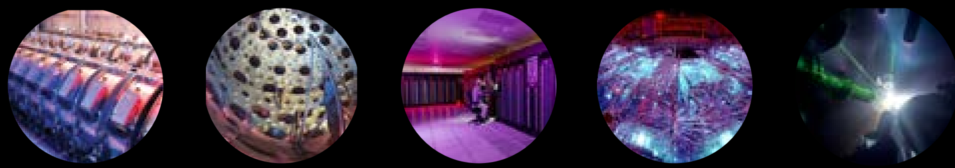


DOE/NA-0070

NNSA National Nuclear Security Administration

Office of Research, Development, Test, and Evaluation

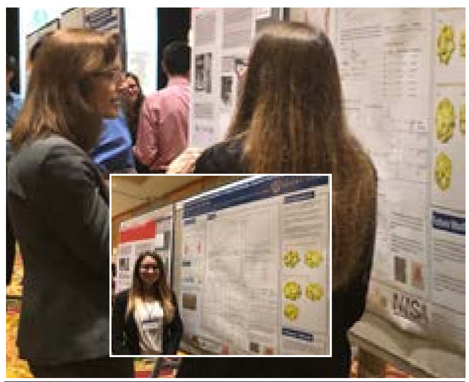
Stockpile Stewardship *Quarterly*

VOLUME 8 | NUMBER 1 | MARCH 2018

Message from the Assistant Deputy Administrator for Research, Development, Test, and Evaluation, Dr. Kathleen Alexander

This issue of the *Stockpile Stewardship Quarterly* focuses on the intersection between computer modeling and the design and conduct of scientific experiments that provide the phenomenological basis for computer models. We kick off this issue with an article that discusses the relationship between verifying and validating the modern nuclear weapons codes and the hierarchy of experiments that must be performed to provide the necessary data. With the cessation of nuclear testing, computer modeling has become key to assessing the safety, security, and performance of weapon systems whose designs have evolved from tested configurations. This requires higher fidelity codes that incorporate multiple, interacting physics phenomena. The level of experimentation required to provide data to verify these codes ranges from small-scale experiments designed to assess a single physics problem to fully integrated experiments that evaluate the interaction of the physics involved in a full weapon system.

Subcritical experiments are performed to gather data of complex, interacting weapons physics. The Enhanced Capabilities for Subcritical Experiments project portfolio is working to achieve the design and creation of a next-generation suite of diagnostics that will allow for data to be gathered on the relevant physics involved in the late-stage implosion of plutonium in weapons-relevant geometries. This data will feed the complex computer simulations to inform design options for upcoming life extension programs, as well as future assessments and certifications.



The research on display during the Poster Session of this year's Stewardship Science Academic Programs Annual Review Symposium, held in Bethesda, Maryland on February 21-22, 2018, generated much excitement. Above right and inset, Sarah Hickam, University of Notre Dame, discusses her research with Dr. Alexander. Read about the symposium and winning posters on page 10.

This issue also features an article on the latest subcritical experimental series, Gemini, Leda, and Lyra. These series were designed to provide data on the physics response of using insensitive high explosives versus conventional explosives in weapon geometries and data on the performance differences between surrogate metals and plutonium in experiments.

Another article discusses a complementary approach that uses laser or pulsed-power facilities to achieve a high energy density (HED) state of matter. The majority of weapon processes occur in the HED state, and so understanding the physics that occurs in this state is essential to modeling weapon systems. These HED experiments are sized in the centimeter-to-micrometer range yet still are able to examine integrated weapons phenomena.

We close this issue with a nod to the next-generation scientists and engineers. We share a review of and honor the awardees from the 2018 Stewardship Science Academic Programs Annual Review Symposium that drew a record number of attendees, and we highlight an academic opportunity at the University of Michigan in the HED field.

Incredible work is happening in the nuclear security enterprise, and this work is vital to the security of our Nation.

Inside

Comments
The *Stockpile Stewardship Quarterly* is produced by the National Nuclear Security Administration (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

Integrated High Energy Density Experiments Yield Critical Data for the Advanced Simulation and Computing Program *by Bradley Beck (Los Alamos National Laboratory), David Etim (National Nuclear Security Administration), Curt Nilsen (Sandia National Laboratories), Joe Sefcik (Lawrence LIvermore National Laboratory), and Arthur Brown (Sandia National Laboratories)*

During the era of nuclear testing, legacy computational codes were used to design the United States nuclear weapons stockpile. Throughout development of each and every weapon, nuclear weapon tests played a critical role in calibrating the models and in assessing actual performance. Since the cessation of nuclear testing in 1992, improved codes with higher fidelity physics models were required to provide confidence in the ability to assess safety, security, and performance of the current and future stockpile.

To accomplish the science-based Stockpile Stewardship Program (SSP) mission requires that the Advanced Simulation and Computing (ASC) program develop simulation codes that accurately predict and assess the full physics and engineering environments these weapons encounter or may encounter. These modern computational codes must simulate the complexities of nuclear physics, weapons component responses, the weapons systems as a whole, and determine the impact of design changes and aging on the nuclear weapons stockpile. Additionally, these modern codes serve as a means to evaluate the full range of a nuclear weapon's operation. For these purposes, the modern nuclear weapon computational codes must couple numerous physics models together accurately. Integration of numerous physics models makes these tools fundamentally different from other scientific computation codes that normally focus only on single physics models or on integration of a few physics models.

Development of these codes and determining the accuracy of their capabilities is further complicated due to the realization that the full physics encountered by a nuclear weapon are unlike normal operating physics regimes on Earth. Critically important is an examination that these codes are accurately representing the necessary and correct physical models.

