Defense Science Quarterly

News about the Science Campaign | March 2009

Inside This Issue

Message from the Director
Chris Deeney, Defense Science Division

This quarterly newsletter was very therapeutic. We are embroiled in so much budget action that taking the time to read these summaries was pleasurable indeed. In lieu of our annual Stewardship Science Academic Alliances (SSAA) Symposium, which we will hold next year, we have focused this quarter's newsletter on our Centers of Excellence. This is timely, with all the national interest in growing the support for the physical sciences in the U.S. We are very proud of the excellence of the work conducted at our centers, and as you will see mentioned in this newsletter, much of our work is world leading. Pardon the pun, but this is not simply an "academic exercise!" The quality and deterrence value of our stockpile depends on the quality of the science and scientists in our program. The SSAA grants and centers have produced some great scientists, many of whom have been recruited to our laboratories. In addition, many of our center directors and their teams provide expert comments and technical peer reviews of our laboratories research – a critical contribution! I hope you enjoy reading these articles as much as I did.

One key discipline for us is High Energy Density Physics. We have a joint program with the Office of Fusion Energy Sciences on this very topic, and we wanted to highlight the recent excellent Fusion Energy Science Advisory Committee (FESAC) report on the topic by Professor Riccardo Betti. Thanks to FESAC and its subpanel for all the hard work. The report is available at http://www.science.doe.gov/ofes/FESAC-HEDLP-REPORT%20(2).pdf.

One staff change in the Defense Science Division I would like to mention is the addition of Dr. Dillon McDaniel, on detail from Sandia National Laboratories (SNL). Dillon received B.S. and Ph.D. degrees in physics from the University of Texas at Austin. He started his career in

SNL's Pulsed Power Program as a research scientist in energy storage technology, liquid and gas breakdown phenomena, electron beam diode design, and electromagnetic insulation. He became a supervisor for Z-pinch research and x-ray generation sources, including collaboration with Russian and French programs and the Defense Threat Reduction Agency. In 2004 Dillon became an SNL Senior Scientist in areas of inertial confinement fusion, high energy density physics, shock physics and x-ray source applications of pulsed power. Welcome Dillon!

Ending on a safety note, our university partners have many complex operations and experiments, just on a smaller scale than our laboratories. I recommend that we all strive for continuous safety improvement in our university and laboratory environments. I want to thank the center directors for their enthusiastic response to the talk given by Jim McConnell entitled *Safety Culture in High-Reliability Organizations* at our Science Execs Meeting in January 2009. If you would like a copy of Jim's talk, please contact Terri Batuyong at 202-586-9342 or Terri.Batuyong@nnsa.doe.gov.

Comments

Questions or comments regarding the *Defense Science Quarterly* should be directed to Terri Batuyong (Terri.Batuyong@nnsa.doe.gov).

Technical Editor: Christina Coulter

The Carnegie-DOE Alliance Center: Six Years of Progress **by Stephen Gramsch & Russell Hemley**

The Carnegie-Department of Energy Alliance Center (CDAC) was created to address critical needs in high *P-T* materials. Formed in 2003 under NNSA's Stewardship Science Academic Alliances (SSAA) program, CDAC comprises a scientifically and technically broad group of Academic and Laboratory Partners, along with a growing network of collaborators, engaged in fundamental science. In this role, CDAC continues to advance and perfect high *P-T* techniques, develop and manage unique facilities, perform key measurements on important materials in newly-accessible *P-T* regimes, and integrate and coordinate static and dynamic compression studies together with theory, modeling and simulation.

High *P-T* materials science, technology and student training have all benefitted tremendously from CDAC. Now at the close of its sixth year, CDAC continues to support the NNSA mission in stewardship science. The Center is managed at Carnegie (Figure 1) by Russell Hemley (Director), Ho-kwang Mao (Associate Director), Stephen Gramsch (Coordinator) and Morgan Phillips (Administrative Assistant). CDAC now consists of 19 formal Academic Partners together with the Carnegie group: Tom Duffy *(Princeton)*, Dion Heinz *(Chicago)*, Dana Dlott *(Illinois)*, Yogesh Vohra *(Alabama – Birmingham)*, Hans-Rudolf Wenk *(UC-Berkeley)*, Brent Fultz *(Caltech)*, Kanani Lee *(New Mexico State/Yale)*, Surrendra Saxena *(Florida International)*, Yanzhang Ma *(Texas Tech)*, Dhanesh Chandra *(Nevada–Reno)*, and Jeffrey Yarger *(Arizona State)*. New partners joining the CDAC group in the past year include Abby Kavner *(UCLA)*, Steven Jacobsen *(Northwestern)*, Ji Li *(Illinois)*, Raymond Jeanloz *(UC–Berkeley)*, Wendy Panero *(Ohio State)*, James Schilling *(Washington University-St. Louis)*, Robert Downs *(Arizona)* and Wendy Mao *(Stanford)*.

