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

We recently celebrated the 20th anniversary of the Stockpile Stewardship Program (SSP). The Washington, DC event (see photo on right) was a wonderful opportunity to highlight the work that has been accomplished to ensure that the stockpile remains safe, secure, and reliable in the absence of nuclear testing. It was an occasion to celebrate the successes of our efforts and to interact with an impressive set of past, present, and future SSP leaders. It is an honor to be part of that leadership team.

In this issue of the *Stockpile Stewardship Quarterly*, we present recent research which encompasses enhanced surveillance, advanced nuclear cross section measurements, and equation of state for shock compressed material. The first article describes the Enhanced Surveillance Program's focus on developing aging models for materials, components, and subsystems in the stockpile. It also describes the development and deployment of the non-destructive interrogation tools needed for surveillance and/or qualification of new materials for use in the stockpile.

The second article discusses the time projection chamber (TPC), a technique for improving our knowledge of fission cross sections for the major actinides, in particular,  $^{239}\text{Pu}$  and  $^{238}\text{U}$ . The TPC effort involves a large number of university and national laboratory collaborators. The third article describes the dynamic observation of phase transitions of materials under pressure. These difficult-to-measure transitions are diagnosed by surface reflectance.

### Comments

The *Stockpile Stewardship Quarterly* is produced by the U.S. Department of Energy/National Nuclear Security Administration (DOE/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](mailto:terri.stone@nnsa.doe.gov).  
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DOE/NNSA celebrated the twentieth anniversary of the Stockpile Stewardship Program (SSP) on October 22, 2015. The SSP was hailed as a remarkable achievement that resulted from the development and application of science-based tools. The event featured remarks by Secretary of Energy Ernest Moniz, Secretary of State John Kerry, and Under Secretary for Nuclear Security and NNSA Administrator Lt. Gen. (Retired) Frank G. Klotz. Attendees of this public event included leading policy officials, thought leaders, and the directors from the three national weapons laboratories.

Also in this issue, we introduce the six talented individuals named to the 2015-2016 Stewardship Science Graduate Fellowship (SSGF) class. The SSGF program, along with the Computational Science Graduate Fellowship program, provide fellowships in key scientific areas of interest to NNSA. These successful programs highlight our continuous commitment to science-based outreach and help develop the next generation of stockpile stewards.

The NNSA RDT&E team—from federal offices to laboratories and sites to academic and industrial collaborators—has had a successful year full of achievements, and we are *getting the job done* and getting recognition for doing

so. Thank you for your hard work. Best wishes to you and yours for a happy holiday season.



### Inside

- 2 Enhanced Surveillance: Finding Tomorrow's Problems Today
- 4 A Time Projection Chamber for Precision Fission Cross Section Measurements
- 7 Dynamic Observation of Phase Transitions
- 9 2015-2016 Stewardship Science Graduate Fellowship Class
- 10 RDT&E Welcomes New Program Managers

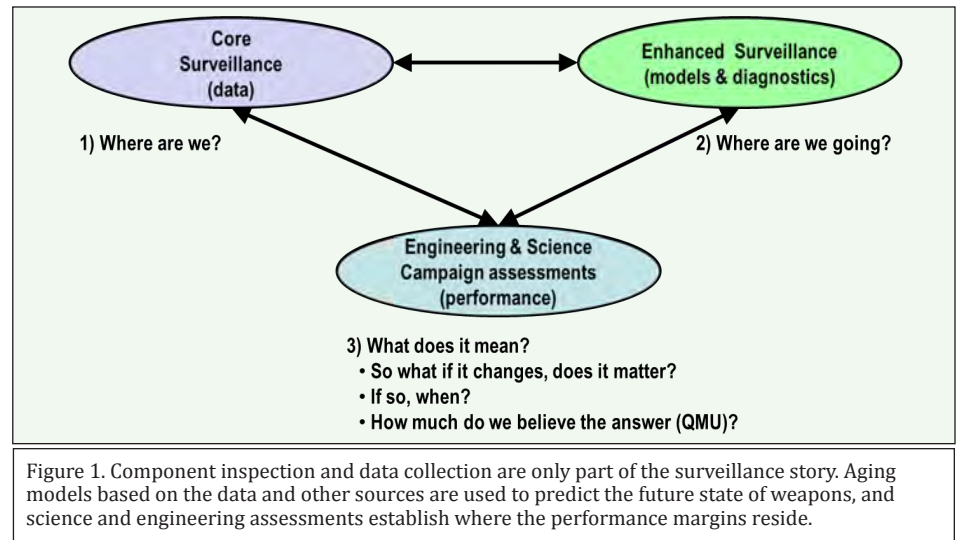
## Enhanced Surveillance: Finding Tomorrow's Problems Today by William McLean (Lawrence Livermore National Laboratory)

The disassembly and inspection of a nuclear weapon reveals the state of the weapon today but does not necessarily predict its future condition. Predictive aging models developed by Enhanced Surveillance (ES) forecast future behavior and, by doing so, buy the time to address changes before weapon performance is adversely impacted. ES also develops and deploys the non-destructive interrogation tools needed to realize a more statistically defensible Surveillance Program and qualifies new materials for use in the stockpile.

### Introduction

The Stockpile Evaluation Program (SEP) was established to oversee the planning and execution of activities aimed at assuring that our aging nuclear weapons remain safe, secure, and effective. The SEP is comprised of three major components (see Figure 1), the first two of which are Core and Enhanced Surveillance. The third component consists of feedback from the Science and Engineering Campaigns. The latter efforts are used to inform all stakeholders when observed or predicted trends might become problems that could affect performance margins and uncertainties.