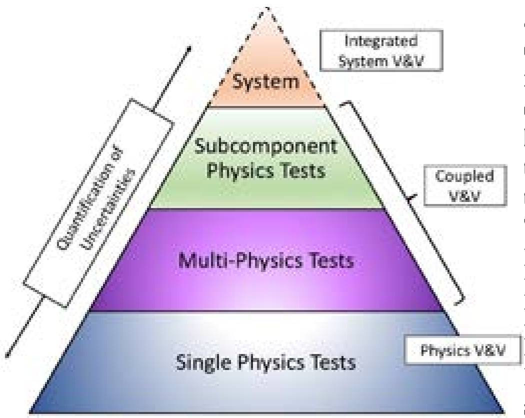


Figure 1. Hierarchical approach to V&V spans the full problem physics.

In the development of the ASC nuclear weapon simulation codes, the appropriate physics must be assessed through determination of the proper equations. These equations are approximated into numerical models and then incorporated into the codes. After implementation, the laboratories verify that the numerical models are accurately reproducing the intended equations (Code Verification) and confirm that the codes are solving the correct equations (Code Validation).[1]

The ASC Verification & Validation (V&V) program employs a hierarchical approach (see Figure 1) in order to span the entire required physics regimes. Single-physics experiments (e.g., modeling of High Explosive detonation) provide the program with required information used to validate individual physics models. Due to the numerous individual physics models required, this necessitates numerous experimental campaigns. Multi-physics tests (e.g., radiation hydrodynamic experiments) enable a small number of physics models be combined for an assessment. Subcomponent physics tests increase the number of interacting physics models assessed, and increase the complexity of the required experiments (e.g., pRad experiments, inertial confinement fusion experiments).

At the most complete and complex end of the hierarchical approach is the integrated system tests. Examples include experiments conducted at the following locations (see Figure 2): U1a Complex at the Nevada National Security Site (NNSS); the Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos National Laboratory; the Contained Firing Facility (CFF) at Lawrence Livermore National Laboratory; and the Thunder Range Facility at Sandia National Laboratories. Experiments conducted at these facilities enable an integrated system assessment and more completely test the multi-physics computational codes in these challenging environments. As the NNSA weapons laboratories continue to work towards delivering fully validated codes, the historical nuclear testing archive and historical integrated experiments are assessed and incorporated into the analysis; these tests are critical to validation efforts as they are the experimental means that explore the full nuclear weapon detonation physics.

Integrated Hydrotest Experiments

Integrated hydrotests experiments provide critical data for the SSP. These experiments enable scientists to detonate a "mock-up" of the primary stage of a nuclear weapon, but with surrogate materials. Instead of using plutonium, scientists use a non-fissile surrogate material to simulate the desired characteristics.

Both the CFF and DARHT field diagnostics record arrival time of an explosively driven surface through use of pin domes and photon Doppler velocimetry (PDV) probes (see Figure 3). The pin dome records when a surface interacts with the pin while the PDV probe records a time velocity record of the surface using laser velocimetry. High-energy radiographs of the experiment are also captured with high-speed cameras to allow for increased exploration of the implosion dynamics. This combination of diagnostics

[1]Code verification is "the process of determining that the numerical algorithms are correctly implemented in the computer code and or identifying errors in the software." Code validation is "the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model." ASME 2006, "Performance Test Code Committee 60: Verification and Validation in Computational Solid Mechanics," Guide for Verification and Validation in Computational Solid Mechanics, American Society for Mechanical Engineers, New York, Standard No. ASME V&V 10-2006.

Figure 2. Key integrated experimental facilities, such as DARHT (top left), U1a (top right), CFF (bottom left), and Thunder Range (bottom right) enable integrated experiments that provide the SSP with critical data used to validate the multi-physics computational codes.

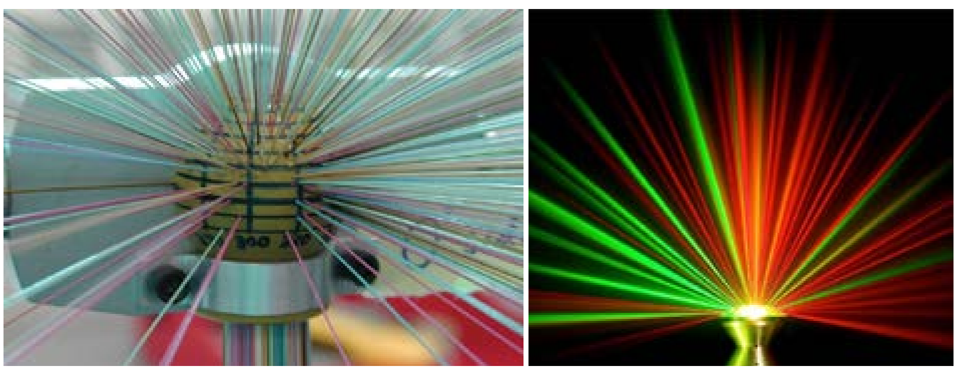


Figure 3. Methods for measuring implosion dynamics; left image is a pin dome where each individual pin records a time of impact; right image is a multiplexed photon Doppler velocimetry (MPDV) probe that measures the velocimetry of a surface by measuring the Doppler shift of optical illumination.

provides a critical capability to obtain comprehensive data on the implosion phases of integrated weapon experiments. Critical to the assessment of these experiments, the laboratories perform a pre-shot prediction of the experimental results and a post-shot analysis.

Integrated Subcritical Experiments

Whereas hydrotest experiments provide critical data for the ASC program and SSP, the use of surrogate materials requires an assessment of how well these materials represent the actual materials. Critically important is understanding the material dynamics similarities and differences. Subcritical experiments conducted in the U1a Complex of the NNSS provide critical data by studying plutonium in relevant configurations.

Experiments like the Vega experiment recently conducted provide similar diagnostics to the current hydrotest experiments, but in a configuration with Plutonium and in a situation where the experiment is prevented from going critical. These experiments provide critical data that is then used by the ASC codes to determine an accurate assessment of their capabilities.

Whereas critical data is provided by the current subcritical experiments, the Enhanced Capabilities for Subcritical Experiments project (ECSE) is planning for improved capabilities and diagnostics that will increase the experimental data available for the SSP and for future assessments.

