Stockpile Stewardship Quarterly

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Message from the Acting Assistant Deputy Administrator for Research, Development, Test Capabilities, and Evaluation, Roger A. Lewis

Greetings. No, we have not gone back to 'the Draft' and I am not representing the Selective Service Bureau. It is my pleasure to introduce a new issue of the *Stockpile Stewardship Quarterly* (SSQ)—which continues to evolve as our overall program does. I hope that you will find much to admire and learn from in this issue. I certainly did.

Years ago, I was part of the Accelerated Strategic Computing Initiative (ASCI) management team, and the ASCI proved so successful that it 'graduated' from an initiative to become a sustained, focused, and funded program that has proven critical to the overall success of the Nation's nuclear weapons program and has extended the scientific, technical, engineering, and computational capabilities that underpin all that we do. As noted in Dr. Holmes article about megabar science (page 4): "In Stockpile Stewardship, our goal is to have a predictive understanding of the nation's stockpile." This article addresses the role of predictive science in combination with physical experiments on JASPER, the use of surrogate material, and comes to some 'shocking' observations. Perhaps most importantly, the author seeks to demonstrate how doing stockpile science can have a broader application. I think from my reading that the demonstration was successful.

Also in this issue, you have an opportunity to capture some very energetic "Zs," deal with non-vampire attracting plasmas, and learn how astrophysical plasma properties research on the Z Machine really ZAPPS our program. This article also nicely folds in the contributions of students in the Stewardship Science Academic Alliances Program. Speaking of students and future stewards of the nation's nuclear weapons and technical base, the Stewardship Science Academic Programs proudly highlights eight Outstanding Poster Awards that were selected from approximately 90 posters at the 2013 Stewardship Science Academic Programs Symposium (page 5). The future is also highlighted in the article about five students selected for the Stewardship Science Graduate Fellowship Program (page 8).

In addition, to highlight the evolution of the Stockpile Stewardship Program, there is an article about the Office of Test Capabilities and Evaluation (TC&E), the newest addition to the Office of Research, Development, Test Capabilities, and Evaluation (RDTC&E). The majority of this new office has migrated from the Office of Stockpile Management [after 'seeing the light' (NIF)] to the Office of Stockpile Stewardship, from which RDTC&E evolved. This article provides a brief introduction to the office (page 6). You will learn more about the new members of the team in the next issue of the SSQ. So, having read this preamble to the end, it is now time for you to read on!

2013 Stewardship Science Academic Programs (SSAP) Outstanding Poster Awards
Chris McGuffey (left), Jennifer Shusterman (right), and 7 others received awards. Read about the recipients on page 5.

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The Z Astrophysical Plasma Properties Collaboration by J.E. Bailey (Sandia National Laboratories) et al.*

The Z Astrophysical Plasma Properties (ZAPP) collaboration addresses a question in astronomy: *How do the fundamental radiative properties of matter affect the formation, evolution, structure, and spectral emission of astrophysical objects?* The answers will provide the basis for specific astronomical diagnostics and affect our understanding of the universe. Furthermore, this research is developing and strengthening academic collaborations with the NNSA. Such academic partnerships are a cornerstone for NNSA laboratories to meet their stockpile stewardship responsibilities. These interactions provide a conduit for recruiting top scientific talent and facilitate the development of talent already at the NNSA laboratories. ZAPP experiments are a new national capability developed in part from grants allocated through the joint U.S. Department of Energy (DOE) Office of Science/NNSA High Energy Density Laboratory Plasmas program and the NNSA Stockpile Stewardship Academic Alliances program. ZAPP unites scientists and students (see Figure 1) from 9 different institutions as they simultaneously work to advance the physics underlying four separate astrophysical topics. The goal of the ZAPP collaboration is to achieve high impact physics results and foster mission-relevant external collaborations.

This work encompasses the area of high energy density physics (HEDP), an area of significant interest to Stockpile Stewardship. It is the science of matter at ultra-high pressures and temperature. HEDP conditions are known to exist in astrophysical bodies and in nuclear weapons. Now, we can create these conditions in HEDP laboratory facilities such as in the Z facility. Our focus in this work will be on properties of radiatively heated plasmas, including opacities and spectral line widths. This increased knowledge from laboratory-based experiments is a key element in enabling the United States to continue its nuclear weapon program without underground weapons testing.

The experiments are conducted on the Z facility at Sandia National Laboratories, a pulsed power machine capable of creating conditions in matter unlike anything else on earth. Benchmark experiments on astrophysical material properties require creation of macroscopic quantities of cosmic matter, uniformly heated to extreme conditions. Z is unique because it provides megaJoules (MJs) of x-rays needed to heat large samples and the ability to create and diagnose multiple samples on a single shot. This latter ability is essential for conducting academic research on MJ-class facilities: it enables multiple academic/NNSA lab teams to access a precious national resource and provides opportunities for exploratory science with heavy student involvement, without a significant impact on the primary mission of the facility.