The Directed Stockpile Work (DSW) Core Surveillance Program employs inspection techniques that are generally destructive in nature as they require breaking a weapon down into its fundamental components. This process is followed by testing of those components to assure that they would have met requirements to perform their functions if the weapons were to be used in a war. Most components were produced in higher quantities than needed for the stockpile and these "reserves" were destructively tested throughout the life of the stockpile to detect unanticipated deviations from the intended design and to screen for age-induced changes in materials that could affect performance or safety of the weapon. It is important to note that, for many systems, the stockpile has exceeded its planned lifetime and the inventories of testable components are being exhausted. Meanwhile the costs



for systems undergoing life extension programs are increased by the need to produce large numbers of "extra" components for this purpose.

The importance of surveillance has grown immensely since the cessation of pit production in 1988 and the termination of nuclear testing in 1992. Prior to those dates, the Nation had active design and production infrastructures that were continuously producing large quantities of new and better weapon systems with ever-increasing levels of inherent safety and reliability. In that environment, problems in the stockpile could be "fixed" by wholesale replacement of marginal systems. Aging was not an insurmountable issue because weapons did not generally remain in the stockpile long enough for aging effects to manifest themselves. The Enhanced Surveillance Campaign (ESC) was established in 1996 in recognition of the fact that the weapons of that time would be required to remain in the stockpile indefinitely. ES was deliberately created to be independent from traditional (or Core) surveillance to focus its resources on solving long-term issues.

The primary functions of ES are as follows:

- Develop material, component, and subsystem aging models that will allow the responsible design agencies to project the future

performance of the system and, more importantly, to anticipate failures with sufficient time to correct them within the confines of the existing infrastructure;

- Develop and deploy surveillance diagnostics to better assess component and material performance with an emphasis on non-destructive diagnostic technologies that can provide data equivalent to or better than that available from traditional destructive testing methods; and
- Identify, develop, and pre-qualify new materials that can substitute for materials that are no longer available in the marketplace.

### Materials Aging Models

One of the early successes of ES was guided by the 1998 JASON study<sup>1</sup> that highlighted plutonium aging as the highest risk to the longevity of the stockpile. The concern of that study's authors was that self-irradiation of plutonium might induce irreversible damage that would affect plutonium performance in the pit (or trigger) of a thermonuclear weapon. This became a national issue as a result of the closure of the Rocky Flats pit production facility and the subsequent inability for the Nation to replace pits for its stockpiled weapons. Between 1998 and 2006, ES invested approximately \$300M to address the risks incurred by the



absence of a pit production facility. ES developed experiments and models led to the conclusion that plutonium aging was not as high a risk as previously anticipated.<sup>2</sup> This assessment forestalled the need for a \$5-10B replacement for the Rocky Flats Plant and illustrates the potential of science-based stockpile stewardship to guide the expenditure of increasingly scarce resources.

Another valuable source of data for aging model development are accelerated aging tests carried out in the laboratory under much more carefully controlled conditions than those encountered in the stockpile. These tests are conducted under higher temperatures and higher radiation dose rates than encountered in the stockpile in order to determine if or when these, or other environmental stresses, will become a problem for our aging weapons. Accelerated aging tests (see Figure 2) are designed to provide the 10 to 15 years early warning of potential problems needed by the production agencies to plan and schedule a response into their respective time tables.

## Diagnostics

ES has developed non-destructive diagnostics that are in use and are transforming surveillance by reducing the overall cost while increasing confidence in the state-of-the-stockpile. Two splendid examples are non-destructive laser gas sampling and x-ray-computed tomography (CT) of pits (see Figure 3). The combination of these two measurements has simultaneously reduced the need for destructive testing while increasing the frequency and numbers of surveys on these expensive assets. Other examples of ES-developed, non-destructive diagnostics include the following:

- Diffuse Reflectance Infrared Fourier Transform (DRIFT) spectroscopy used to determine the initial moisture content of piece parts used in Canned Subassemblies (CSAs);
- the air-bearing system used at Y-12 National Security Complex to probe potential changes to in-flight response to aging materials in the CSA,

- improved instrumentation for determining cushion load retention and compressibility at all DOE/NNSA sites; and
- the implementation of photonic Doppler velocimetry instruments to measure the detonation shock pressure output of aging high explosives.

Other diagnostic capabilities in the development stage include advanced x-ray scintillators for faster data acquisition, neutron imaging—a complementary imaging technique for radiographically dense components, hand-held instruments for determining the intrinsic moisture content of piece parts, and multi-mass leak detectors for improved quality assurance of new or re-manufactured components.

## New Materials

Many materials in the stockpile were manufactured under processes that are no longer environmentally acceptable and many others have been made obsolete and replaced by materials that have not been tested for compatibility with the ensembles of other materials in a nuclear weapon or with nuclear weapon environments. Yet other materials have been “improved” by adding constituents that enhance commercial attributes such as color or shelf-life, but the additives have not been tested for compatibility with other weapons materials. ES has worked to overcome these difficulties by fielding a new generation of compatibility testing tools that use micro-samples, accelerated aging methods, and state-of-the-art analytical chemistry tools to screen out materials incompatibilities in a fraction of the time and expense of

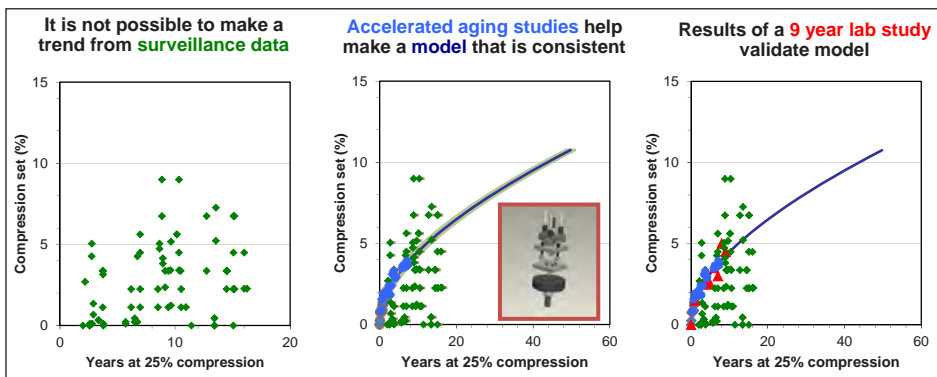


Figure 2. Superposition of surveillance data (dots) with master aging curve for percent compression set for polydimethylsiloxane foam versus time derived from accelerated aging tests.