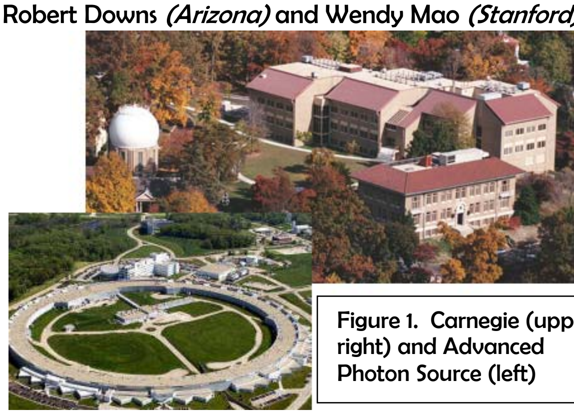


Figure 1. Carnegie (upper right) and Advanced Photon Source (left)

Scientists from high-pressure research groups at the NNSA National Laboratories obtain beam directly from the CDAC discretionary share, and in so doing obtain technical training and exposure to the high *P-T* technique development taking place at the High Pressure Collaborative Access Team (HPCAT), the dedicated high-pressure synchrotron x-ray facility at the Advanced Photon Source (APS), of which CDAC is a member (Figure 1). Laboratory scientists are also able to take advantage of facilities at Carnegie and the National Synchrotron Light Source (NSLS). In addition, groups within CDAC interact with staff from the Los Alamos Neutron Science Center (LANSCE) on high *P-T* neutron scattering and analysis techniques.

Research on material properties at extreme conditions continues to expand with the development of new methodologies, for example, in the overlap of static and dynamic compression. In just the last two years, CDAC facilities at NSLS and HPCAT have played a key role in enabling the first synchrotron x-ray measurements of dynamic compression events, complementing developments within the NNSA laboratories such as those at NIF and *Z*. CDAC continues to enable participation of the academic community in all of these areas. With the potential of these and other facilities, CDAC continues to promote the integration of static and dynamic experiments for stewardship science needs.

CDAC focuses heavily on the training and outreach aspects of its mission, both in terms of graduate student education and helping to grow the high pressure research community. Highlights from the last two years in this important effort include:

- Supporting Ph.D. thesis work of 18 graduate students at CDAC partner universities and Carnegie. Thus far, 15 graduate students from Academic Partner institutions have received Ph.D. degrees with CDAC support.
- Hosting undergraduate and high school interns at Carnegie.
- Supporting the growth and operation of the HPCAT sector. In part, through the 30% partnership CDAC retains in HPCAT, the number of users carrying out original research and working on technique development at the facility has grown to over 400.
- Hosting the 4th Annual SSAA Symposium, held at the Carnegie Institution Headquarters Building in Washington, DC, on February 26-28, 2008.
- Promoting dynamic compression work through training and participation in the Workshop on Understanding Condensed Matter Dynamics at the Microscopic Level, held at the APS on June 23-24, 2008.

During the six years since May 2003, when CDAC began formal operations, over 610 papers based on the research of Academic Partners and their graduate students, Laboratory Partners, and collaborators have been published with support from the grant. This total also includes papers describing Carnegie research supported by the CDAC grant and research carried out at HPCAT and CDAC facilities at NSLS. These papers represent a significant amount of post-doctoral and student training, and many describe important technique developments.

An increasing number of papers represent work carried out in collaboration with NNSA laboratory scientists. The number of articles appearing in high-impact journals continues to grow: to date 39 papers have appeared in *Physical Review Letters*, 12 in *Science*, 22 in *Nature*, and 29 in the *PNAS*.

Cornell Center for the Study of Pulsed Power Driven High Energy Density Plasmas

by David Hammer

Cornell's Center for the Study of Pulsed Power Driven High Energy Density Plasmas is the Stewardship Science Academic Alliances Center of Excellence with the mission of studying the dynamics and physical properties of hot, extremely dense plasmas produced by 0.5-1.5 MA pulsed power generators. Together with Center partners at Imperial College, London, the Weizmann Institute of Science, the P.N. Lebedev Physical Institute in Moscow, the University of Nevada, Reno, and the University of Rochester, Cornell faculty, staff, graduate and undergraduate students are studying the fundamental properties and potential applications of high energy density (HED) plasmas produced from exploding very fine (few micrometer diameter) metal wires in various configurations. Experiments are performed using the 0.5 MA XP and the variable pulse length 1.0 MA COBRA generators at Cornell and the 1.5 MA machine at Imperial College. We also carry out computer simulation studies of the pulsed HED plasmas to help us understand the experiments and to try to predict interesting configurations to test. The Cornell Center also hosts and collaborates with staff scientists, faculty and students from other institutions, such as Sandia National Laboratories and other universities, to carry out HED plasma experiments on Center facilities.