Our experimental platform has demonstrated Z's capability to create radiation-heated matter over a broad range of conditions. On a typical ZAPP shot, four distinct astrophysical questions are addressed. The densities achieved in the four samples span six orders of magnitude, and the temperatures span a factor of 200. Up to 59 spectra are recorded in a single experiment using 13 individual spectrometers, providing thorough diagnosis of the achieved conditions. These features are critical because a high level of accuracy and plasma control are required to produce data that can influence the large, diverse community of astrophysical researchers.

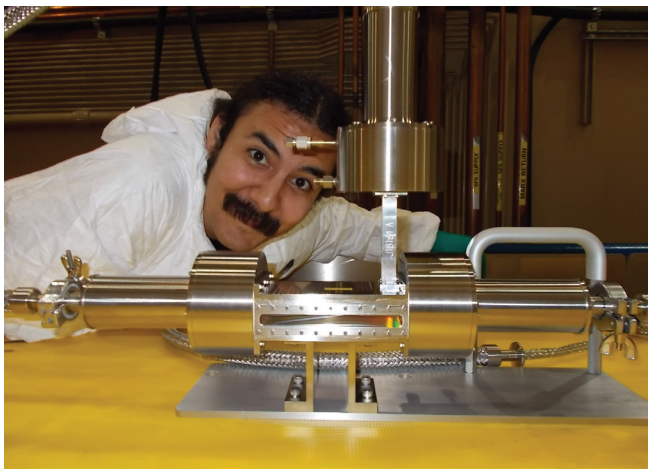
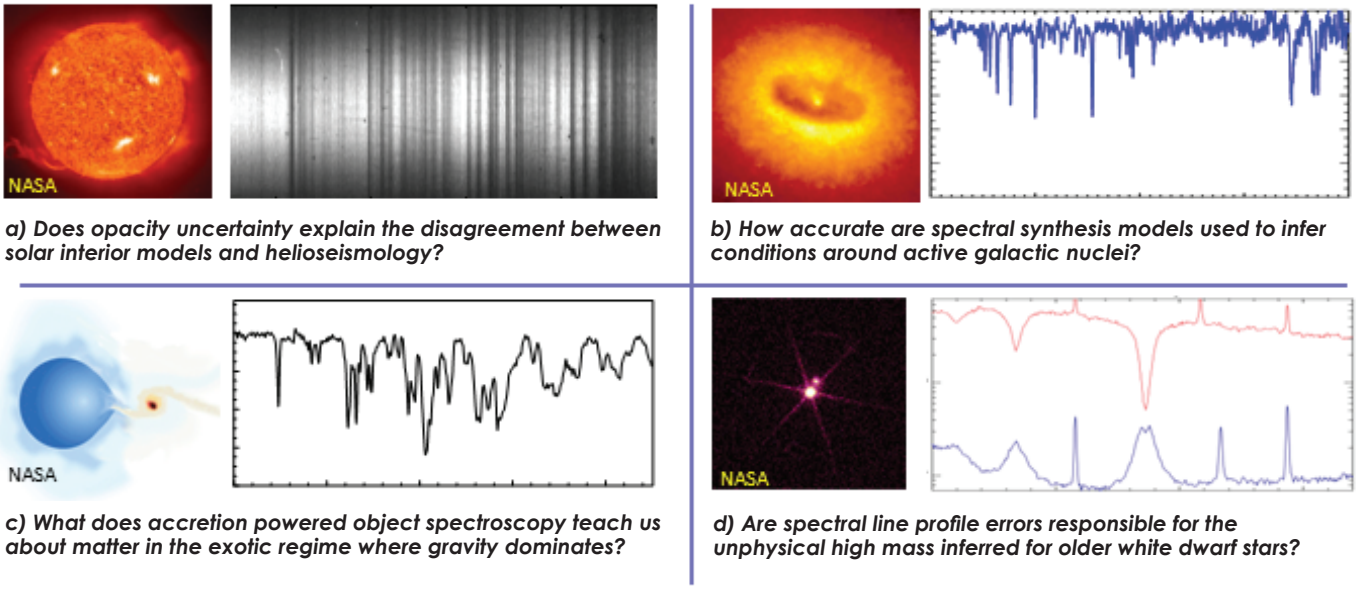


Figure 1. University of Texas student Ross Falcon assembling a component of the white dwarf photosphere experiment conducted at Sandia's Z facility.