Figure 3. The CoLOSSIS (Confined Large Optical Scintillator Screen & Imaging System) X-ray CT system at DOE/NNSA's Pantex Plant is dramatically increasing the inspection rate for pits. A second unit is being planned to meet future demand.

previous technologies. Many of these screening tools (such as solid phase micro extraction) have transitioned into Core Surveillance and are being used on a routine basis to track the evolution of deleterious gases within warhead assemblies. Shown in Figure 4 is a silicone structure (formulated from all new constituents) designed to replace a legacy foamed material. This formulation has passed through the initial suite of compatibility screening assessments and is entering into a matrix of long-term tests.

### Summary

Surveillance is a vital part of assessing the state of the nuclear arsenal. From the outset of our nuclear history, weapon designers and engineers have conducted surveillance to identify, monitor, and understand features that could potentially degrade the military

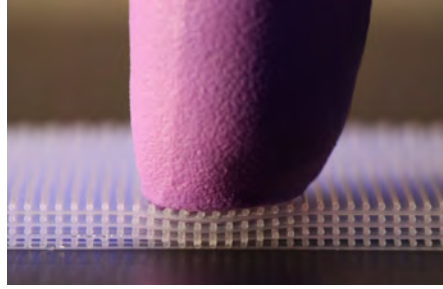


Figure 4. The structure of additively manufactured silicone foam to replace legacy material is controlled and allows deliberate design of mechanical response. Accelerated aging tests show that this material has properties equal to or better than legacy material.

performance of as-built weapons. The weapon design agencies have established requirements to periodically inspect and evaluate weapon components for the presence of design and manufacturing defects as well as for the emergence of

age-induced changes that could affect their ultimate performance. In the past, surveillance protocols have required large numbers of destructive tests to achieve statistical confidence in the state of the stockpile. The aging models and advanced non-destructive diagnostics developed by ES are dramatically improving the Nation's ability to conduct these surveillance activities in a manner that is robust, scientifically defensible, and cost effective. Without these improvements, our ability to have confidence in a lower-than-ever population of weapons in the stockpile would not be possible.

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## A Time Projection Chamber for Precision Fission Cross Section Measurements *by Nathaniel Bowden (Lawrence Livermore National Laboratory) and Rusty Towell (Abilene Christian University) for NIFFTE Collaboration*

### Introduction

Since their invention in the 1970s, time projection chambers (TPCs) have seen wide use in high energy physics research, where they are used for tracking and identifying particles produced in accelerator experiments. These gas-filled detectors provide detailed information about individual charged particles, including three-dimensional (3D) trajectory, energy, and particle type. A collaboration of national laboratories and universities on the Neutron Induced Fission Fragment Tracking Experiment (NIFFTE) has the goal of performing precise measurements of nuclear cross sections by extending this established technology to a new operational regime.

Specifically, NIFFTE seeks to improve our knowledge of fission cross sections for the major actinides, in particular  $^{239}\text{Pu}$  and  $^{238}\text{U}$ , as a function of incident neutron energy. These cross sections are essential inputs for many applications, including stockpile stewardship and the design and operation of nuclear reactors. Current knowledge of these important nuclear data, which describe how readily an incoming neutron of

a given energy can cause a nuclear fission reaction, were measured with devices called fission chambers. Individual experiments achieved accuracies of 2-3%, but were not in good agreement with one another, raising the possibility of unaccounted for systematic uncertainties. NIFFTE will use the additional information provided by the TPC technique to study sources of measurement uncertainty and, ultimately, measure fission cross sections with 1% accuracy.

The NIFFTE Collaboration currently comprises scientists from Lawrence Livermore National Laboratory (LLNL); Los Alamos National Laboratory (LANL); Abilene Christian University (ACU); California Polytechnic State University, San Luis Obispo (CalPoly); University of California, Davis; the Colorado School of Mines (CSM); and Oregon State University (OSU). Institutions that made contributions in earlier stages of the project include Idaho and Pacific Northwest National Laboratories, Georgia Institute of Technology, Idaho State University, and Ohio University. Experiments are conducted at LLNL and the Los Alamos Neutron Science

Center (LANSCE) at LANL. The effort is supported by DOE/NNSA's Stockpile Stewardship Program, and previously by DOE's Office of Nuclear Energy.

Since the beginning of the project, collaboration between the laboratories and universities has been critical to the project's success. For example, OSU has provided all of the actinide targets used by NIFFTE, and CSM built the gas handling system. While the laboratories focused on the design and development of much of the hardware for the measurements, the software for data acquisition and offline reconstruction and analysis was pioneered by collaborators and students at two undergraduate institutions, ACU and CalPoly. Over the course of the project, approximately 30 undergraduates and 12 graduate students have contributed to the success of the experiment. Many of these have proceeded to graduate school or postdoctoral positions in nuclear science. Recently CSM (with subawards to ACU, CalPoly, and OSU) was awarded a Stewardship Science Academic Alliances grant to support their participation in the NIFFTE collaboration.