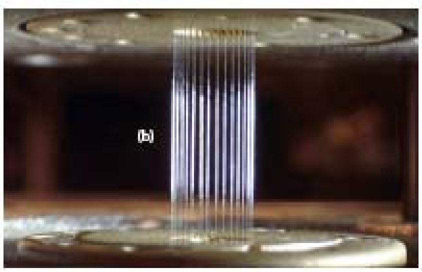


Figure 1. Cylindrical wire-array Z-pinch with 32 aluminum wires; 8 mm diameter, 20 mm tall wire-array on COBRA (From Ryan McBride)

The two configurations most frequently investigated are cylindrical wire-array Z-pinches (Figure 1) and X-pinches (Figure 2) as these configurations facilitate the generation and study of plasmas ranging in temperature from 0.1 – 20 million Kelvin and densities approaching that of solid matter. X-pinches generate micron-scale, hot plasmas that can be used for point projection x-ray imaging of exploding wire-arrays (Figure 3). From these images accurate assessments of the plasma density near the wires can be obtained. Isaac Blesener is shown in Figure 4 setting up an X-pinch load on COBRA. Experiments using radial and conical arrays and computer simulations have also been used to model and study astrophysical plasma phenomena. Future experiments using thin foils and gas puff configurations are being considered.

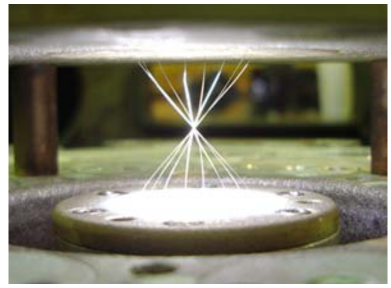


Figure 2. X-pinch configuration with 12 tungsten (W) wires on COBRA (From Dan Sinars)

High energy density, rapidly evolving plasmas are central to the NNSA stockpile stewardship program and pulsed-power generators are a very cost effective way to produce the desired experimental conditions. As a result, our Center has been able to provide important fundamental scientific information as well as new diagnostic methods to the NNSA laboratories. In addition, many of our graduate students have accepted jobs at the national laboratories upon completion of their doctorates.

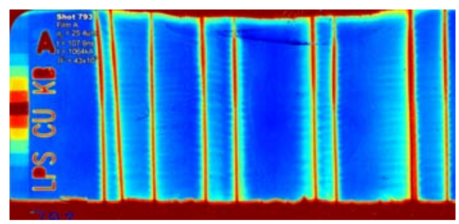


Figure 3. Point projection image of a 10-wire W array obtained using a Mo wire X-pinch x-ray pulse 108 nanoseconds after the start of a 1 MA current pulse on COBRA (From Jon Douglass)

Figure 4. X-pinch being set up on COBRA

Center of Excellence for Radioactive Ion Beam Studies for Stewardship Science by Jolie Cizewski

The Stewardship Science Academic Alliances Center for Radioactive Ion Beam Studies was founded in May 2003 under the direction of Jolie Cizewski at Rutgers University. This Center brings together professors, their students and postdoctoral scholars from universities across the U.S. to work in collaboration with scientists at Oak Ridge Associated Universities (ORAU) and Oak Ridge National Laboratory (ORNL) to study reactions with and decay of radioactive beams of atomic nuclei, in particular fragments following the fission of uranium. To date all of the experimental research efforts have been focused at the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL. SSAA funding has not only provided the support to attract highly talented undergraduate and graduate students and postdocs to stewardship science, but also has enabled the development of new tools needed to study reactions on and decay of nuclei far from stability.

The initial thrust of the Center was to study reactions on uranium fission fragments, studies important for both stewardship science and understanding how the elements heavier than iron are formed in explosions in the cosmos. The fission fragment accelerated beams currently available at HRIBF are displayed in Figure 1. The relatively weakly bound nuclei with neutron number 50 and 82 are not only fission fragments, but also waiting points along the rapid r-process path of nucleosynthesis believed to take place in supernova explosions. These studies have been realized in part because of the recently commissioned array of position-sensitive silicon strip detectors, the Oak Ridge Rutgers University Barrel Array (ORRUBA), shown in Figure 2.

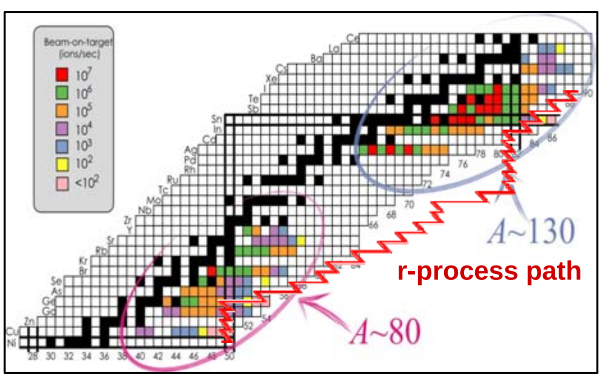


Figure 1. Intensities of fission fragment radioactive ion beams at HRIBF at ORNL. Highlighted in red is a possible r-process nucleosynthesis path.