The four distinct ZAPP experiments are unified by the importance of radiation in either the plasma formation or the observable emission. These characteristics are a foundation astronomers rely on to formulate physical descriptions of the observed objects. The specific objects explored here are: stellar interiors, accretion disks, active galactic nuclei, and white dwarf stars (see Figure 2).

The evolution and internal structure of stars like our sun depend on how efficiently radiation created in the stellar core is transported outward to the surface. The material property that controls this radiation transport is called 'opacity'. Presently, predictions using the Standard Solar Model fail to match helioseismic observations, and one possible explanation is inaccurate opacities. Testing opacity models requires creating uniform macroscopic plasma at stellar interior temperatures and densities. The Z opacity experiments heat iron, an important stellar constituent, to the same conditions as exist at the radiation/convection boundary within the sun. Preliminary results indicate that these first-ever stellar interior opacity measurements disagree with widely used opacity models. Hence, this data may have an impact on the understanding of nearly every star in the universe.

Most galaxies, including our Milky Way, are now believed to host a black hole at the galactic center. Surrounding the center of some galaxies is a large (parsec scale) 'warm absorber' plasma heated by radiation emitted from the black hole accretion disk. Astronomers infer the



a) Does opacity uncertainty explain the disagreement between solar interior models and helioseismology?

b) How accurate are spectral synthesis models used to infer conditions around active galactic nuclei?

c) What does accretion powered object spectroscopy teach us about matter in the exotic regime where gravity dominates?

d) Are spectral line profile errors responsible for the unphysical high mass inferred for older white dwarf stars?

Figure 2. Z Astrophysical Plasma Properties experiments exploit megaJoules of x-rays to address four astrophysical topics simultaneously. (a) Optical image of the sun (left) and Z absorption spectrum from an iron sample heated to the degree of ionization of the solar interior (right). Dark bands represent photon energies with relatively high attenuation, or opacity. Lighter bands correspond to more easily transmitted photon energies. (b) Hubble Space Telescope image (left) of the accretion disk at the center of active galactic nucleus (NGC4261). Accretion-powered radiation photoionizes the surrounding Warm Absorber plasma. Z spectrum from photoionized neon (right) tests photoionization models. (c) Artist conception of an x-ray binary (left). The Z Si absorption spectrum (right) tests photoionization models used for x-ray binaries. (d) X-ray image of emission from white dwarf companion of Sirius (left). Simultaneous absorption (red) and emission (blue) hydrogen spectra on Z typical of a hydrogen-rich white dwarf photosphere (right). These first-ever simultaneous absorption (red) and emission (blue) hydrogen spectra demonstrate which spectral line profile models are most accurate.

warm absorber conditions by observing x-ray absorption and emission spectra with space-based observatories such as NASA's Chandra satellite. However, this requires a spectral synthesis model for photoionized plasma, a class of plasma impossible to study in the lab until the advent of MJ class high energy density facilities. Our ZAPP experiments are providing extensive data using photoionized neon and include the first measurements of variations in plasma conditions with changes in the driving radiation flux. These measured trends are proving difficult for spectral synthesis models to reproduce, hinting that revisions to present understanding for warm absorber conditions may be forthcoming.

Accretion disk studies are motivated by a conundrum: x-ray lines known as L-shell K-alpha satellites are observed from x-ray binaries, but not from black holes. A proposed theory may explain the differences, but that theory lacks an experimental foundation. The evaluation of the theory will impact the physical picture of black hole disk structure and provide a new class of black hole diagnostics. Our ZAPP experiments have created photoionized silicon plasma similar to those observed from x-ray binaries. The data can already be used to test plasma formation models and provide a foundation for future experiments to evaluate spectral line formation in black hole accretion disks.

White dwarf (WD) stars are useful for a host of astronomical information including cosmochronology, which is the dating of the universe. However, these inferences depend on the accuracy and precision of methods for determining stellar masses and effective temperatures. The most widely used method relies on fits to the observed spectral emission but creates a dilemma: the masses inferred for the oldest stars are unphysically large and the mean inferred mass of all WD stars does not agree with other methods. A leading hypothesis is that the fundamental spectral line profiles for hydrogen and helium are inaccurately modeled at the relevant densities. A replica of a WD photosphere is challenging to make because it requires a large volume of hot, uniform plasma (about 20 cm^3). Our ZAPP experiments have created such a replica using the copious x-rays on Z. Detailed analysis of the associated hydrogen line emission and absorption are in progress and will provide fresh insight into whether inaccuracies in the line profile theory explain the discrepancy.