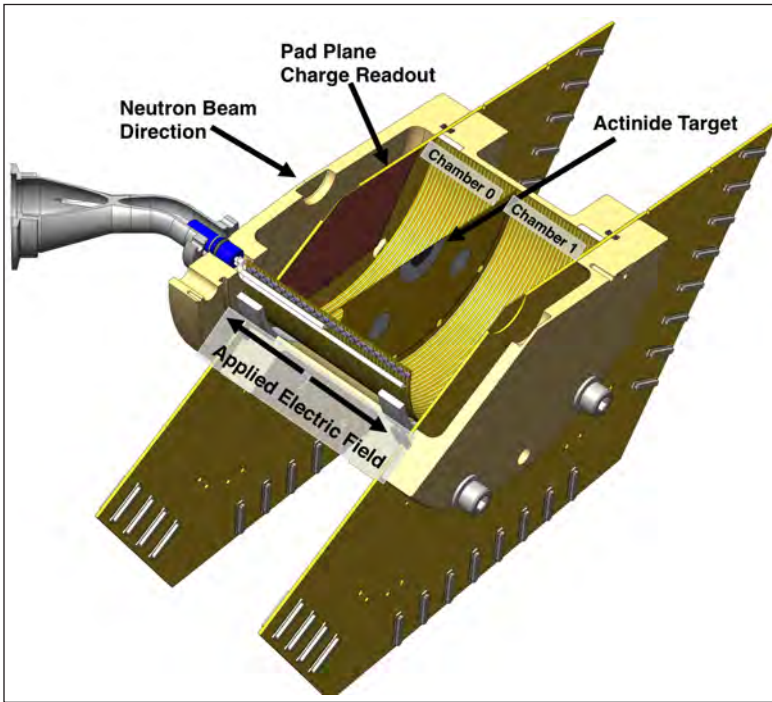


Figure 1. Cut away view of the fissionTPC. Incident beam neutrons induce fission reactions in a thin actinide target at the center of the device. The resulting fission fragments exit either side of the target, generating ionization tracks that are individually recorded in both chambers. The applied electric field drifts the ionization charge to the pad plane readout structures.

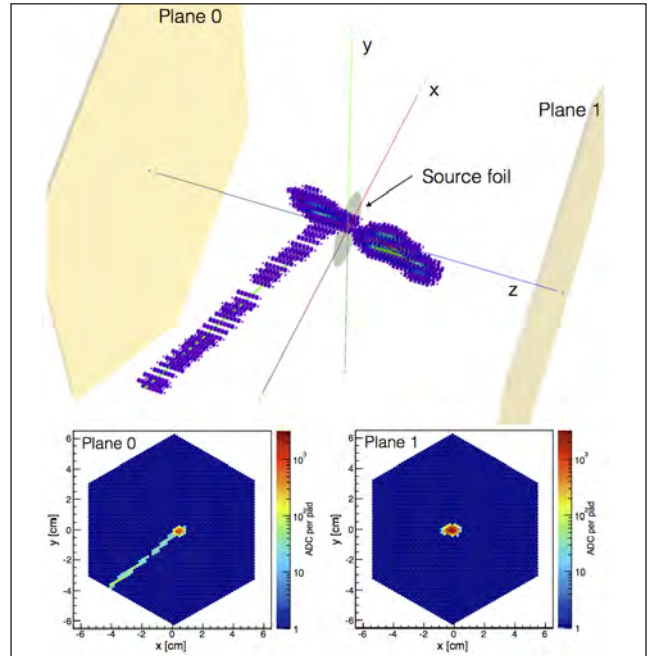


Figure 2. Data from a single event in the fissionTPC. The top diagram illustrates the reconstructed particle tracks. The bottom plots are a projection of the same event as recorded on each amplification pad plane, i.e., without the timing information used to reconstruct along the z direction. Colors indicate the amount of charge, where blue is sparse and red is dense. The event contained two fission fragments (short tracks) and an alpha particle (long track).

## Time Projection Chambers and the FissionTPC

A TPC comprises a gas-filled interaction region across which an electric field is applied and a 2D charge readout system. The passage of a charged particle through this region leaves a track of ionization charge produced as the particle loses energy. Even though the particle interaction is effectively instantaneous, the applied electric field drifts the ionization charge to the readout plane over several microseconds. Recording the ionization charge arrival time as well as the 2D position allows full 3D reconstruction of the particle trajectory. Detailed examination of the amount of charge arriving as a function of time, i.e., the ionization density along the particle track, identifies the particle type, while the sum of the charge is proportional to particle energy.

To perform fission cross section measurements, the NIFFTE Collaboration has designed and constructed a device specifically suited to the task, the fissionTPC<sup>1</sup> (see Figure 1) which differs in many significant respects from both the fission chambers used previously, and from TPCs typically used in high energy physics. In contrast to fission

chambers, which record a single quantity related to particle type and energy, the fissionTPC records a full 3D ‘image’ of every particle track as well as its start and end locations. And unlike TPCs typically used in high energy physics to measure through-going particles with energies exceeding many GeV, the fissionTPC is tailored to measure lower energy tracks of three distinct particle types simultaneously. These are heavy fission fragment nuclei with  $\sim 100$  MeV of energy, alpha particles from actinide radioactive decay with  $\sim 5$  MeV of energy, and hydrogen nuclei set in motion by elastic scattering from incident beam neutrons (‘recoil protons’).

A thin target coated with the actinide (or actinides) of interest is placed at the heart of the fissionTPC, separating two identical chambers of 15 cm in diameter. A broad energy neutron beam generated by LANSCE passes through one chamber before impinging on the target. Fission fragments, proton recoils, or other charged particles induced by the neutron beam ionize the TPC gas, producing ions and electrons. The strong electric field applied in the fissionTPC drifts these electrons toward gaseous electron multiplier

amplification structures and electronics at the ends of both chambers before they can recombine with the residual ions. These amplification structures contain a two-dimensional array of almost 6,000 hexagonal pads that collect the electrons and measure the total ionization charge.

