Defense Science *Quarterly*

News about the Science Campaign December 2008

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Message from the Director
Chris Deeney, Defense Science Division

It's been another productive year. I am so proud of the progress we have made this year – boost, DARHT, energy-balance, JASPER... The list is too long to go through. Thank you. My father had a simple piece of advice that he used to give me: "leave a place better than you found it!" In October 2008 the Science and ICF campaigns left stockpile stewardship better than it was in October 2007. How do I know? Well here are some memorable events:

> The audible "oooh" when Dr. Marcus Knudson shared the latest diamond equation-of-state data at the JASON fall meeting.
>
> The obvious excitement of Dr. Lars Bildsten, JASON study lead for boost, when he gave the outbrief - coupled with the smile on Dr. Frank Graziani's face.
>
> The gleam in Dr. Ray Scarpetti's eye when he showed the four pulses on DARHT.
>
> The bombardment of emails filled with pride from the team at the Nevada Test Site when the Full Toss Experiment was executed.
>
> The bubbling enthusiasm of the students and fellows at our Stewardship Science Academic Alliance symposium.

Now onto FY 2009! These are exciting times, but the January to March time frame is going to be busy with budgets (three in play all at once), so we plead for your patience.

This quarter's newsletter includes an update on the boost initiative and a discussion of some radiation experiments; both of which are great examples of team work between the laboratories. We also discuss a number of awards and highlight three excellent journal papers that cover three out of our four science pillars of stewardship.

This quarter brings a few staff changes in the Defense Science Division. Dr. Christian Mailhiot recently returned to Lawrence Livermore National Laboratory (LLNL) and I'd like to take this opportunity to thank him for his outstanding service to Defense Programs (DP). During his several tenures at DP, he was a driving force in creating the Dynamic Materials Properties Campaign, the Stewardship Science Academic Alliances Program and the Physics and Engineering Modeling subprogram of ASC. He forged an important link with the DOE Office of Science and provided a leadership role in the formation of several joint programs, in particular, the highly successful HP-CAT beamline at the Advanced Photon Source at Argonne National Laboratory and the first solicitation for the Joint Program in High Energy Density Laboratory Plasmas. All of us here in DP wish Christian the best as he returns to LLNL in his new position.

Kathleen Alexander (Kathi) has joined our staff on detail from Los Alamos National Laboratory (LANL). Kathleen is a materials scientist with a PhD in Materials Science and Engineering from Carnegie-Mellon University. Kathleen was at Oak Ridge National Laboratory, as a technical staff member and then a group leader, for nearly 11 years. Since she came to LANL in 1998, she has held several program management positions, ranging from the Science and Engineering Campaigns to the Hydro Program. Kathleen has also held several division management positions at LANL in Materials Science & Technology, Applied Physics, and Hydrodynamic Experiments Divisions. Welcome Kathi!

Since this is the last newsletter before the holiday season and the administration transition, I want to wish you all a very happy and safe holiday season. We should all thank the NA-121.1 and NA-123 offices at headquarters and in the field for keeping our programs moving. For all our friends that may transition with the change in administration, we thank you and wish you good luck in your future endeavors.

Happy Holidays

The National Boost Initiative: What is it and what is it doing? by Frank Graziani (LLNL), Brad Beck (LANL), Mark Chadwick (LANL), Tom Mehlhorn (SNL), Paul Miller (LLNL) and Maurice Sheppard (LANL)

The boost process is at the core of the operation of all nuclear weapons in the U.S. stockpile and it is no overstatement to say that the modern nuclear deterrent exists because of boost. Its use allows for the high yield-to-weight ratio and miniaturization option that modern designs rely upon.

September 26, 2008, marked the sixteenth anniversary of the U.S. nuclear test moratorium. During the intervening period, the Stockpile Stewardship Program (SSP) has developed the understanding, experimental facilities, and computational resources to continue maintaining the U.S. nuclear deterrent, but the effects of stockpile aging and evolving geopolitical issues are creating new challenges. This predictive capability is essential to:

- address problems posed by the aging of the legacy stockpile,
- enhance the safety and surety of our nuclear weapons,
- provide a reliable nuclear deterrent and maintain nuclear preeminence while reducing stockpile numbers, and
- enable responsiveness to U.S. leadership directions regarding the stockpile and the NNSA Complex,

A substantial advance in our understanding and predictive capabilities in primary performance are critical to providing the ability to maintain high confidence in the U.S. nuclear deterrent while meeting the technical and geopolitical issues the nation is facing. All of these goals are central to our effort to mitigate the nuclear threat in a changing global environment.

To meet these challenges, SSP is pursuing a science based predictive capability for the nuclear explosive packages in the absence of nuclear testing.