Neutron capture reactions are responsible for heavy element nucleosynthesis and take place in nuclear reactors and explosions of nuclear devices. In weakly bound nuclei near N=50 and N=82 these reactions are direct processes, the probability of which can be deduced from direct neutron transfer reactions. These reactions are studied with beams of the heavy nuclei interacting with deuterated plastic targets and measurement of the reaction protons with arrays of silicon detectors, including ORRUBA.

Figure 2. Rutgers graduate student and Stewardship Science Graduate Fellow Patrick O'Malley inspects ORRUBA

The neutron-rich fission fragment nuclei that beta decay often have energies sufficiently high that neutrons are also emitted. Therefore, the Center is also furthering the understanding of the decay of fission fragments to probe the properties of these nuclei far from stability, as well as to understand the neutron decay spectra important for nucleosynthesis and stewardship science.

With recent renewal of the Center's funding, the efforts are expanding to measure reactions on other unstable nuclei for both basic and applied nuclear science, including to understand reactions on radio-chemical detectors deployed in tests of nuclear devices. To realize these efforts requires enhanced interactions with nuclear theorists at universities and national laboratories, developing new and higher-quality radioactive ion beams, and developing new techniques and instruments. One focus is the Versatile Array of Neutron Detectors at Low Energy (VANDLE) which will have the flexibility to measure neutrons from nuclear reactions, beta-decays and fission.

All of the efforts of the Center require the active engagement of students and postdocs; a total of 10 postdocs, 16 graduate students, and 23 undergraduate summer students have participated as of 2008. To date three former postdoctoral scholars from this project have moved on to an NNSA laboratory where two are now staff members. William Peters, shown in Figure 3, is one of the current postdocs. His efforts are focused on providing neutron-capture reaction information important for understanding the role of arsenic as a radchem detector.

Figure 3. Rutgers postdoc William Peters inspects the detectors used in the neutron capture surrogate reaction study with arsenic beams

Highlights from The Texas Center for High Intensity Laser Science by Todd Ditmire

The Texas Center for High Intensity Laser Science (TCHILS) is a Stewardship Science Academic Alliances (SSAA) Center established by NNSA at the University of Texas at Austin (UT) with the mission of performing academic research on high energy density (HED) plasmas and shock waves that can be created and probed by high peak power lasers. TCHILS is composed of a number of faculty in the Physics and Mechanical Engineering Departments at the University of Texas as well as collaborating faculty from the Department of Physics at Ohio State University. With the importance of high power lasers in the science portfolio of NNSA, one of the principal missions of TCHILS is to train graduate students in the techniques of HED and shock physics using intermediate to large scale high power lasers, a mission which the Center often pursues by conducting collaborative experiments with the NNSA laboratories. At present, TCHILS has active participation by seven university faculty, 12 research staff and post docs and over 20 graduate students pursuing their thesis on high power lasers at UT, Lawrence Livermore National Laboratory (LLNL) and Sandia National Laboratories (SNL).

Figure 1. Photo of the Texas Petawatt Laser amplifiers. The large blue amplifier modules are glass laser amplifiers from the NOVA laser decommissioned at LLNL in the late 1990s.

The research emphasis of the Center is predominantly focused in three sub-areas of HED science: (1) the study of fundamental properties of hot, dense plasmas created with intense ultrashort lasers, (2) the probing of the dynamics of high velocity and high strain-rate shock waves driven by laser pulses, and (3) the investigation of charged particle acceleration in plasmas irradiated by intense laser pulses. TCHILS has made important progress in all three areas in the past few years. For example, in a collaboration with V-division at LLNL, TCHILS faculty and staff have just completed a set of experiments in which they have used laser accelerated protons generated at LLNL's Titan laser facility to heat Al plasmas at solid density to temperatures approaching 1 million degrees Celsius and have studied the equation-of-state and conductivity properties of this exotic dense state of matter. Recently, TCHILS students have also been working with SNL in Albuquerque on the Z-Beamlet laser there to study the dynamics of how metal alloys fail under the extremely fast shock loading that is possible when such metals are irradiated by a high energy laser. In the arena of particle acceleration, TCHILS has conducted a number of exciting experiments including a recent collaboration with scientists from the University of Nevada, Reno, in which the flow of high energy electrons was examined when these electrons were produced at the tip of a cone illuminated by ultra-intense pulses from the Texas High-Intensity Optical Research Laser (THOR) multi-terawatt laser at UT.

The principal highlight from TCHILS in the past year, however, has been the activation in 2008 of the Texas Petawatt laser on campus at UT (see Figures 1 and 2). This laser is now the highest power laser operating anywhere in the world. Using a combination of new nonlinear optical technology and well tested glass amplifier technology derived from a collaboration with the NIF Directorate at LLNL, this laser has taken a step beyond the first Petawatt laser demonstrated at LLNL in the late 1990s. The Texas Petawatt, while delivering somewhat less laser energy than the first LLNL Petawatt, delivers the energy in a pulse which is substantially shorter. This technology now accesses a parameter space which allows Petawatt laser experiments at a university for the first time. Experiments with the Texas Petawatt began in late in 2008, with the first experiments being devoted to a novel technique for generating very high fluxes of fusion neutrons which will be used for materials science and other applications.