Amplifier and data-acquisition systems connected to the pads acquire a 2D set of coordinates for each cluster of amplified electrons. Compact electronics designed especially for the fissionTPC enable full waveform readout of all 6,000 charge collection pads in a space-, energy-, and cost-efficient manner.<sup>2</sup> Given knowledge of the electron drift speed (approximately  $5 \text{ cm}/\mu\text{s}$ ) the charge arrival time combined with the 2D charge readout yield a 3D image of each particle track. An example of this capability is shown in Figure 2: a reconstructed ternary fission event containing two heavy fission fragments and an alpha particle.

## Using the FissionTPC Capabilities for Improved Cross Section Measurements

Potential sources of systemic uncertainty in past fission chamber measurements

are particle identification, target and beam spatial non-uniformity, and the cross-section uncertainty of the reference material. The fissionTPC is designed to directly examine, quantify, and/or reduce these sources of uncertainty.

In a fission chamber, different particle types—fission fragments, alpha particles, and other particles set in motion by the neutron beam—can be difficult to distinguish since incomplete information is recorded. The fissionTPC records the deposited energy, the length of the ionization track, and the rate of energy loss along the track or ionization density, all of which depend on each particle's mass and charge. Heavy fission fragments lose energy quickly and thus leave short ionization tracks with a high ionization density, while alpha particles lose energy more slowly as a function of length and therefore have longer trajectories (see Figure 2). Furthermore, when ionization density is examined as a function of distance, alpha particles and recoil protons have a pronounced spike, or Bragg peak, indicating increased energy loss near the end of the track. These unique features obtained from detailed ionization information enable the fissionTPC to identify particle type.

Target and beam non-uniformities may also contribute to the discrepancy amongst past measurements, as fission chambers cannot measure these quantities. For fission chamber measurements, the target atom spatial distribution was typically determined using alpha-particle decay measurements of the actinide by separate dedicated detectors, which could not map out the spatial distribution of the target in detail. The fissionTPC can use information from individual alpha particle tracks to determine the emission location, providing a map of target thickness in situ. With this method, the target shape and distribution of actinide atoms can be characterized to within a few hundred micrometers because the measured tracks of identified alpha particles point back to precise locations on the target surface.

The fissionTPC also measures neutron beam profiles by tracking another kind of interaction—recoil protons set in motion by neutron scatter interactions. The spatial distribution of starting points of these protons corresponds to the neutron beam spatial distribution (see

Figure 3). In this way the fissionTPC allows one device to perform in situ measurement of the target and beam uniformity simultaneously. With the target thickness map and the beam profile, the effect of spatial non-uniformities on the cross section calculation can be directly accounted for, reducing the effect of systematic errors in fission chamber measurements.

### Current Status and Outlook

The NIFFTE Collaboration has collected data at LANSCE using multiple actinide targets ( $^{239}\text{Pu}/^{235}\text{U}$  and  $^{238}\text{U}/^{235}\text{U}$ ). These datasets comprise millions of particle tracks and hundreds of terabytes of information on disk. Software tools to reconstruct particle tracks, particle types, and particle energies have been developed and are being refined. These tools are now being used to calculate the inputs to a cross section measurement, and critically, to explore the impact of the measurement technique upon the resulting uncertainty. Further data will be taken using thin backed targets to further explore the impact of particle identification uncertainties in the two-chamber fissionTPC. Furthermore, the collaboration is actively working on techniques to measure the  $^{239}\text{Pu}/^1\text{H}$  cross section ratio. Since the neutron elastic scattering cross section on  $^1\text{H}$  is amongst those most precisely known in nuclear physics, this will reduce the the uncertainty associated with the  $^{235}\text{U}$  standard. While this experimental program will require several more years of focused effort, the central capabilities of the fissionTPC have been demonstrated and their impact on cross section measurement uncertainties will soon become apparent. The NIFFTE Collaboration has already made a lasting impact on the 42 students that have contributed to this work and the collaboration is committed to continuing

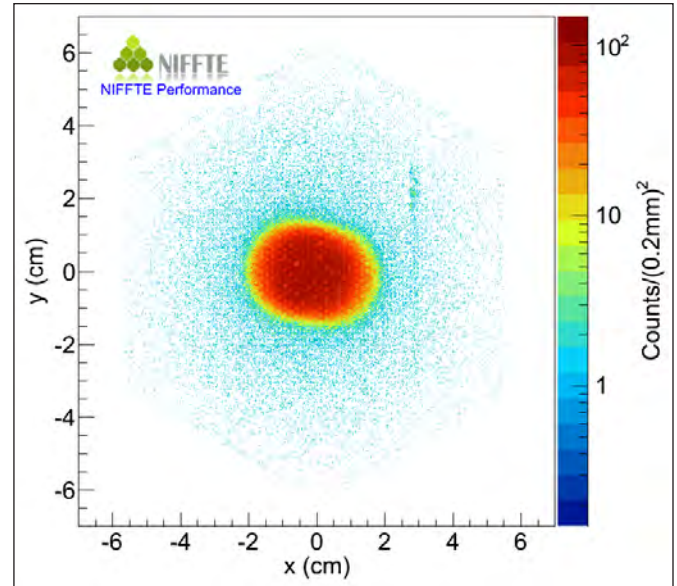


Figure 3. The spatial profile of the neutron beam delivered to the fissionTPC by LANSCE. Proton recoils are identified by examining the ionization profile of individual events and the start position of the tracks recorded in the 2D plane where the actinide target of interest is located. Measuring and accounting for the spatial non-uniformity of both beam and actinide target is one way in which the fissionTPC will study and reduce systematic errors in fission cross section measurements.

to mentor and train the next generation of nuclear scientists.