Engineering Challenges

Due to the diversity of engineering challenges that a nuclear weapon may encounter, a variety of types of integrated engineering system tests are required. Examples of these tests at Sandia National Laboratories include nuclear safety tests at the Burn Facility, centrifuge/vibrafuge[2] experiments at the Large Centrifuge Facility, and explosive testing at the Thunder Range to study the effects of hostile atmospheric blast. Thunderpipe tests were performed recently at Thunder Range to support the Navy and Air Force programs (see Figure 2). The data generated are used to validate modeling predictions from ASC tools for the shock loading and weapon response. Together, experimental data and simulation predictions support current and future weapon qualification efforts.

Conclusion

To accomplish the mission of sustaining a safe, secure and effective nuclear deterrent requires that the SSP has modern computational tools with verified and validated models of an increased physics fidelity. Critical to being able to deliver these capabilities are integrated experiments that explore the full physics required as completely as possible. These integrated experiments provide critical data to the NNSA programs and enable critical assessments of the nuclear weapon computational simulation codes. Facilities such as DARHT, CFF, U1a, and Thunder Range enable these experiments and increase confidence for current and future assessments. ●

[2]Vibrafuge is a combined examination of vibration testing on a centrifuge.

Continuous Evolution of the Stockpile Stewardship Program: Enhanced Capabilities for Subcritical Experiments *by Kirk Keilholtz (National Nuclear Security Administration)*

The United States conducted 1,054 nuclear tests before entering the current moratorium in 1992. The archived data from these tests is the backbone of our Stockpile Stewardship Program (SSP) to continue the annual assessment and certification of the safety and reliability of our nuclear stockpile without full-scale nuclear testing. The SSP relies on an extensive program of surveillance, examining the current and aging stockpile, coupled with advanced computational models which are, in turn, validated against both new and archived small- and large-scale integrated experimental data. As computing power, and the sophistication of the physics-based simulation models, has increased over the years, our understanding of fundamental operations of weapon systems and especially the behavior of weapon materials has also evolved, leading to the identification of knowledge gaps. NNSA addresses these gaps through the development of new theoretical and analytic models, implemented in advanced simulation techniques, and through the diagnostics and drivers needed to produce the experimental data to validate the simulations. This methodology, applied for over 25 years of stockpile stewardship, has allowed NNSA to develop a deep understanding of nuclear weapon science and engineering—both reinforcing our existing hypotheses and allowing us to form new ones.

One area that NNSA is currently exploring in detail is the aging of our nuclear weapon systems and, specifically, changes in the special nuclear materials. Our weapons are composed of a variety of materials and understanding their interaction during weapon operation is extremely important to assess the safety and reliability of the stockpile. Through most of the first 50 years of the nuclear weapons program, that understanding was developed, and then demonstrated, through nuclear testing. Throughout the life of the program, our scientists and engineers have always questioned if a weapon system will behave with the same characteristics after 30 years, and without underground tests, those scientists and engineers have had to look elsewhere to answer this critical question.

In addition to the aging of critical components, NNSA must regularly replace or refurbish many other weapon components. Many of the materials and processes that were used in the original production are no longer available. Changes to our original designs, materials, and processes require qualification and certification that, in turn, require new small-scale and large-scale integrated experiments. Necessarily, each change that we make moves us incrementally away from the designs and processes that were successfully tested and archived in our nuclear testing database. Barring a return to nuclear testing, the SSP is responsible for ensuring our nuclear weapons continue to work as designed. Every year, the three directors at the NNSA national laboratories—Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and Sandia National Laboratories (Sandia)—assess for the President whether the stockpile is safe, secure, reliable, and effective. Each year, this has been the case.

We have developed important experimental platforms such as the National Ignition Facility (see Figure 1a), Z Pulsed Power Facility (see Figure 1b), Omega Laser Facility, Joint Actinide Shock Physics Experimental Research (JASPER) facility, Advanced Photon Source, THOR, Los Alamos Neutron Science Center, Cygnus, and others that probe specific material properties under the extreme conditions encountered in the operation of a nuclear weapon (see *Stockpile Stewardship Quarterly* V7 N4, December 2017). Other facilities explore the interaction of materials in nuclear weapon geometries such as the Dual Axis Hydrodynamic Test Facility (DARHT) (see Figure 1c) at LANL and the Flash X-Ray-Contained Firing Facility (FXR-CFF) at LLNL. However, these facilities do not have the capability to perform dynamic implosion experiments with plutonium, the special nuclear material at the heart of many weapons.

To explore the dynamic behavior of high-explosively-driven plutonium in weapon-like geometries and near weapon-like conditions, the NNSA conducts Subcritical

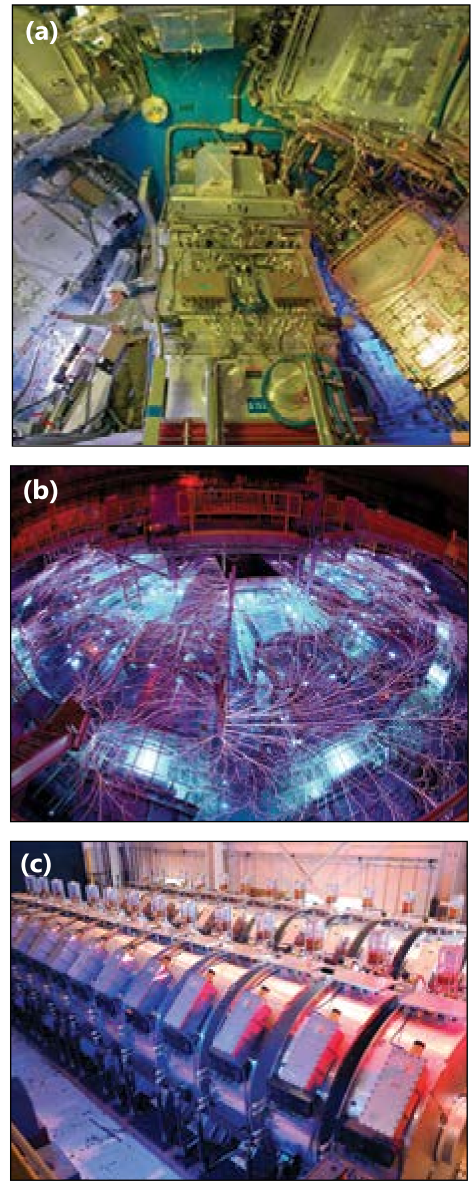


Figure 1. Some of NNSA's experimental platforms: (a) the National Ignition Facility optics, (b) Z Pulsed Power Facility, and (c) DARHT.