*This work was performed by a collaboration with essential contributions from G.A. Rochau, T. Nagayama, G. Loisel, S.B. Hansen, T.J. Nash (Sandia National Laboratories); C.A. Iglesias, B. Wilson, and D. Liedahl (Lawrence Livermore National Laboratory); M. Sherrill, J. Colgan, C. Fontes, and D. Kilcrease (Los Alamos National Laboratory); J.J. MacFarlane, I. Golovkin, and P. Wang (Prism Computational Sciences); I. Hall, T. Lockard, D. Mayes, T. Durmaz, and R.C. Mancini (University of Nevada, Reno); C. Blancard, Ph. Cossé, G. Faussurier, F. Gilleron, and J.C. Pain (CEA, France); J. MacArthur and D. Cohen (Swarthmore College); A.K. Pradhan, S.N. Nahar, C. Orban, and M. Pinsonneault (Ohio State University); R.E. Falcon, J.L. Ellis, T. Gomez, S. Moorhead, E. Chen, D.E. Winget, and M.H. Montgomery (University of Texas).

Science Using Guns at a Million Times Atmospheric Pressure: Megabar Science

by Neil C. Holmes (Lawrence Livermore National Laboratory)

Why another article about shock physics for the *Stockpile Science Quarterly*? For one thing, stockpile devices, in the words of Prof. Yogendra M. Gupta of Washington State University, "begin with a shock, end with a shock, and have shocks in between." That's one way to think about the process, and it is absolutely true. I am going to provide a different take on it for this article. In Stockpile Stewardship, our goal is to have a predictive understanding of the nation's stockpile. At its root, that means we have to know and understand deeply the way materials behave at very high pressures and temperatures. Only when we have that can we have confidence in the reliability and safety of the stockpile in the absence of testing. Shock compression is one of the most useful ways to achieve that understanding. And along the way, we can do some really interesting science—and not just with materials such as plutonium (Pu).

A shock is an abrupt change in density or temperature in a material that moves faster than the normal speed of sound in a material. What makes shock waves uniquely useful is twofold. One, we can use a shock wave to achieve very high pressures, from kilobars to gigabars (1 bar = atmospheric pressure ≈ 15 psi), and temperatures from a few hundred or thousand degrees up to a million degrees — for a short time, rather like in a device. Two, we can determine the final pressure, density, and energy we have imparted to a material using direct measurements of velocity and density, without recourse to theory or models. In other words, we can make an absolute measurement.

There are many ways to make shock waves in the lab. Guns are particularly good for our purposes. A large two-stage light-gas gun, like the one at the Joint Actinide Shock Physics Experimental Research (JASPER), can launch 28 mm-diameter projectiles weighing 25 grams to nearly 8 km/s or nearly 18,000 mph. When a projectile like that impacts a metal, a pressure of many megabars, and a temperature of a few thousand degrees are generated; that pressure and temperature is constant for about 1/3 of a microsecond. If we carefully measure the speed of the projectile, the speed of the shock wave, and the initial density of the sample, we can determine the final pressure, density, and energy of that sample to better than 1%. A series of experiments of this type that attain a range of pressure define what is called the Hugoniot. The Hugonoit curve is a way to represent how the density or energy in a shock wave relates to the shock pressure. Figure 1 shows the Hugoniot of tantalum (Ta), one of the metals we use at JASPER in our projectiles. It is the most common basic shock physics experiment, and is the basis upon which we design more complex experiments. Data like these, and from other methods such as diamond-anvil cells, which are static devices used to compress submillimeter materials to a few megabars, are used to both validate and guide theories that are used ultimately for simulations of stockpile weapons.

In this article, I am not going to talk about the science we do as a laundry list of materials, from hydrogen to Pu. Instead, I will demonstrate how doing stockpile science can have a broader application. In fact, that is the rule rather than the exception. I could, for example, describe how in the process of understanding the detonation products of stockpile explosives we learn about the materials that form the interior of the gas giant planets in our Solar System (Jupiter, Uranus, etc.). Or how one of the materials we proposed to measure energy deposition by large lasers was used in NASA's Stardust mission. Instead, I'll describe a current physics problem.

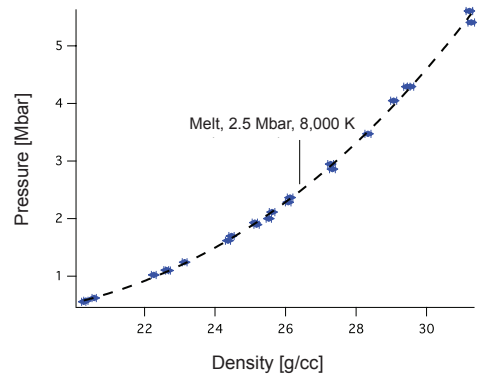


Figure 1. Each point on the Hugoniot (dashed line) of tantalum results from an individual experiment with a two-stage gun. The smooth Hugoniot curve shows no evidence of melting at 2.5 Mbar. The high accuracy in the experiments is evident from the small errors bars shown.