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## Dynamic Observation of Phase Transitions by Gerald Stevens, Brandon La Lone, W. Dale Turley, and Lynn R. Veaser (National Security Technologies, LLC)

### Introduction and Motivation

Certification of our Nation's aging stockpile requires complex weapons performance models that predict the behavior of designs and components without the benefit (and cost) of nuclear testing. At the core of these calculations are material models, or equations of state that govern how a material behaves under extreme dynamic pressures. Under pressure, a material transforms to other phase states (liquid, or gas), and many materials have multiple distinct high-pressure solid phases. Determining the location of phase-boundaries is difficult and has been a long standing goal of the National Security Laboratories community. Velocimetry has historically been the key diagnostic used to indicate shock-induced phase transitions. As a material changes phase, an accompanied change in density can leave a signature in the measured velocity profile. However, phase transitions with small density changes are difficult to identify with velocimetry. In addition to a density change, there may be a change in crystal or electronic structure, thermal conductivity, dielectric constants, optical reflectance, or other quantities which could be used to indicate a phase transition. Many of these characteristics are difficult to observe dynamically.

Surface reflectance is one of the more accessible properties of a metal in a shock experiment. We have previously seen correlations between reflectance and material phase.<sup>1</sup> In a series of recent explosive experiments,<sup>2-4</sup> our group developed integrating sphere reflectance techniques to determine the emissivity and temperature of shocked tin in a region up to about 30 GPa, well above the tin  $\beta$  to BCT (body centered tetragonal) phase transition near 9 GPa.<sup>5</sup> In these experiments, the Taylor wave release, which is a time-dependent pressure release that immediately follows detonation, allowed us to obtain estimates of the temperature versus stress,<sup>4</sup> and the dynamic reflectance measured in those experiments showed pronounced changes while changing phase.

### Project

In addition to explosive drive experiments, we performed shock compression experiments using a half-inch-diameter gas gun to measure the dynamic reflectance of tin samples shocked through the  $\beta$ -BCT solid-solid polymorphic phase transition near 9 GPa. Figure 1 shows a schematic of the experimental setup. Complete details about this setup will be published in the *2015 Proceedings of the APS Conference on Shock Compression of Condensed Matter*. A copper or aluminum impactor strikes the tin target, driving a high-pressure phase transition in the tin at the sapphire window interface. The sapphire window maintains the pressure at the interface during the measurement. Light from a xenon flash lamp fills an integrating sphere which illuminates the shocked surface prior to, during, and after the phase transition occurs. An integrating sphere is a hollow sphere with a highly reflective and diffuse coating on the inside surface. For our purpose, the integrating sphere acts as a large area, large solid angle, and diffuse illumination source which makes the reflectance signal insensitive to surface motion and tilt. Light reflected from the tin is collected by a 1-mm fiber,

and split to six spectrally filtered photo receivers and recorded on high speed (1 GHz) digitizing oscilloscopes. A small ( $\sim 1$  mm) hole opposite the window along the normal to the sample holds a collimated photonic Doppler velocimetry probe for simultaneous velocity measurement of the interface.

### Measurement Results

Figure 2 shows the dynamic reflectance changes,  $\Delta R$ , for all seven experiments. In the low-pressure  $\beta$  phase, the reflectance decreases with increasing pressure at shorter wavelengths. Reflectance increases abruptly (over a 2-3 GPa range) with increasing pressure at the  $\beta$  to BCT transition for all wavelengths. Once the transition is complete, the reflectance in the BCT phase decreases with stress.

The low-pressure dependence of the  $\beta$ -phase may be described for each wavelength by a linear fit (dashed lines). Likewise, the high-pressure behavior of the BCT phase for the two highest pressure experiments was fit by a line. At intermediate stresses near the phase transition, the tin is likely in a mixed phase, so that some fraction ( $\alpha$ ) is in the BCT phase and the remainder in the  $\beta$  phase. In order to estimate the phase fraction from our experiments,

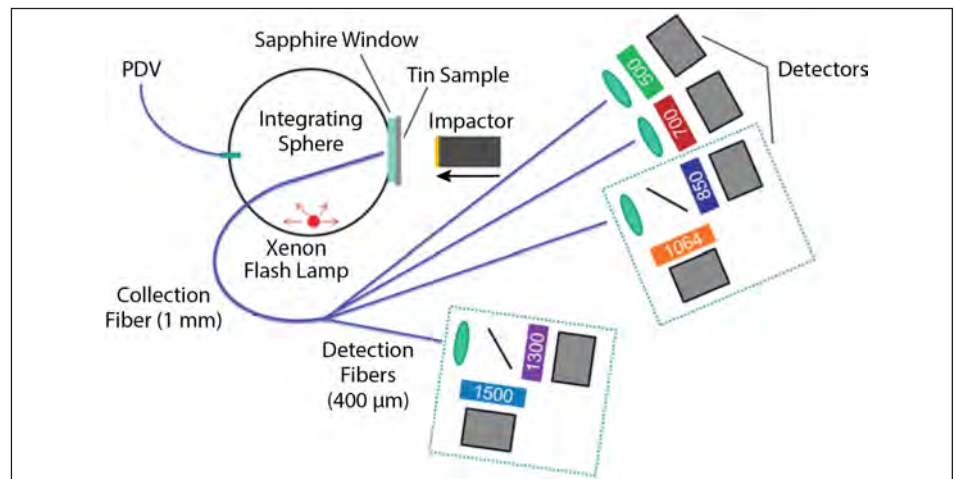


Figure 1. Schematic diagram of the experimental apparatus used to measure the spectral reflectance of tin during shock wave compression. An impactor is launched by a gas gun toward a tin sample backed by a sapphire window. The sample is illuminated by an integrating sphere with an internal Xenon flash lamp. Light reflected from the tin/sapphire interface is collected by a 1-mm core fiber optic and distributed via several 400- $\mu$ m fibers to a collection of photodetectors. Each detector has an optical bandpass filter which is labeled by the center wavelength in nm, ranging from 500 nm to 1,500 nm. A photonic Doppler velocimetry probe is used to simultaneously record the velocity history of the tin/sapphire interface.