Experiments (SCE) at the Nevada Nuclear Security Site (NNSS). SCE provide essential information for stockpile life extension programs, significant finding investigations, and advance the understanding of how the stockpile evolves. SCE address one of the critical knowledge gaps in the properties of plutonium by measuring its behavior during the final stages of a primary implosion. To make those measurements,

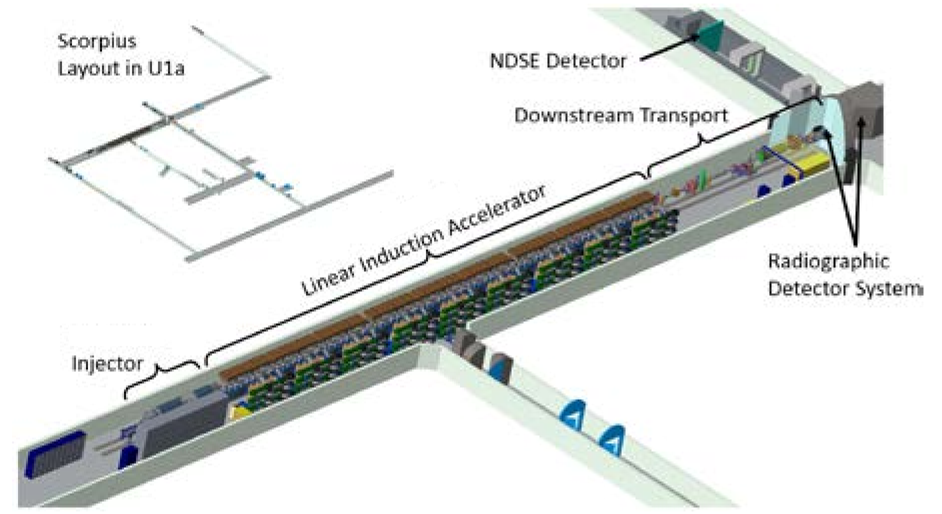


Figure 2. Shown is an illustration of the Scorpius Infrastructure at the NNSS. The main accelerator hall ("drift") will be just over 400 feet long.

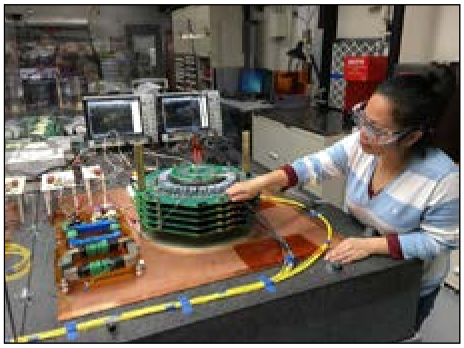


Figure 3. Daisy Acosta-Lech performing design verification testing on the five stage solid state pulser.

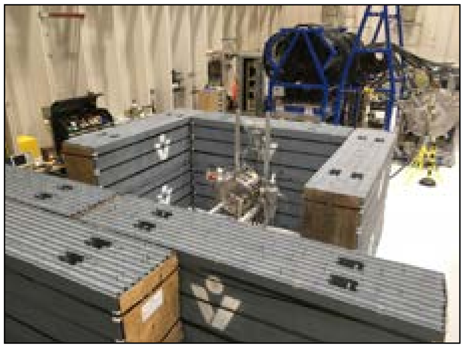


Figure 4. Two-Pulse Test Cell from LANL undergoing multi-pulse testing on Centipede at Sandia.

high precision penetrating radiography (such as that used with surrogate materials at DARHT and FXR-CFF) and a diagnostic under development known as the Neutron Diagnosed Subcritical Experiments (NDSE) are the essential tools.

NNSA's activities in support of these essential tools is called the Enhanced Capabilities for Subcritical Experiments (ECSE) portfolio, which includes the project to deploy a new radiographic system (Scorpius) under the Advanced Sources and Detectors (ASD) component of the portfolio; the U1a Complex Enhancements Project Line Item that will construct the underground laboratory; and, the NDSE diagnostic currently under development.

Scorpius is a DARHT-class, multi-pulse, single axis, linear induction accelerator (LIA)-based radiographic system. The ECSE Radiography & Integration Project is responsible for the technology maturation, design, fabrication, installation, and commissioning of Scorpius at the NNSS.

The Scorpius LIA-based radiographic system consists of four major subsystems: injector, accelerator, downstream transport, and detector (see Figure 2). The injector subsystem generates a high current electron beam using a pulsed, high-voltage vacuum diode. The high current of the beam means that space charge effects dominate the beam transport so that externally applied magnetic fields are used to guide the beam into, and through, the accelerator. The accelerator subsystem consists of a series of many 10s of similar accelerator cells each of which applies a pulsed electric field adding energy to the electron beam. The energy added at each cell is a small fraction of the total energy and is typically limited by the engineering requirements of the accelerator cell and pulsed power system powering the cell. After the beam has acquired the required energy while transiting through the accelerator cells, it enters the downstream transport subsystem that transports and focuses the beam onto a Bremsstrahlung x-ray converter where the x-rays that will penetrate the experimental test object are created. Beyond the experimental test object, the detector subsystem uses advanced scintillators to convert the x-rays to visible light, captures and stores the images on a very high-speed digital camera, and records the data for subsequent analysis. In addition to the four components of the radiographic system, operation of Scorpius requires detailed attention to the "Global" engineering support systems (control, power, fluid and gas, mechanical, tooling, and safety systems) common to all parts of the accelerator and the interface with the U1a Complex to support installation, commissioning, accelerator readiness certification, and the transition to operations for the final Scorpius system.