Please take another look at Figure 1, the Ta Hugoniot. Tantalum melts at about 2.5 Mbar, at an estimated temperature of 8,000 K. But, the Hugoniot looks perfectly smooth at that pressure, with no suggestion of anything exciting going on. This is the issue we need to solve: how to determine structural changes in a metal as pressure and temperature vary, at a high pressure and in short duration experiments, such as at JASPER. Solving that problem in Pu will be the major focus of JASPER over the next five years, and more generally in shock physics over the next decade.

One of the most important changes in structure is melting. Not only does the structure change from a regular crystal lattice to a disordered fluid, but also the material's strength, i.e., the ability to resist deformation, changes remarkably. In shock experiments, we exploit this to observe where melting occurs. Sound velocity depends on both the compressional and shear strength of a material. The loss of shear strength on melting implies that sound velocity ought to decrease at melting. Thus, we want to do a series of experiments to measure the sound speed in shocked Pu at different pressures to determine the melting pressure on the Hugoniot.

Now, if we are to learn how to do this kind of experiment in Pu, we always begin that task by doing experiments on surrogate materials. We needed to learn how to design, simulate, and execute the experiments, and how to analyze the data. We chose iron (Fe) as our surrogate material. We knew the Hugoniot already. It's easy and cheap to obtain pure, homogenous iron. Perhaps, the most important thing was that the melting pressure of Fe is vital to models of

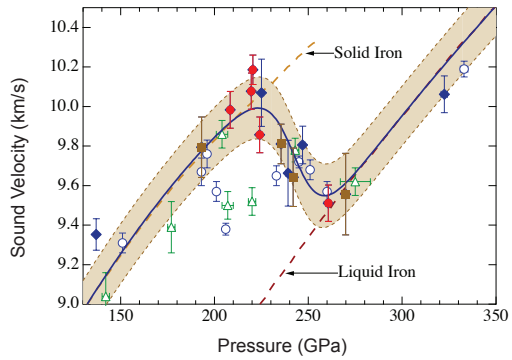


Figure 2. The speed of sound in iron is plotted against pressure. The large decrease in speed between 220-250 GPa (2.2-2.5 Mbar) is an unambiguous sign of melting.

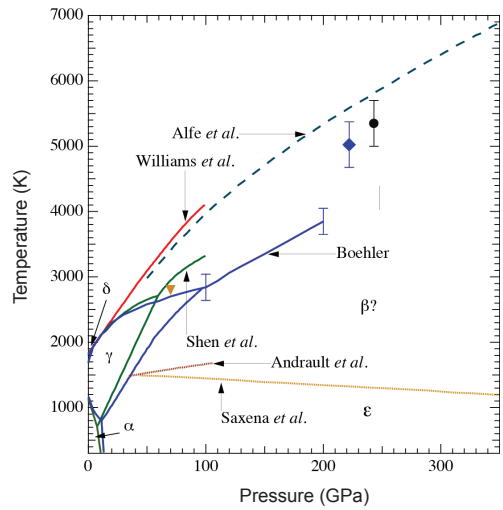


Figure 3. A high-pressure phase diagram of iron. This graph describes our current knowledge of the boundaries between differing equilibrium crystal structures (Greek letters) and the liquid phase as temperature and pressure are varied. The solid lines represent the results from different workers. The dashed line is from theory and probably represents an upper bound for the melting temperature. The filled, colored points represent the results shown in Figure 2. Those temperatures were estimated.

Earth's core. This meant that our results would have a broad and important application; the importance would ensure that our work would be under intense worldwide scrutiny. Further, there was a controversy about the structure of solid iron at these conditions. By way of explanation, we note that Earth's core is in two parts: the inner core of nearly pure solid iron, and an outer core of mostly molten iron believed to be mixed with some other elements like oxygen and sulfur. The boundary between the two is at the melting pressure and temperature of iron at Earth core conditions. Those conditions are extreme: 3 Mbar (45 million psi) and a temperature of about 5,000 K.

The results are shown in Figure 2, where the measured sound velocity is plotted against pressure. The decrease in sound velocity due to a loss of shear strength is very clear. That's just what we hope to see in Pu. The takeaway from this: by learning how to do melting in Pu, we made a fundamental measurement in geophysics.

In Figure 3, we show the phase diagram of iron, and where we think the measurements lie, the filled, colored circle and diamond. We've shown some of the other experimental data (the Greek symbols denote different crystalline structures) and the dashed line shows a result from theory. The results agree well in some areas, and at higher temperatures and pressures, there is either no data or large uncertainty. The temperatures of our data are estimates based on some simple arguments. This defines our major challenges at JASPER, and indeed in the physics of shocked metals at high temperature and pressure: What is the temperature, and what is the crystalline structure?