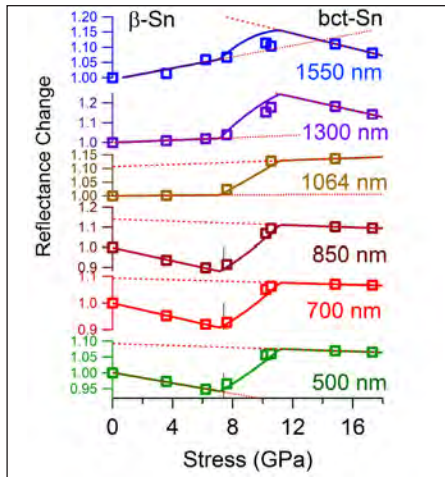


Figure 2. Reflectance changes at six different wavelengths versus stress for all seven experiments. Red dashed lines are linear fits to the low-pressure and high-pressure behaviors at each wavelength.

we created a reflectance change function  $R(\lambda, P, \alpha)$  from the extrapolated low- and high-pressure linear response and found the phase fraction that minimized the sum of squared residuals, i.e.,  $(\sum \lambda (R(\lambda, P, \alpha) - R_{meas}(\lambda, P))^2)^{1/2}$  from our measured reflectance data  $(R_{meas}(\lambda, P))$ . This approach allowed us to fit all wavelengths in the experimental reflectance data with

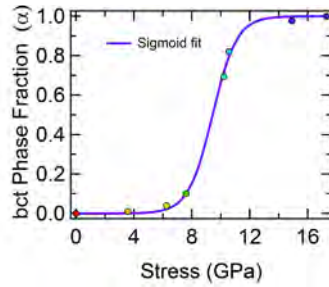


Figure 3. Inferred phase fraction versus stress from our experiments.

a single estimate of the phase fraction. The results are shown in Figure 3, with a sigmoid fit to guide the eye. This figure highlights the gradual onset and completion of the phase transition with stress which was not evident in the velocimetry data. This phase fraction versus peak stress curve would be nearly impossible to determine from velocity wave profile measurements alone.

### Summary

We have developed a methodology to obtain the dynamic phase-fraction of shocked materials using optical reflectance. Our method extrapolates the low- and high-pressure behavior of two isomorphous phases and finds the

phase fraction which best matches the measured reflectance to six spectral channels. For tin, we see the  $\beta$  - BCT transition begin at 6 GPa and completes at 12 GPa, which is more gradual than indicated by velocimetry. The technique works well for tin; future experiments will look for the high-pressure melt boundary in tin and begin investigating zirconium.

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STEWARDSHIP SCIENCE

# GRADUATE FELLOWSHIP

The Department of Energy National Nuclear Security Administration Stewardship Science Graduate Fellowship (DOE NNSA SSGF) program provides outstanding benefits and opportunities to students pursuing a Ph.D. in areas of interest to stewardship science, such as **properties of materials under extreme conditions and hydrodynamics, nuclear science, or high energy density physics**. The fellowship includes a 12-week research experience at Lawrence Livermore National Laboratory, Los Alamos National Laboratory or Sandia National Laboratories.

### BENEFITS +

- \$36,000 yearly stipend
- Payment of full tuition and required fees
- \$1,000 yearly academic allowance
- Yearly program review
- 12-week research practicum
- Renewable up to four years

APPLY ONLINE: [www.krellinst.org/ssgf](http://www.krellinst.org/ssgf)

The DOE NNSA SSGF program is open to senior undergraduates or students in their first or second year of graduate study.

Applications for the 2016-2017 class are being accepted through January 13, 2016.



This equal opportunity program is open to all qualified persons without regard to race, gender, religion, age, physical disability or national origin.



## 2015-2016 Stewardship Science Graduate Fellowship Class

Six new doctoral candidates were accepted into the DOE/NNSA Stewardship Science Graduate Fellowship (SSGF) program this fall, joining 15 previous recipients. The program supports doctoral candidates studying high energy density physics, nuclear science, or materials under extreme conditions and hydrodynamics. They receive full tuition, a stipend, a practicum at a DOE/NNSA national laboratory, and other benefits.

**Nathan Finney**, working with Columbia University's James Hone, plans to probe the behavior and physics of two-dimensional materials, like graphene and semiconducting transition metal dichalcogenides, under extreme strain. His tools include photocurrent measurement, Raman spectroscopy, atomic force microscopy and electrical measurements to understand strain-related effects, his research statement says. First, the micro/nanoscale engineering student is working to solve problems like keeping thin films from slipping under load, suspending the materials and making instruments compatible for simultaneous measurement.



**Leo Kirsch** has helped develop the High Flux Neutron Generator (HFNG) at the University of California, Berkeley to help improve nuclear reaction data accuracy for reactors, accelerators, and other devices. Under Karl van Bibber, the nuclear and accelerator physics student fabricates targets of isotopes that have insufficient nuclear data. He helps devise detection electronics and operate the HFNG. Kirsch also uses computers to model the beam optics and neutron beamline and to analyze gamma ray spectra. "Using the appropriate



theoretical means I am able to interpret the results to publish reaction cross sections" within a suitable margin of error, his research summary says.