The project, led by LANL, is composed of partners at LLNL, Sandia, and NNSS (see Figures 3 and 4). The team works under a governance structure agreed to in a Memorandum of Agreement signed by the three laboratory directors of their respective LLCs and supported by industrial partners such as L-3 Technologies and several component and subsystem development contractors, and the Naval Research Laboratory. With this many organizations involved, the project team must continuously emphasize the need for frequent and engaging communication.

With ECSE coming online in the mid 2020s, our weapon scientists and engineers will have diagnostic tools at their disposal to answer important questions about the Nation's current nuclear weapons stockpile as well as to provide flexibility in the form of materials and advanced manufacturing techniques that are necessary for our life extension programs. ●

Vega & the Lyra Series *by Garry R. Maskaly (Los Alamos National Laboratory)*

The Vega Experiment

Vega, the plutonium experiment that served as the capstone to the Lyra series, was executed in the U1a Complex at the Nevada Nuclear Security Site (NNSS) on December 13, 2017. After facing many challenges, including the need for an enhanced authorization basis and to reauthorize work at TA-55, Vega became the first subcritical experiment (SCE) fired since Pollux was executed in December 2012.

In Gemini, a conventional high explosive (CHE)-driven primary implosion was studied in both a surrogate (Castor) and in plutonium (Pollux). The Lyra series provided data comparing that performance to experiments using the same pit driven with insensitive high explosives (IHE). In both series, scaling is used to reduce the reactivity of the device and to keep it subcritical.

IHE is being strongly considered for potential future designs and also for reuse of a CHE pit in an IHE implosion system. However, before Vega, the Nation had not performed any experiments for which there was a direct measurement of the plutonium dynamic behavior driven by an IHE charge. As part of a plan to certify a new design without nuclear testing, plutonium data are required to validate the models being used to underwrite that design. The Vega experiment is an important step in that process.

As shown in Figure 1, the experiments conducted under the Lyra series fit together with those from the Gemini and Leda series in a differential experiment framework with only one change between each experiment. Two experiments were conducted at the Dual-Axis Radiographic Hydrotest (DARHT) facility, and six were conducted at the U1a Complex. In the framework, there were six surrogate experiments that provided a means to better understand the high explosive drive which then, ultimately, allowed for a better understanding of the plutonium dynamics in the SCE. Multiple surrogate experiments provide a means to reduce any compensating errors that might be introduced by relying too heavily

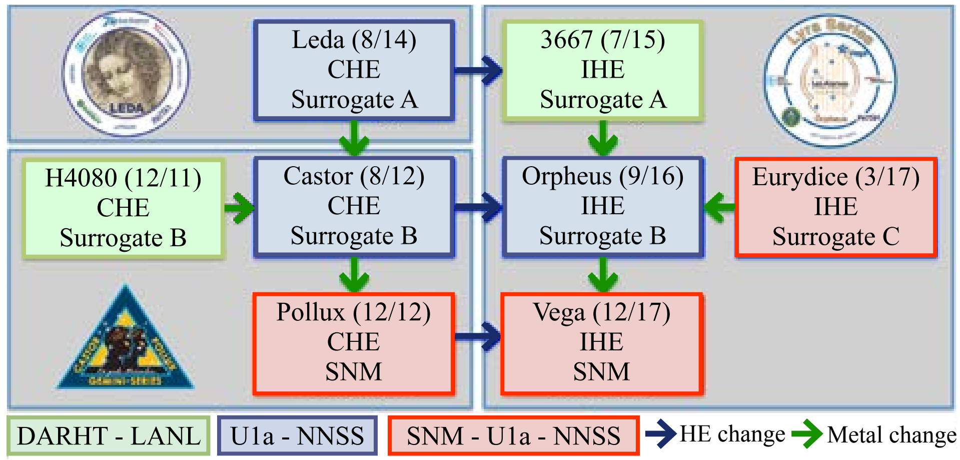


Figure 1. The Gemini/Leda/Lyra series differential experiment framework. H4080 was a developmental experiment with limited velocimetry coverage..

on any one surrogate, which might be computationally represented with imperfect models and could then lead to erroneous model calibration. In addition for Lyra, the design team focused on creating a device that used various design features to minimize the experiment's sensitivity to other potential areas of physics uncertainty. This approach allowed for a more direct focus on the plutonium dynamics in the final experiment.

By building off of the Gemini series and using the same pit configuration, the Lyra series allowed for a very direct comparison of the dynamics between a CHE- and an IHE-driven implosion. This approach provided a useful means to understand the impacts the drive difference had without a large need to focus on understanding the impacts of the design changes as well. This approach also more directly tied to several pit reuse concepts for which similar questions will be asked of a weapons system.

In order to execute this series, a large team across the complex was required. Scope included such activities as parts manufacturing, vessel systems, diagnostics development, materials science, design physics, assembly, and transportation. Each assembly required an extensive team to produce high-precision parts. This precision was required to allow for a focus on the physics rather than trying to understand deviations that might be caused by part variations.

The Need for Advanced Diagnostics

Learning from the Gemini series, the design team has identified what types of questions can be asked with the new diagnostics now being fielded. In particular, velocimetry enables a whole new series of questions to be asked of the data. In addition, other questions were raised that would benefit from continued advances in diagnostics.