These are two very difficult problems, and I can only briefly describe an approach. For temperature, we will use optical pyrometry. At these high temperatures, the metal is incandescent. So we record the light emitted from the metal sample, and basically measure the color of the light. If only it were that simple! One has to account for the color of the metal, heat that flows from the target into the optical window needed to keep the sample surface at high pressure, optical emission and absorption in the window, and so on. We are confident that all these issues can be addressed—if not simply, at least in a straightforward manner. Then, we can determine the temperature in the Earth's core, and the temperature of Pu at the extreme conditions needed for stockpile science.

The crystal structure can be determined by x-ray diffraction. One "simply" shines a short, intense, and monochromatic x-ray beam at a glancing angle to the target's rear surface; the x-rays scatter off the crystal lattice and a large-area detector can record the spatial pattern they make. The pattern can be used to determine the crystal structure. We expect to make the first measurements of this type using a two-stage gun at Lawrence Livermore National Laboratory in early FY 2014. Once we get it to work, then we can plan on fielding it at JASPER.

2013 Stewardship Science Academic Programs Outstanding Poster Winners

Nine students received Outstanding Poster Awards at the 2013 Stewardship Science Academic Programs Symposium held on July 27-28 in Albuquerque, New Mexico. This year's symposium hosted more than 220 attendees and featured approximately 90 posters. The poster winners follow.

Alex Zylstra, Massachusetts Institute of Technology: Characterizing ρr Asymmetry of Inertial Fusion Implosions Using Protons.

Cody Parker, Ohio University: Measurement of the ^{3}H(d,gamma)/^{3}H(d,n) Branching Ratio at Low Energy.

Jennifer Shusterman, University of California, Berkeley: Solid Phase Extraction Materials for Separations of Trivalent Actinides and Fission Products.

Pamela Burnley, University of Nevada, Las Vegas: Patterning in Stress: A New Insight into the Deformation Behavior of Polycrystalline Materials.

Continued on page 8

NNSA Office of Research, Development, Test Capabilities, and Evaluation: Spotlight on the Office of Test Capabilities and Evaluation

The Office of Test Capabilities and Evaluation was created as part of the recent reorganization of the Office of Defense Programs and the evolution of the Office of Stockpile Stewardship into the Office of Research, Development, Test Capabilities, and Evaluation (RDTC&E). This name change is not cosmetic, but substantive, and reflects the close integration of Defense Programs investments in science, technology and engineering with keeping our nuclear weapons safe, secure and reliable and maintaining the capabilities to achieve this for the enduring future. The mission of this organization is to provide for development of engineering tools and manufacturing capabilities to implement advanced technologies to support the life cycle of a nuclear weapon. The organization provides management oversight, policy guidance, and coordination for the integration of engineering, design, manufacturing, and testing technology for the nuclear security enterprise. A key responsibility is the coordination of the annual assessment process to assure the safety, and effectiveness of the nuclear weapon stockpile.

The Office of Test Capabilities and Evaluation is currently composed of two divisions. The first is the Assessment Surveillance Requirements Division, the majority of which is part of the Engineering Campaign and was formerly part of the stockpile management investment portfolio (rather than the stockpile stewardship area in which it now resides). The second is the Nuclear Experiments Division, formerly part of the Office of Defense Science before the reorganization.

Assessment Surveillance Requirements Division

The Assessment Surveillance Requirements Division provides development of engineering tools and capabilities that support the life cycle of a nuclear weapon (see Figure 1). It also coordinates the assessment and surveillance requirements process which is a key input into the annual assessment process. The annual assessment process is currently a key mechanism by which the Secretaries of Defense and Energy, supported by the Commander of Strategic Command and by the directors of the three nuclear weapons laboratories, assure the president that our nuclear weapons are safe, secure, and effective.

The Division accomplishes its mission primarily through the following activities:

- Provide assessment and surveillance requirements for Directed Stockpile Work (DSW) and Enhanced Surveillance;
- Coordinate with the Office of Stockpile Management to develop the joint RDTC&E and Surveillance and Assessment memorandum of understanding to include a yearly update;
- Provide coordination for the Annual Assessment Process;
- Oversee the evaluation and assessment of nuclear weapons in the active and inactive stockpile;

Figure 1. Diassembled B-83.