Michigan State University theoretical nuclear physics student **Amy Lovell** is tackling two problems with advisor Filomena Nunes, her research summary says. The first: three-body calculations for the two-neutron decay of neutron-rich nuclei. Recent experiments found evidence of  $^{16}\text{Be}$  to  $^{14}\text{Be}$  decay via the emission of two neutrons, but it was unclear whether the neutrons were correlated. She's using a three-body model ( $^{14}\text{Be} + n + n$ ) to reproduce this system and portray the decay mode more clearly. Second, Lovell is studying uncertainty quantification for reaction theories, especially accounting for reaction cross-section calculation errors resulting from imperfect fits to experimental data.



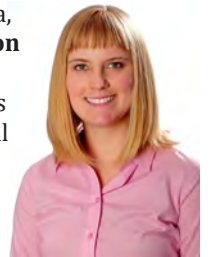
At the Georgia Institute of Technology, mechanical engineering student **Christopher Miller** uses computer simulations to understand how pressed granular explosives (HMX, specifically) respond under shock loading. His cohesive finite element framework models grain structure at the mesoscale level, allowing Miller and advisor Min Zhou to study how hotspots evolve due to fracture and plastic deformation, Miller's research summary states. They want to better understand how ignition happens in high energy density explosives and how microstructure variation affects it. Their results could have broader implications, including illuminating polycrystalline strength and structure, leading to stronger materials.



**Brooklyn Noble** is thinking small for her research under the University of Utah's Bart Raeymaekers. They're probing the ultra-thin, polymer-based lubricants that make devices like micro- and nano-electromechanical systems (MEMS/NEMS) possible, focusing on how they interact with each other and their environment. Noble and Raeymaekers hope what they learn will guide lubricant design for nanoscale applications and spur progress in miniaturizing new devices, her research statement states.



University of California, Berkeley student **Alison Saunders** uses x-ray scattering experiments on the Omega, National Ignition Facility, and Linac Coherent Light Source facilities to study warm dense matter, hoping to illuminate its underlying physics. Typically, the tests heat samples of elements like carbon or beryllium to high temperatures and pressures and measure their properties with a range of x-ray instruments, according to her research statement. Working with advisor Roger Falcone, Saunders uses modeling tools to analyze experiment data, helping define the path to inertial confinement fusion, and understand extreme environments like the interiors of planets and white dwarf stars.



To learn more about the DOE/NNSA SSGF program, visit [www.krellinst.org/ssgf/](http://www.krellinst.org/ssgf/). •

## RDT&E Welcomes New Program Managers to the Office of Research and Development

### William Rhodes

For the past seven years, Dr. William (Bill) Rhodes has been a member of the DOE/NNSA Defense Nuclear Nonproliferation organization. Rhodes supported the mission of his office, which is to strengthen the United States Government capacity to detect and prevent weapons of mass destruction-related commodity and technology transfers to foreign programs of concern and to support international export-control supplier regimes, such as the Australia Group.

Prior to joining NNSA, Rhodes was a research scientist at the Savannah River National Laboratory (SRNL) where he was the Principal Investigator on a DOE-sponsored Fuel Cell research program. At SRNL, he also conducted R&D activities



supporting the Tritium mission and H Canyon (PUREX flow-sheet development and computer simulation of nuclear fuel dissolution processes). Bill served as a nuclear analyst at the Bettis Atomic Power Laboratory, supporting the United States Naval Nuclear Propulsion Program before going to SRNL. Bill received his Chemical Engineering degrees from the University of Cincinnati (BS) and the University of Pittsburgh (MS, PhD) and his MS in Nuclear Science and Engineering from Idaho State University. He is a registered Professional Engineer in South Carolina.

### Sarah Wilk

Before joining RDT&E, physical scientist Dr. Sarah Wilk was a staff scientist with Pacific Northwest National Laboratory, on assignment with the Defense Threat Reduction Agency in the Basic and Applied Sciences division. Sarah earned her BS in chemistry with Distinction in the Major from the University of



California, Santa Barbara while also conducting materials science research. She earned her doctorate in chemistry (nuclear) from the University of California, Berkeley with Professor Heino Nitsche, studying odd-Z transactinide compound nucleus reactions, including the discovery of the new isotope  $^{260}\text{Bh}$ .

Sarah completed postdoctoral research at Lawrence Livermore National Laboratory where she conducted research in the areas of nuclear chemistry diagnostic development for the National Ignition Facility, measurements for advanced neutron multiplicity detector designs, and analysis of various nuclear systems for domestic counterterrorism applications, while remaining involved with the Livermore-Dubna superheavy element collaboration. Through her work in the area of superheavy element research, she has co-discovered 14 new transactinide isotopes including the new element  $Z=117$ . Sarah was also selected as a Christine Mirzayan Science & Technology Policy Fellow of The National Academies for the Winter 2012 class, assisting the Board on Physics and Astronomy. •

DEPARTMENT OF ENERGY

# Computational Science Graduate Fellowship



The Department of Energy Computational Science Graduate Fellowship (DOE CSGF) program provides outstanding benefits and opportunities to students pursuing doctoral degrees in fields of study that utilize high performance computing to solve complex problems in science and engineering.

**BENEFITS >>**  
 \$36,000 yearly stipend / Payment of full tuition and required fees  
 Attend yearly program review / \$5,000 academic allowance in first year  
 \$1,000 academic allowance each renewed year  
 12-week research practicum / Renewable up to four years

**APPLY ONLINE**  
 The DOE CSGF program is open to senior undergraduates and students in their first year of doctoral study. Access application materials and additional information at: [www.krellinst.org/csgf](http://www.krellinst.org/csgf)

Applications for the 2016-2017 class are being accepted through January 19, 2016.



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