In Vega, we started with 11 primary physics hypotheses that would be directly tested in the series. That list has grown as new data were taken and now stands at around 15 hypotheses, some of which have already been addressed. In that list, there were questions that could perhaps be better answered with newer diagnostics in conjunction with the original multiplexed velocimetry. In particular, there were times when more dynamic range would have aided the analysis. In Lyra, Generation 3 Multiplexed Photon Doppler Velocimetry (MPDV) was fielded on a dynamic experiment for the first time; as expected, it gave a large increase in signal-to-noise over the original systems fielded on Pollux. Also new to Lyra were 8 channels of Broadband Laser Ranging (BLR) fielded to address specific areas of physics. Building off of some questions on Pollux, the design team pushed for the incorporation

Figure 2. Many of the Lyra team members at U1a.

of stereoscopic visual imaging (first fielded on Leda with monovision). The combination of these diagnostics and Cygnus radiography allows for cross-correlation between each diagnostic to better understand questions that might appear in the data.

As the final experiment in the series, the Vega experiment did not disappoint. It provided exquisite detail of the imploding plutonium. The diagnostic suite performed as hoped, providing a means to better understand what is happening within the device. Even though the data analysis is in its early phases, several hypotheses have already been addressed, and several new questions have been raised. Even within an experiment that has defined hypotheses from the start, there is still room for exploratory observations that are not related to those hypotheses, but that raise questions of their own.

This series again points to the need for a strong SCE program. Due to the complexity of plutonium dynamic behavior, surrogates simply do not provide all of the properties needed to understand the details of a plutonium implosion. The data obtained in these experiments enable model validation and model development that will be used in the current assessment process but that also will become even more important as we become further removed from direct calibration to the nuclear test history.

The Next Steps in the Lyra Series Analysis

The data acquired in December are now being analyzed, and a preliminary data package was delivered in February. This data package will give the primary physics teams involved a chance to examine the data and see if there are any regions that need further examination before the final data package is released. The preliminary data package will be released simultaneously to the three laboratories that provided a preshot prediction. The final data package is expected to be released in 2018. After this, the design team will begin preparing the final post-shot report, which is expected to be completed approximately one year after the release of the final data package.

Acknowledgement

While many people contributed to the success of these experimental series, David Holtkamp was instrumental in having a vision for all-optical hydrodynamic and subcritical experiments. He also was instrumental in developing the diagnostics needed to ask these important questions. Shortly after the Eurydice experiment, David passed away suddenly. He is deeply missed by those with whom he interacted, and his large contributions of these experiments, to the SCE program, and to the Nation will be felt for many years. ●

Integrated Experiments in the Stockpile Stewardship Program *by Njema Frazier and Sean Finnegan (National Nuclear Security Administration)*

Predicting the performance of an operating nuclear weapon requires understanding both how matter behaves in the high energy density (HED) regime and also the nature of key physical phenomena such as radiation transport, radiation driven hydrodynamics, and thermonuclear burn. The Inertial Confinement Fusion (ICF) Program within the National Nuclear Security Administration (NNSA) uniquely provides experimental access to extreme HED environments through a set of complementary, specialized facilities. The National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory, the Z Pulse Power Facility at Sandia National Laboratories, and the Omega Laser Facility at the University of Rochester provide data that are informing design options for Life Extension Programs, validating models important for weapon design codes, and providing hostile environments for vulnerability and hardness testing. However, there are limits to our current capabilities. To more completely access HED regimes in the laboratory, HED facilities capable of driving experiments with hundreds of megajoules of energy are required. The demonstration of ignition is the required technological threshold to that future multi-megajoule capability, and it is for this reason, as well as nearer-term benefits, that demonstrating ignition is a major Stockpile Stewardship Program (SSP) goal of the ICF Program. Each of the HED facilities plays a unique role in developing the underpinning science and technology towards enabling the first step to an igniting plasma.

The experiments conducted in support of the ICF mission fall into two broad categories: (1) focused experiments that attempt to isolate and test our understanding of a specific code algorithm or material property such as radiative opacity; and (2) integrated experiments of varying complexity that serve several distinct functions. While each facility provides unique capabilities, together they enable the study of physical phenomena using different drivers in regimes of overlap that is essential for building confidence in results obtained in new HED regimes. Below we describe three such efforts that typify how these experiments are used in today's SSP. These examples are drawn from the NIF, but comparable experiments are performed on the Z and Omega facilities.

Ignition and Uncertainty Quantification

Ignition research and development involves some of the most complex integrated experiments performed at the HED facilities. In these experiments, solid cryogenic layers of deuterium-tritium (DT) fuel are imploded nearly symmetrically inside millimeter radius capsules to pressures required in an attempt to ignite DT fuel (see Figure 1). These experiments are heavily diagnosed with x-ray and nuclear instruments and are designed to test hypotheses aimed at understanding and improving target performance. At present, implosions on the NIF are approaching the burning plasma regime in which the alpha particle energy deposited in the fuel is almost equal to the mechanical energy provided by the imploding capsule. This extra heating from the fusion alpha particles results in a yield amplification required for the experiment. Analysis suggests that shell distortions resulting from drive asymmetries and hydrodynamic instability cause the assembled fuel to disassemble before the fusion self heating from alpha particles has time to run away. Resolving these issues is the current focus of research. Similar efforts are underway exploring the physics of alternate compression schemes at the Z and Omega facilities.

An exciting emerging application of these ignition experiments is to test and advance our uncertainty quantification (UQ) methodology. A multi-disciplinary team of weapons scientists, ICF scientists, engineers, and computational scientists is developing new tools for application across the stockpile stewardship enterprise, using deep learning methods to combine simulation results and experimental observation. Ignition experiments at NIF are providing a stressing test of these new methods, particularly where little to no data yet exist.