It is now possible to achieve a quantum leap in our predictive capability utilizing investments in the advanced computational capabilities and major experimental facilities such as the National Ignition Facility, Z, and the Dual Axis Radiographic Hydrodynamics Test facility. Boost has been identified as the greatest current source of uncertainty in weapon behavior[1].

In order to address this uncertainty, a tri-lab National Boost Initiative (NBI) was formed in the winter of 2007; it built upon the successes of SSP and with a goal of advancing significantly the understanding of boost. Leadership of NBI was provided by an NBI Integrated Product Team (IPT) consisting of the following people: Frank Graziani and Paul Miller of LLNL; Maurice Sheppard, Brad Beck (who is now leading DPE for LANL) and Mark Chadwick from LANL; Tom Mehlhorn from SNL; and Chris Deeney and Robert Hanrahan from NNSA. This difficult national undertaking began with a kick-off meeting in Washington, DC, where designers, computational physicists and experimentalists from Lawrence Livermore, Los Alamos and Sandia National Laboratories discussed the critical uncertainties surrounding boost and the path forward. Technical Working Groups (TWG) were formed, each focused on a particular subject matter discipline (materials, hydrodynamics, plasmas and nuclear physics). An integration technical working group concerned itself with data, experiments and designs to encourage cross-disciplinary discussions. The purpose of the TWGs was to identify critical uncertainties and prioritize the work necessary to address those uncertainties. Members of the TWGs consulted with their colleagues and met with one another and the NBI IPT for approximately a year. Each TWG produced a report addressing (1) outstanding technical issues (2) prioritization of outstanding technical issues and (3) a path forward to understanding key uncertainties. These reports formed the backbone of the National Boost Strategy document.

The National Boost Strategy document outlines the approach to resolving performance uncertainties in the assessment of primaries, demonstrating a fundamentally new understanding and associated predictive capability by the year 2018. It identifies key topics of concern, prioritizes issues by impact, and outlines the optimum path towards progress as part of a tri-lab effort involving LLNL, LANL, and SNL.

Using the National Boost Strategy document as a guide, activities in 2008 centered on executing the work needed to address the key uncertainties. Working with the Science Campaign leads and laboratory management, a work scope, timeline and plan have been developed. Activities have started at all three national laboratories in such areas such as validation suites, high energy density physics experiments, molecular dynamics simulations of plasmas, transport properties of warm dense matter, data re-analysis, material properties, and hydrodynamics. The planning and technical work was reviewed during the 2008 JASON Summer Study period and the report has been accepted by NNSA.

In summary, the NBI's goal is to resolve current primary performance uncertainties, by replacing ad hoc factors and assumptions with physics-based models, thereby allowing assessments of any primaries without reliance on additional nuclear tests. The objectives are to maintain high-quality assessments and mitigating strategies for the aging legacy stockpile in the face of unexpected developments enhance surety in response to evolving geopolitical issues, and to be prepared to implement future U.S. leadership directions regarding the stockpile and the NNSA Complex.

[1] "NBI Strategy Document" cover letter, B. Beck, M. Chadwick, F. Graziani, T. Mehlhorn and P. Miller

HEDP to Support Our Understanding of Radiation Flow by Randy Kanzleiter (LANL)

Since the cessation of testing, the underpinnings of our nuclear performance predictions have slowly transitioned from a base of design validation through nuclear testing to one of improved predictability through the Science and Advanced Simulation and Computing (ASC) programs.

The only current or anticipated U.S. facilities capable of producing sufficiently intense conditions for radiation driven experiments relevant to astrophysics or nuclear weapons are the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL), Omega at the University of Rochester's Laboratory for Laser Energetics (LLE) and Z at Sandia National Laboratories (SNL). NIF and Omega use intense bursts of laser radiation while Z employs an imploding wire array in a configuration called a Dynamic Hohlraum (DH). Each facility is capable of producing drive conditions of at least 150 eV (where 1 eV ~ 11,600° K). Using these sources, the Los Alamos National Laboratory (LANL) Secondary Assessment program is actively designing experiments to validate and test the limits of our radiation flow models.

Prior to the ZR upgrade at SNL, DH configurations on Z were reaching 200 eV equivalent hohlraum temperatures driving radiation experiments examining bulk energy propagation. The last such radflow experiment before the Z shutdown is shown in Figure 1. The high-temperature DH source filled a truncated cone with approximately 100 kJ of hot x-rays. The radiation propagated down a cylinder with (or without) a gap and exited the target into a surrounding SiO_2 aerogel. As the propagating radiation spreads out and loses energy, it eventually stalls and forms a hydrodynamic shock in the aerogel that is visualized with radiography as seen in Figure 2. By comparing the unperturbed (without a gap) and perturbed (with gap) shock positions we were able to make quantitative measurements of energy transport[1].