- Provide tools and technologies to design and qualify components and subsystems to meet requirements for radiation, space, and other hostile environments;
- Coordinate required stockpile modeling and simulation activities with the Campaigns;
- Conduct development activities to support resolution of Significant Finding Investigations and safety issues;
- Direct component assessment and certification/ qualification activities;
- Provide guidance for weapons program implementation, including development of certification/qualification plans; application of Quantification of Margins and Uncertainties; and development of weapon-specific, small- and large-scale hydrodynamic experiments/tests;
- Provide the scientific understanding, experimental capability, diagnostic development and data required to develop and validate engineering computational models;
- Develop technologies, design, engineering, and manufacturing methods;
- Develop predictive capability for aging effects on weapon performance and lifetime assessments; and
- Increase integration and coordination among facilities, operations, processes, and management.

For additional information on the Assessment Surveillance Requirements Division or its activities, contact David Cameron at (202) 586-0812.

Nuclear Experiments Division

The Nuclear Experiments Division supports the Stockpile Stewardship Program by conducting experiments with special nuclear material. This Division oversees planning,

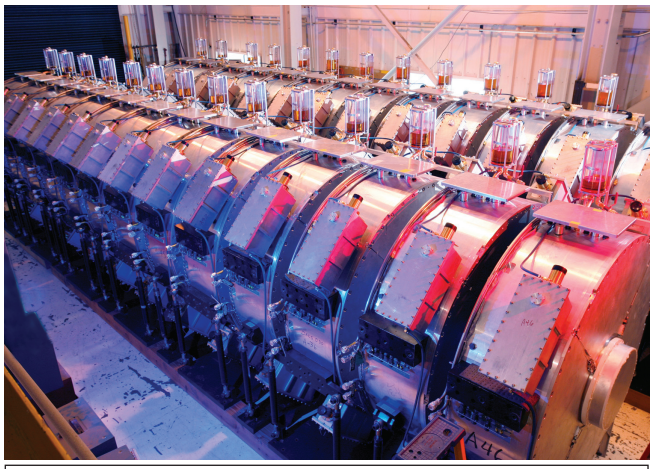


Figure 2. Second axis of the DARHT Facility.

Figure 3. A vessel for Pollux in the U1a Pre-Staging Area at NNSS.

Figure 4. Multiplexed Photon Doppler Velocimetry (MPDV) development.

budgeting, and execution of a range of projects, with a focus on experiments and associated operations at the Nevada National Security Site (NNSS), Dual Axis Radiographic Hydrodynamic Test (DARHT) facility, and other firing sites and manages the plutonium experiments and hydrodynamic experiments components of the Dynamic Materials Properties, Advanced Certification, and Primary Assessment subcampaigns, along with the portfolio of plutonium, hydrodynamic, and subcritical experiments formerly part of DSW Research & Development (see Figure 2). This Division also provides the key plutonium experimental data and integrated surrogate hydrodynamic experiments to support stockpile stewardship and national security needs, without nuclear explosive testing. The key activities of the Division are as follows:

- Planning, budgeting and execution of plutonium experiments. Planning and development of subcritical experiments at the U1a Complex at NNSS;
- Cooperating in the development of integrated experiments using scaling and surrogacy to obtain an improved understanding of weapons performance without nuclear explosive testing;
- Planning and managing high-explosive driven integrated experiments supporting Stockpile Stewardship;
- NNSA lead for the development of the National Hydrotest Plan, in coordination with the Office of Research and Development and the Office of Stockpile Management;
- Developing integrated experiments using scaling and surrogacy to obtain an improved understanding of weapons performance without nuclear explosive testing;
- Coordinating the long-range development of advanced radiographic and other diagnostic techniques; and
- Oversight of the U.S. Department of Energy-U.S. Department of Defense (DoD) Joint Munitions Program.

For additional information about the Nuclear Experiments Division or its activities, please contact Paul Ross at (202) 586-4027.

It is important to note that, as specified in some instances above, the activities of the Office of Test Capabilities and Evaluation are conducted through close coordination not only with the other organizations within RDTC&E, but also with the Office of Stockpile Management, the Office of Major Modernization Programs, and our colleagues in the Office of Defense Nuclear Nonproliferation, Office of Emergency Operations, Office of Defense Nuclear Security and Office of Counterterrorism & Counterproliferation, as well as with other government agencies, particularly organizations in the DoD and the Intelligence Community. It is through this close collaboration that the organization maximizes both its direct, immediate and sustained support to the nation's nuclear weapons stockpile but also develops, maintains, enhances and sustains the capabilities to keep our nuclear weapons safe, secure and effective for the enduring future.

Our biggest challenge is to maintain the quality of science, technology and engineering expertise and experience needed. The people in our enterprise are more important than our facilities and equipment—but our people need to be given the tools needed to be successful and challenging enough problems to keep them engaged intellectually and professionally satisfied enough to devote the better part of their professional career to the nuclear weapons program.

