplier channel and its associated hardware and housing.

NSTec supported an innovative Sandia National Laboratories Lab Directed Research and Development project using the reflectance spectrum of a thin gold foil to sense temperature.[1]

This is an alternative to pyrometry, especially for the low temperature conditions expected from isentropic-compression experiments at facilities such as Z. To test the technique, a specialized heated impactor to generate a known elevated temperature and

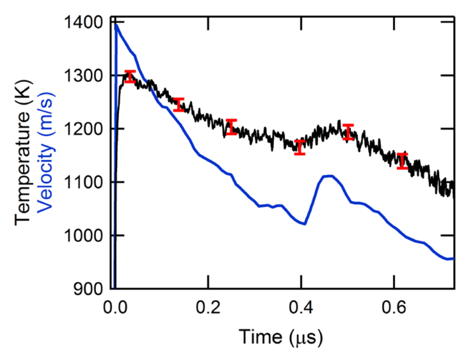


Figure 2. Velocity record (blue) and temperatures (black) from an explosively shocked tin sample beneath a lithium fluoride window. The interface temperature and error bars (red) are calculated from combining radiance and reflectance measurements. The interface pressure may be calculated from the velocity data, and combined with the temperature data to give a pressure-temperature release isentrope for this experiment. Details of the measurement technique may be found in Reference.[2]

pressure state within the gold foil was designed. A streak camera spectrometer capable of recording the time-varying spectrum of light reflected from the foil was developed and built. Continuing effort supports the development and transition of this technique to experiments at Z.

An FY 2014 Site-Directed Research and Development project continues to refine our dynamic measurement techniques by focusing on heat transfer, or more specifically the dynamic effusivity of shocked metal i.e. the amount of thermal energy a material is able to absorb and exchange with its surroundings. Because the temperature within a bulk metal target cannot be observed, the effusivity is measured to infer the bulk temperature from an optical pyrometry measurement of the surface. This is one of the key remaining "pieces of the puzzle" to be solved before the routine measurement of shock temperatures allowing the results to be accurately plotted on phase diagrams.

References

[1]Daniel H. Dolan, Christopher T. Seagle, and Tom Ao, Sandia Report, SAND2013-8203, 2013.

[2]B.M. La Lone, G.D. Stevens, W.D. Turley, D.B. Holtkamp, and A.J. Iverson, Journal of Applied Physics 114, 063506, 2013.

Another Successful Stewardship Science Academic Programs Symposium

The 2014 Stewardship Science Academic Programs (SSAP) Symposium was held in Bethesda, Maryland on February 19-20, 2014. The Symposium, with approximately 250 attendees, featured overviews of work to date from ongoing grants and cooperative agreements from the following programs: Stewardship Science Academic Alliances, High Energy Density Laboratory Plasmas, and the National Laser Users' Facility.

Highlights of the Symposium included the research presentations, keynote speaker Bruce Held, NNSA Acting Administrator and Undersecretary for Nuclear Security, and the Poster Session featuring the students' cutting-edge research, held on the first night of the Symposium. The winners of the Poster Session follow.

Dhakal Sushil, Ohio University, *Measurement of Neutrons from DD Reaction and Neutron Transmission from Iron Sphere*

Jennifer Shusterman, University of California Berkeley, *Solid Phase Extraction Materials for Separations of Actinides and Lanthanides*

Emma Rainey, University of California Los Angeles, *High-Pressure Thermal Conductivity of (Mg,Fe) Si03 Perovskite Measured in the Laser-Heated Diamond Anvil Cell*

Dane Tomasino, Washington State University, *Dynamic Thermo-Mechanical Loading of Simple Molecular Systems*

Pamela Kaercher, University of California Berkeley, *Understanding Lower Mantle Rheology from Two-Phase Deformation Experiments*

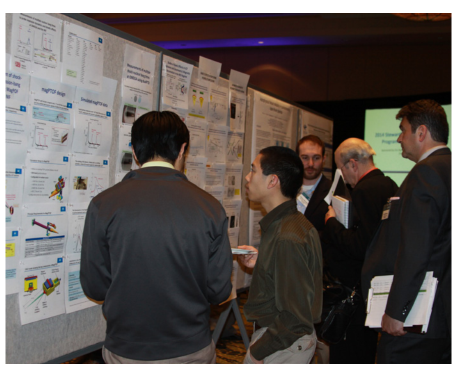
Daniel Sneed, Undergraduate University of Nevada Las Vegas, *Molecular Diffusion at Extreme Conditions*

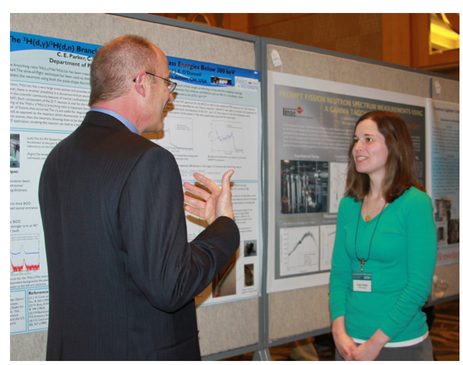
Wesley Wan, University of Michigan, *Development of a Supersonic, Single-Mode Kelvin-Helmholtz Instability Experiment*

Alex Zylstra, MIT, *Observations of a 5^{th} Shock and Low-Mode Asymmetries in Surrogate Ignition Scale NIF Implosions*

Nathan Riley, University of Texas at Austin, *Magnetized Radiative Blast Waves*

Benjamin Galloway, University of Colorado at Boulder, Krell Fellow, *VUV-Pumped High Harmonic Generation and Observation of Isolated Attosecond Pulse*





This year's Stewardship Science Academic Programs Symposium hosted approximately 250 attendees. Left (L-R): Ike Silvera of Harvard University talks with Keith LeChien, NNSA Stewardship Science Academic Alliances Program Manager and (Acting) Director, Office of Inertial Confinement Fusion, and Bruce Held, NNSA Acting Administrator and Undersecretary for Nuclear Security. Middle: Attendees of the Poster Session held on February 19 view posters and discuss research. Right: Also during the Poster Session, Bruce Held, keynote speaker of the SSAP Symposium, discusses the poster of Cody Parker of Ohio University.