Figure 2. Photo of the target bay of the Texas Petawat showing the white vacuum tank housing the pulse compressor at the target chamber which is devoted to the fusion neutron generation experiments

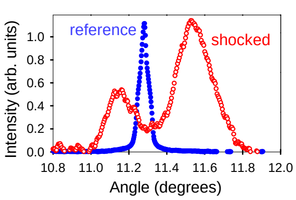
The Institute for Shock Physics at Washington State University by Yogi Gupta

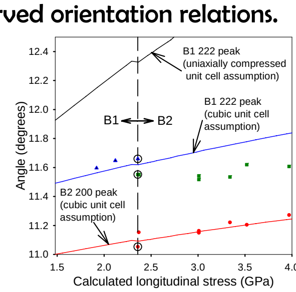
The Institute for Shock Physics (ISP) is a multidisciplinary research organization with a focus on understanding condensed matter response under dynamic and static compression, using state-of-the-art multiscale (continuum-to-atomic scale) measurements and analysis. Building on more than 50 years of sustained research excellence and rigorous education in shock wave science at Washington State University, the Institute's activities emphasize scientific innovations; hands-on training of graduate students and postdoctoral research associates from different disciplines (physics, chemistry, materials science, and mechanical engineering); and long-term programmatic relevance to NNSA's national security mission. Strong partnerships and collaborations with the NNSA laboratories are an integral element of the Institute's research effort. The close synergy between dynamic compression (shock wave and shockless experiments) and static compression research is a unique and valuable feature of the scientific activities. The research program integrates experiments, theory, and computations to achieve a fundamental understanding of mechanisms and processes at different length and time scales. The major scientific themes governing the Institute's research activities are: structural transformations including electronic transitions; chemical reactions including bounding and metastability; and deformation and fracture.

Representative examples of recent activities, including abbreviated abstracts, are listed below:

Shock Induced Phase Change in KCl Single Crystals: Orientation Relations between the B1 and B2 Lattices Stefan J. Turneaure, Y.M. Gupta, Paulo Rigg (LANL), Journal of Applied Physics (2009)

The relative orientations between the lattices of the low pressure (B1) and high pressure (B2) phases of shock compressed KCl single crystals were examined using plate impact loading along the [111] and the [110] directions. The results are discussed in terms of the compatibility between the macroscopic uniaxial strain imposed by shock wave loading and the microscopic rearrangement of atoms leading to the observed orientation relations.

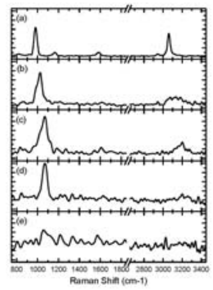




XRD Data and Results

Chemical Changes in Liquid Benzene Multiply Shock Compressed to 25 GPa S. Root (SNL) and Y.M Gupta, Journal of Physical Chemistry (2009)

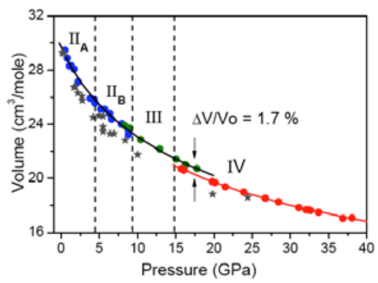
Shock wave experiments utilizing step-wise-loading, with peak stresses ranging between 4 and 25 GPa, were performed to examine the dynamic high pressure response of liquid benzene at thermodynamic conditions not attainable in single shock experiments. The results from the work demonstrate the importance of time, pressure, temperature, and phase in chemical changes associated with π-bonded molecules.



TR15 experimental results: time-resolved Raman spectra of liquid benzene multiply shock compressed to 24.5 GPa

Physical and Chemical Transformations of Sodium Cyanide at High Pressures J.Y. Chen and C.S.Yoo (Under Review)

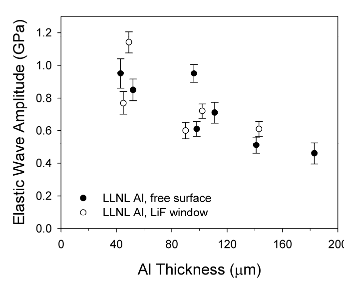
Pressure-induced physical and chemical transformations of Sodium Cyanide (NaCN) were studied up to 50 GPa in diamond-anvil cells, using micro-Raman spectroscopy and angle-resolved synchrotron x-ray diffraction. Observations from this work include phase transitions and an irreversible chemical change at large pressure ranges.