Material Strength of Solids at High Pressure

Understanding the strength of materials at high pressure is important to the SSP. Strength is a quantitative measure of a material's resistance to deformation and affects compressibility and the material's evolution under deformation. It is a function of temperature, pressure and strain rate. Microscopically, strength is the resistance to dislocation generation and transport. Direct observation of dislocations requires transmission electron microscopy (TEM)-level spatial resolution and is not available in current

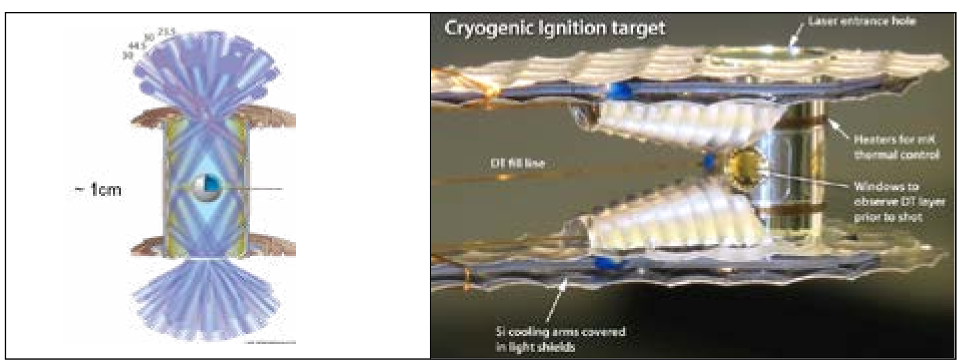


Figure 1. Schematic of a NIF hohlraum surrounding a capsule containing a cryogenic solid layer of DT fuel. The fuel is injected through a ultra-fine fill tube less than 5 μm in diameter (a human hair is 100 μm in diameter). NIF's 192 laser beams enter the hohlraum from the top and bottom in 4 cones of beams positioned so that the x-rays generated inside the hohlraum symmetrically illuminate the capsule and implode it symmetrically. Actual NIF hohlraum (right) is a highly complex multi-component assembly that must be assembled to tolerances of a few 10s of μm and that must survive the cryogenic environment.

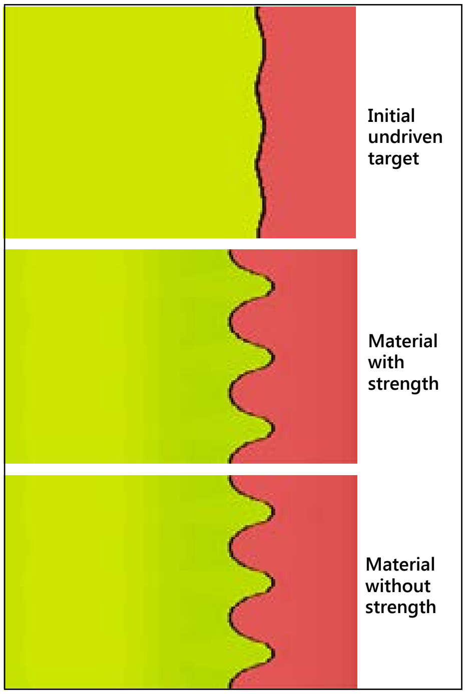


Figure 2. Simulations of material samples (red) accelerated to the right viewed in a frame moving with the sample. The degree to which pre-imposed perturbations become amplified depends on the strength of the material. Measuring this amplification allows us to test strength models under conditions relevant for the SSP.

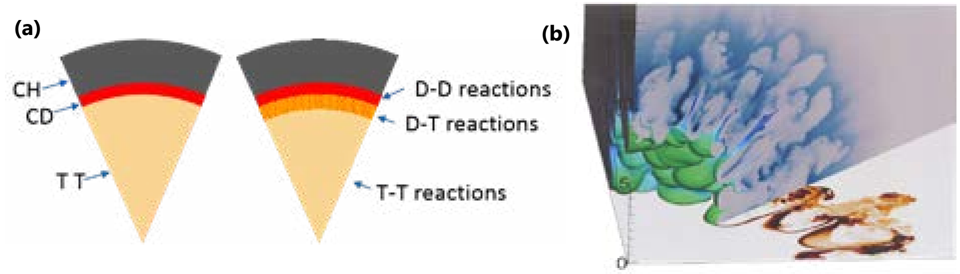


Figure 3. (a) Schematic of the capsule used in the two-shock experiment. Initial configuration (left). After implosion (right), the D and T reactants have mixed producing DT neutrons. The signal increases as the mixing increases. (b) Three-dimensional direct numerical simulation of interface mixing during deceleration stage using the high-order code Miranda, showing diffusive mixing in the interior of the capsule near the hot-spot, and turbulent mixing further out in the cooler regions of the shell.

dynamic experiments. Instead, integrated experiments on the NIF assess material strength by measuring its effect in suppressing the growth of hydrodynamic instabilities such as the Rayleigh-Taylor (RT) instability (see Figure 2). Detailed measurements of the seeded instability growth are compared with hydrodynamic simulations to assess the veracity of various strength models.

Two-Shock Campaign

The recent NIF two-shock campaign [S.F. Khan et al., Phys. Plasmas 23, 042708 (2016)], so called because it uses a two-shock x-ray pulse to implode a capsule, was designed to test the effectiveness of various implosion phase mix modeling techniques important for the SSP. In this platform, a plastic capsule is filled with tritium gas while a deuterated plastic tracer layer is situated at the inner surface of the capsule (see Figure 3). As the capsule decelerates during stagnation, the tritium makes a "hot spot" and copious TT neutrons are produced. At the same time, RT instability causes the deuterated capsule material to "mix" into the outer layers of the T gas, cooling the mixed layer of gas and reducing the TT neutron yield. The further the capsule material penetrates, the lower the TT yield. Some of the capsule material that penetrates the gas mixes with the tritium at an atomic level. If this material contains deuterium from the tracer layer, the magnitude of the resulting DT neutron signal diagnoses how much of the tracer material has penetrated the gas and mixed atomically. The DD neutron signal over and above that consistent with the DT signal is a separate measure how much tracer material penetrated the tritium hot spot but did not mix atomically. Together, these signals provide a tight constraint on models. •

Highlight

2018 High Energy Density Summer School

To promote the spread of broad, fundamental knowledge and to train new entrants into the field of high energy density physics, the University of Michigan, Ann Arbor is offering a High Energy Density Summer School from June 11-22, 2018. The in-depth introduction to the field will include approximately 40 hours of lectures over 11 days. The lectures will be based primarily on the book High-Energy-Density Physics, 2nd ed., by Prof. R. Paul Drake. Topics to be covered include (1) fundamental equations and equations of state, (2) shocks, rarefactions, and their interacations, (3) hydrodynamic instabilities, (4) radiative transfer, (5) radiation hydrodynamics, (6) creating high energy density conditions, (7) inertial fusion, (8) experimental astrophysics, (9) relativistic systems, and (10) magnetohydrodynamic.