Five Students Selected for the Stewardship Science Graduate Fellowship by Krell Institute

Five doctoral candidates researching fission barriers, supernovae and other phenomena entered the NNSA Stewardship Science Graduate Fellowship (SSGF) this fall. The program supports 21 fellows focusing on high energy density physics, nuclear science, or materials under extreme conditions and hydrodynamics. Fellows receive full tuition and fees, a stipend, a 12-week research practicum at an NNSA national laboratory, and other benefits.

At the University of Colorado, Boulder, Benjamin Galloway is applying unusual table-top lasers to researching warm, dense plasmas. His advisor, Margaret Murnane, and her collaborator, Physics Professor Henry Kapteyn, study high-harmonic generation to produce ultrafast x-ray laser sources. Such lasers pass an intense, ultrashort laser pulse through a medium, converting it to an even shorter pulse (in the tens of attoseconds) of harmonics with higher photon energies. High-harmonic generation can produce shorter x-ray pulses at lower cost than x-ray free electron lasers. Galloway says his research involves developing, characterizing and applying more advanced high-harmonic generation sources to study warm, dense plasmas found in high energy density environments. Little is known about such plasmas because their strong coupling prevents the use of models used to represent weakly coupled plasmas. Galloway and his colleagues hope to shed light on these elusive states of matter so high-impact applications such as fusion have a better chance at success.

Fabio Iunes Sanches at the University of California, Berkeley plans to create a theoretical framework for materials and model how they behave under different conditions. His tool of choice is the phase field crystal model, which can describe materials at relatively large length scales while maintaining atomic resolution, allowing investigations of atoms forming different lattice structures. Under advisor George Martins, he's worked with a ferroelectric phase field crystal model to describe the influence of electric fields on the behavior and properties of these structures. Including magnetic terms when simulating multiferroic materials could lead to a new framework for many devices, allowing the control of electric magnetic fields through properties of substances used in these devices, Iunes Sanches says in his research summary. To complement his materials research, he plans to study other fields, including the behavior of materials under extreme conditions.

Fellow Io Kleiser plans to help in a supernovae hunt in her research with Christian Ott at the California Institute of Technology. Scientists have some ideas of how massive stars (about eight solar masses or more) and low-mass stars (less than six solar masses) explode and die. They know far less about the supernovae of stars between those masses. Such stars may create a large white dwarf with a different composition than smaller white dwarfs, allowing it to accrete mass from other stars and collapse to a neutron star rather than sustain a thermonuclear disruption. Such events would be weaker and fainter than other supernovae, making them difficult to detect, Kleiser says in her research summary. She plans to use general relativistic hydrodynamical models to simulate the explosion physics of such events and calculate their electromagnetic, gravitational-wave and neutrino signatures, giving astronomers an idea of what to seek in sensitive supernova surveys.

Fellow Juan Manfredi will study experiments that probe nuclear fission at the limits of stability at Michigan State University's National Superconducting Cyclotron Laboratory. Under advisor Betty Tsang, he'll investigate the fission barrier of lead-196 (produced by a thallium-195 beam on a hydrogen gas target) using the Prototype Active-Target Time Projection Chamber to find the fission cross section as a function of excitation and as a result of the fission barrier. The measurement, Manfredi says, will serve as a proof of principle experiment for an international program to study exotic fission barriers at the laboratory. The research is important to understanding the r-process, which produces about half of all neutron-rich isotopes heavier than iron via the quick capture of neutrons.

At the University of California, Los Angeles, Sarah Palaich probes the structure and behavior of minerals deep in the Earth. She currently focuses on the high-pressure phases of kutnohorite, a manganese-bearing carbonate, and plans to use synchrotron x-ray powder diffraction and refinement to determine its structure at 36 GPa. Such carbonate minerals are candidates for hosting carbon in the deep mantle. Studying them helps understand the deep Earth's role in the global carbon cycle, Palaich says.

To learn more about the SSGF program, visit the Krell Institute website at http://www.krellinst.org/ssgf/.

– Outstanding Poster Awards *(Continued from page 5)*

Pamela Kaercher and Eloisa Zepeda-Alarcon, University of California, Berkeley: Crystallographic Preferred Orientation in Stishovite: In Situ Observations at High Pressure.

Lisa Mauger, California Institute of Technology: High Temperature Phonon Behavior in Iron and Cementite.

Chris McGuffey, University of California, San Diego: Study of Fast Electron Transport and Energy Deposition into Imploded High Density Plasma using Cu-Doped CD Shell Targets.

Zeyu Li, University of Michigan: Carbide-Dominant Inner Core Inferred from Anomalously Low Shear-Wave Velocity of Dense Fe7C3.