The pressure-volume data of NaCN phases as a function of pressure

Large Elastic Wave Amplitude and Attenuation in Shocked Pure Aluminum Y.M. Gupta, J.M. Winey, P.B. Trivedi, B.M. LaLone, R.F. Smith (LLNL), J.H. Eggert (LLNL), G.W. Collins (LLNL), Journal of Applied Physics (2009)

Shock-induced elastic-plastic deformation in pure aluminum was examined at 4 GPa peak stress by measuring wave profiles in thin (40–180 μm) samples under plate impact loading. The combination of large elastic wave attenuation in thin samples and differences in sample thicknesses between the present and past work suggests a consistent picture of shock propagation in pure aluminum.



Elastic wave amplitude vs Al sample thickness for impact loading to 4 GPa

For more information, contact shock@wsu.edu.

The High Pressure Science and Engineering Center at the University of Nevada, Las Vegas

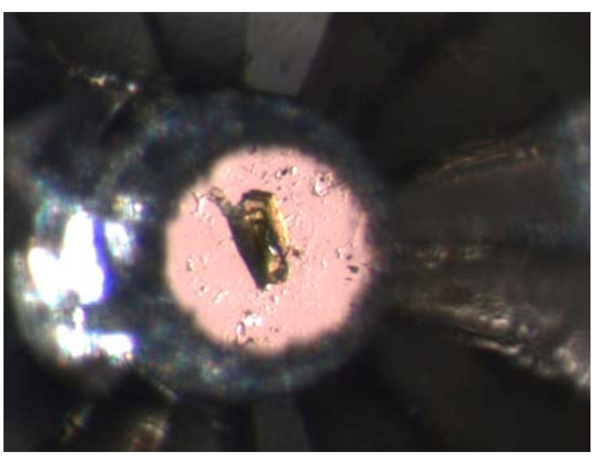
by Malcolm Nicol

The University of Nevada, Las Vegas (UNLV) High Pressure Science and Engineering Center (HIPSEC) was founded in July 1998 with NNSA support. HIPSEC now brings together chemists, geoscientists, and physicists to consider fundamental problems of materials under high pressures by experimental and computational approaches. We also introduce faculty, postdoctoral scholars, graduate and undergraduate students to these problems. In January 2009, nine faculty investigators lead HIPSEC team of eight professionals and postdoctoral scholars, 14 graduate students, and 23 undergraduate researchers. Nearly 150 scientists from university, national, and international laboratories collaborated in HIPSEC activities during 2008.

Materials relevant to the Stockpile Stewardship Program are central to HIPSEC's mission; that is, we give high priority to studies of static and dynamic high-pressure material properties for validating and improving computational models of d- and f-band metals, energetic materials, detonation products, low-Z elements and their compounds, and geological materials. We measure equilibrium thermochemical properties, reaction kinetics, and reaction products at static pressures using in situ x-ray diffraction; absorption, emission, light-scattering spectroscopy from infrared to x-ray wavelengths and other chemical and physical methods. Theoretical and computational studies focus on fundamental properties of solids and strengths of hard materials.

HIPSEC (25%), Lawrence Livermore National Laboratory, and the Geophysical Laboratory are members of the High Pressure Collaborative Access Team at the Advanced Photon Source (APS) of Argonne National Laboratory. There we study materials by x-ray diffraction and spectroscopy. We also regularly perform experiments at other APS beam lines; at Los Alamos Neutron Science Center (LANSCE), and at Cornell High Energy Synchrotron Source (CHESS), National Synchrotron Light Source (NSLS), Pohang Accelerator Laboratory (PAL) (Korea), and other synchrotrons where higher-resolution diffraction allows us to identify complex structures.

Recent results include studies as diverse as: establishing melting conditions for copper under hydrostatic and shock wave compression; measuring and modeling the phonon density of states of three phases of tin and several iron-tin compounds; determining the structure of the thermoelectric material $Na_{0.75}CoO_2$ at high pressures; establishing the effect of crystal-melt partitioning on the budgets of copper, gold and silver; developing a self-consistent elastic-plastic model of deformation under pressure; modeling atomic scale friction between grapheme sheets; analyzing the post-perovskite polymorph of an aluminum-bearing magnesiumsilicate that may occur between the Earth's lower mantle and outer core; and calculations that identify diamond-like boron carbide as a superhard conductor. Figure 1 depicts the diffraction pattern collected with monochromatic excitation from a single crystal of the explosive triaminotrinitrobenzene (TATB) in a diamond-anvil cell. Such measurements are used to study how the structure of TATB changes under compression.