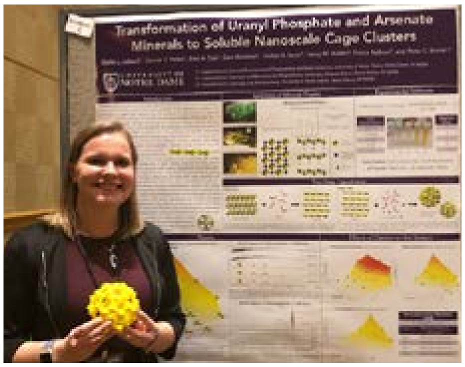
For more information, you may contact Jan Beltran at (734) 936-0494 (jbeltran@umich.edu) visit http://clasp-research.engin.umich.edu/workshops/hedss/index.html. •

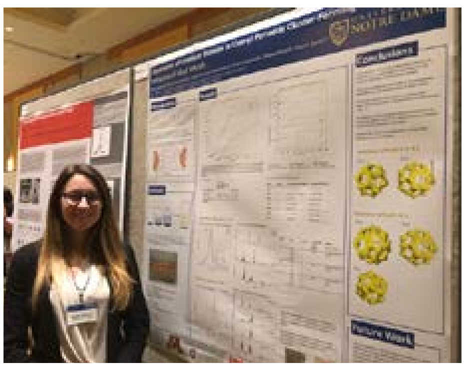
Suggestions or Comments?

Do you have a great idea for an article or comments about this issue of the Stockpile Stewardship Quarterly? If so, please email Terri Stone at terri.stone@nnsa.doe.gov.

2018 Stewardship Science Academic Programs Annual Review Symposium

This year's Stewardship Science Academic Programs Annual Review Symposium drew a record number of attendees. Approximately 350 individuals from the National Nuclear Security Administration (NNSA) and other government agencies, DOE/NNSA national laboratories, and academia attended this year's annual review symposium held in Bethesda, Maryland on February 21-22, 2018. The symposium featured overviews of work to date from ongoing grants and cooperative agreements from the Stewardship Science Academic Alliances Program; the NNSA-supported grants from the Joint Program for High Energy Density Laboratory Plasmas; and grants awarded under the National Laser Users' Facility Program.





Top: Haylie Lobeck, University of Notre Dame (ND), presented her poster, Transformation of Uranyl Phosphate and Arsenate Minerals to Soluble Nanoscale Cage Clusters, during the poster session. Bottom: Full-size photo of the inset from the cover featuring Sarah Hickam. The title of her poster is Dissolution of Uranium Dioxide in Uranyl Peroxide Cluster-Forming Conditions: Influence of Alkali Metals.

The Office of Research, Development, Test, and Evaluation's (RDT&E's) Dr. Kathleen B. Alexander gave the keynote address this year. She shared with the attendees the experiences that led to her current role as the Assistant Deputy Administrator for RDT&E. She highlighted her work at the national labs, and the value of those experiences in her work at NNSA. She also spoke to how she came to the decision to enter management at the Federal level, and the personal commitment that that decision required. When asked what she plans to do next, Dr. Alexander replied, "I have the best job in the Federal Government. Why would I want to do anything else?"

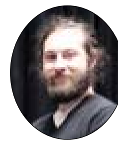
The Poster Session and reception followed. There were approximately 135 posters, 107 of which were student posters, on view during this year's session on topics including low energy nuclear science, radiochemistry, properties of materials under extreme conditions and/or hydrodynamics, and high energy density physics. The winners of the Poster Session follow.

Kristyn Holley Brandenburg
Ohio University
Developing a Long Counter for (alpha,n) Measurements Relevant to the Alpha-Process and Nuclear Reactor Diagnostics at Ohio University

Samantha Couper
University of Utah
Deformation of a Lower Mantle Assemblage at High Temperature

Sakun Duwal
Washington State University
Transformation of Hydrazinium Azide (N5H5) to N8 at 40 GPa

Yuankan Fang
University of California, San Diego
High Pressure Effects on BiS2-Based Compounds



Dan Hoff
Washington State University in St. Louis
Producing Huge Spin Alignment in Inelastic Excitations of Clustered Nuclei

Rebecca Lewis
Michigan State University
Experimentally Constrained 73Zn(n,g)74Zn Cross Section

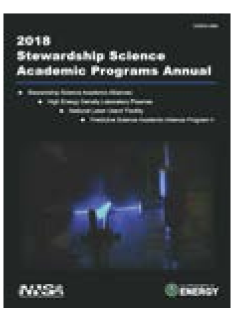
Marc-Andre Schaeuble
University of Texas, Austin
Helium at White Dwarf Photosphere Conditions: Experimental Line Shifts and Widths

Hannah Shelton
University of Hawaii, Manoa
Cristobalite X-I: A Bridge Between Low and High Density Silica Polymorphs

Hong Sio, Massachusetts Institute of Technology
Implications of Differences Between Measured and Rad-Hydo-Simulated Reaction Histories in Hydro-like Implosions on OMEGA

Jeff Woolstrum
University of Michigan
New Computational and Radiographic Capabilities at the University of Michigan

Liangyu Yao
Oregon State University
Target Making for Nuclear Reaction Studies



2018 Stewardship Science Academic Programs Annual

To request copies of the 2018 SSAP Annual, contact Terri Stone at terri.stone@nnsa.doe.gov. •