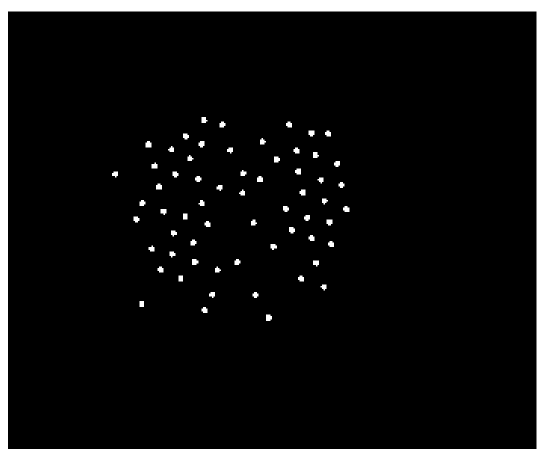


Figure 1. (Left) Photomicrograph of a single crystal of TATB in a diamond-anvil high-pressure cell; (Right) Single-crystal diffraction pattern for one orientation of this sample

HEDP Research at the Nevada Terawatt Facility **by Joseph M. Kindel**

The Nevada Terawatt Facility (NTF) at the University of Nevada, Reno (UNR) hosts a 2-TW pulsed power generator (Zebra), a 50-TW, 350-fs laser (Leopard), a 10-TW, 35-fs, 10-Hz laser (Cheetah), and an 86-node computer cluster. These resources are used by seven NTF research faculty, several UNR Physics Department faculty, and 16 graduate students. The NTF is currently in the third year of a five-year renewal of a DOE/NNSA-UNR Cooperative Agreement for High Energy Density Stewardship Science (July 1, 2006 – June 30, 2011). A competitive process with off-site reviewers has been developed for allocating experiment time. In the calendar year 2008, 367 science shots were performed on Zebra for a variety of experiments, some of which included the use of the Leopard laser in conjunction with Zebra.

Figure 1. Zebra operator looking towards the experimental chamber

The main focus of the research performed at the Nevada Terawatt Facility is on understanding fundamental Z-pinch physics and developing Z-pinch technology (diagnostics and pulsed-power). Recently, several groups reported progress in this direction. Several non-traditional wire arrangements (such as single- and multi-planar, star-like, compact cylindrical) have been studied, compared and optimized for dynamics, stability, and x-ray output. Systematic experiments revealed that double planar wire arrays radiate the highest x-ray power and energy, when driven with current peaking in the range 0.8-1.4 MA. Both scale nearly quadratically with the maximum current. In addition, this wire array configuration shows promise for x-ray pulse shaping. Numerical modeling with electro-dynamic and hybrid codes is being used in the experimental design and data interpretation.

In the pinch implosion experiments performed, the radiation yield (~20 kJ) significantly exceeds the kinetic energy of the implosion (~4 kJ). Several candidates for the additional pinch heating are being investigated by experiment and modeling. For example, enhanced ion viscosity could result from microturbulence with spatial scale comparable to the ion Larmor radius. To model the pinch dynamics while taking into account such effects, algorithms are being developed to modify the magnetohydrodynamic equations in large simulation codes, to adequately describe kinetic regimes of plasma turbulence.

Modeling of electromagnetic flute instabilities in the conditions of the Z-pinch precursor plasma showed that in the nonlinear stage the perturbations develop both towards small spatial scales (responsible for enhanced plasma heating) and large spatial scales (that leads to the disruption of the current-carrying plasma column). The effect of a sheared plasma flow on long-wavelength pinch instabilities has been investigated experimentally. Using conical wire arrays with a kink-perturbed central wire leads to the mitigation of the kink instability in the precursor phase and to increased x-ray emission, when compared with equivalent cylindrical wire arrays. In addition, the growth of flute instabilities is being addressed in a more basic way by investigating the interaction of laser-produced plasma flows with external magnetic fields. Using separate generators for plasma and field allows covering a broader range of parameters and more insight into the instability mechanism.

Multi-component Z-pinches were investigated to both control and better diagnose the plasma. On one hand, the radiative effects associated with mixing high-Z and low-Z elements allow controlling the hardness of the emission spectrum. On the other hand, systematic studies (by experiment and modeling) of multi-material wire arrays have shown that simultaneous analysis of spectral features of the low-Z element K-shell and mid-Z element L-shell that substantially change in time provides valuable insight into the implosion dynamics, that could not be obtained by any other method.

The higher current values mentioned above were obtained by using a Load Current Multiplier developed as an upgrade of Zebra. The development work was performed by a collaboration of UNR with École Polytechnique (A. Chuvatin), the Naval Research Laboratory (L. Rudakov), and Sandia National Laboratories (M. Cuneo). In short-circuit loads, a current multiplication coefficient of 1.8 was achieved, in excellent agreement with prior theoretical predictions. This upgrade makes NTF's Zebra the highest-current university pulsed power generator in the world.

To advance the understanding of Z-pinch plasmas, a considerable effort has been concentrated lately on diagnostics development. Ultraviolet laser refractometric techniques as well as high-resolution (2-3 μm) laser diagnostics have recently been demonstrated. X-ray radiography is under development. An advanced variation, namely absorption spectroscopy, is being considered to determine the plasma density and temperature during the non-radiative phase of the Z-pinch. Laser scattering diagnostics of the magnetized Z-pinch plasma are considered both theoretically and experimentally. The goal over the next year is to extend our diagnostic capability with absorption spectroscopy and x-ray backlighting to determine plasma density and temperature as a function of space and time.

[*] This report includes results contributed by V. Ivanov, V. Kantsyrev, R. Presura, A. Safronova, Y. Sentoku, and V. Sotnikov

Publication Highlights by Dillion McDaniel

In this section we highlight recent publications in high-impact scientific journals of research supported by the NNSA Science Campaigns.

"Spectroscopic study of low-lying ^{16}N levels"

D. W. Bardayan et al. Phys. Rev. C 78, 052801(R) (2008)

Understanding the direct capture of neutrons on light atomic nuclei is important in modeling the synthesis of the elements in stars as well as for stewardship science. Recent observations have found F overabundances of up to 250 times solar values in extremely hot post Asymptotic Giant Branch (ABG) stars. Models are unable to explain this. An important neutron capture cross section that is needed is the ^{15}N(d,p)^{16}N reaction. A recent measurement of the neutron transfer (d,p) reaction with beams of ^{15}N ions has provided the neutron spectroscopic factors required to determine direct neutron capture cross sections. These experiments were done at the Oak Ridge National Laboratory Holifield Radioactive Ion Beam Facility using a 100-MeV ^{15}N beam bombarding a 90 μg/cm^2 CD_2 target. A critical diagnostic for these experiments was the Oak Ridge Rutgers University Barrel Array of position-sensitive silicon strip detectors. These experiments have shown that the spectroscopic factors are consistent with the near-unity expectations and that the ^{15}N(n,γ)^{16}N reaction rate is a factor of 2 larger than calculated from previous experiments. This is an important step in understanding the factor of 250 overabundances of F in the ABG star branch.

"Mitigation of plasma implosion in homogeneity in "star"-like wire array Z-pinches" V. V. Ivanov et al. Phys. Rev. Lett. 100, 025004 (2008)

Understanding the stabilization process in Z-pinch implosions is important to optimize the radiated power output from the implosion. A star wire array is a sparse multiple wire array. An example of this is a nested wire array with six wires at a given radii and then a total of four different radii aligned so that all wires are aligned radially. (For example Six 10 μm Al wires at each of 16mm, 12mm, 8mm, and 6mm diameters for a total of 24 wires.) Over 24 different wire arrays were studied on the Zebra facility running at 1 MA current pulses rising in 80 ns at the University of Nevada, Reno. The diagnostic used to observe these implosions were many ranging from x-ray diode, x-ray imaging, bolometry, and x-ray spectrometers. The optimum wire implosion that was observed was with the quadruple arrays and they produced radiation pulses of 12 ns full-width half maximum with x-ray power levels of 0.4 TW. The imaging diagnostics indicated that there were significantly less trailing mass in the implosion that with a simple single cylindrical array that is optimized for the outer radius of the multiple wire arrays. This is over a factor of two increase in the radiated power.

Awards and Highlights

The International Association for the Advancement of High Pressure Science and Technology has awarded Carnegie's Russell Hemley, director of the Geophysical Laboratory, the 2009 Bridgman Award. Hemley will receive the honor in Tokyo, Japan, next July.

The Bridgman Award is presented at the association's conferences "to a person who has made outstanding contributions to this field." The award is named for P. W. Bridgman who won the Nobel Prize in Physics in 1946 for his discoveries in high-pressure physics and for inventing many high-pressure techniques.

Reinhard Boehler, president of AIRAPT, remarked: "The list of potential candidates for the Bridgman Award 2009 that the members of AIRAPT and the selection committee put together was quite impressive. It therefore should be regarded as a very special honor for Rus Hemley to emerge as the winner. Through presenting this award to Rus, we are honoring him for his many outstanding contributions to science and acknowledging his excellent leadership in high pressure research."

Hemley explores matter under intense pressures and temperatures and has uncovered many new discoveries about the nature of materials under extreme conditions. He has also discovered entirely new materials and his work has shed light on the interiors of planets. Hemley and his team are also leaders in developing new tools, many of which have become worldwide standards.

Stewardship Science Graduate Fellowship (SSGF) Program

The Department of Energy National Nuclear Security Administration Stewardship Science Graduate Fellowship (SSGF) Program is now entering its fourth year. It provides outstanding benefits and opportunities to some of our nations brightest students pursuing a Ph.D. in areas of interest to stewardship science, such as high energy density physics, low energy nuclear science, or properties of materials under extreme conditions. Fellows also participate in research at a NNSA laboratory.

There are 14 current fellows at 10 different universities. Fifty applications were received for the 2009-2010 academic year program. A committee consisting of lab researchers and academics reviewed these proposals and were able to select a significant fraction of applicants considered worthy of fellowships, and from this group, 5 or 6 will be selected. These new fellows should be notified by the first week of April and their first activity distinct from their academic study is to participate in the SSGF Annual Meeting in Washington DC July 13-16, 2009. This meeting is an excellent opportunity for NNSA headquarter staff and Laboratory staff to meet fellows who are in their first through final year of study, learn about their academic and research accomplishments, listen to exceptional research presentations and recruit these fellows to their laboratories for practicum experience or for employment after they complete their degree. Recruitment of new fellows for the 2010-2011 academic year will begin fall 2009.