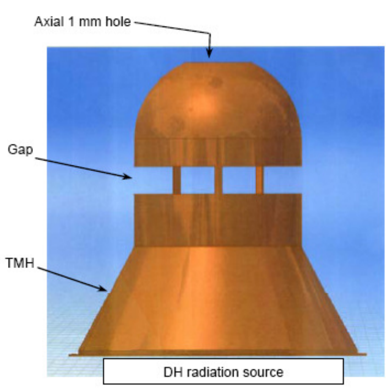

Figure 1. Target design for the Features II experimental campaign fielded in 2006 on the SNL Z facility. The 200 eV DH source, as measured by a Taper Monitor Hole, provided the drive for experiments characterizing bulk energy flow.

The future of Los Alamos' High Energy Density (HED) radflow program is focused on both generating data to improve our understanding of radiation flow in complex geometries and provide essential validation of LANL's energy balance philosophy. Both LANL and LLNL are committed to meeting a FY10 L1 milestone on Energy Balance delivering improved predictive capabilities for stockpile assessment. Once met, and as outlined in the Predictive Capability Framework (PCF), outstanding issues regarding validation and reduction of uncertainties are waiting for the eventual completion and access to the LLNL NIF facility. NIF will produce hohlraum drives in excess of 300 eV; enabling closer ties between experiments in both the HED and weapon regimes. In addition to a well-characterized and reproducible drive, ensuring the availability of necessary non-ignition related diagnostics on NIF is critical to achieving our scientific goals. As the NIF program transitions from achieving ignition to a broader focus on general weapons physics issues such as radiation flow, additional diagnostics such as calibrated DANTE, hi-energy radiography including phase contrast imaging, and temporally/spatially resolved spectroscopy for temperature measurements are needed to capture the data required for closure.

The Los Alamos Science Campaigns are eagerly awaiting NIF access to address questions of stockpile relevance. Our HED radflow program is concentrated under the banner "Pleiades"; a collection of experiments in increasingly complex geometries. Current plans call for early experiments in FY10 examining potential hohlraum configurations generating the highest possible drive temperatures. Allowing for suitable resources and availability, our planned experiments will provide the data needed to close the energy balance issue by the 2015 PCF goal.

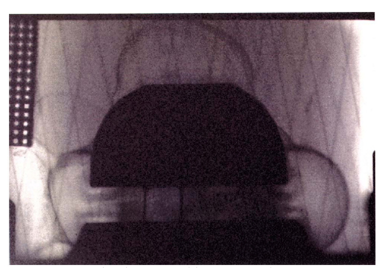

Figure 2. Data from the Features II experiments on Z acquired by imaging a radiation driven, hydrodynamic shock. Measurements of the shock position along the axial and radial axis directly relate to the delivered energy and subsequent radiation flow.

[1]Watt, R.G., et.al., *"Validating Hydro-code Predictions of ICF Hohlraum Energy Loss using the Z Accelerator at Sandia National Laboratory (U)",* Nuclear Weapons Journal, (to be published).

Publication Highlights by Brad Wallin

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

"An Experimental Investigation of Mixing Mechanisms in Shock-Accelerated Flow"

C. Tomkins *et al.*, J. Fluid Mechanics **611**, 131 (2008) *[Cover article!]*

An experimental investigation of mixing mechanisms in a shock-induced instability flow is described. For the case of a shock accelerated cylinder of heavy gas in air, quantitative two-dimensional maps of the heavy-gas (SF6) concentration using planar laser-induced fluorescence is obtained. The instantaneous scalar dissipation rate, or mixing rate, is estimated experimentally for the first time in this type of flow, and used to identify the regions of most intense post-shock mixing and to examine the underlying mechanisms. Instability growth is observed in certain regions of the flow beginning at intermediate times. The mixing rate results show that while these unstable regions play a significant role in the mixing process, a large amount of mixing also occurs by mechanisms directly associated with the primary instability, including gradient intensification via the large-scale strain field in a particular non-turbulent region of the flow. Such understanding of the true physical mechanisms is critical for accurate, predictive simulations and proper design of models of turbulent flow.

"Ultrafast Dynamic Compression Technique to Study the Kinetics of Phase Transformations in Bismuth"

R.F. Smith et. al., *Physical Review Letters*, 101, 065701 (2008)

Structural phase-transformation kinetics has been an active area of theoretical and experimental research in condensed-matter physics for several decades. Despite this, there remains a lack of quantitative data primarily due to the limitations in experimental techniques to measure these extremely rapid phenomena. Studies of time-dependent transformations have typically used shock compression, in which a single point in stress-temperature (*P-T*) space is reached over the shock-wave rise time. If *P* lies beyond a phase boundary, a two-wave profile propagating in the sample can develop due to wave speed differences between the two phases. Measurement of the intermediate temporal slope connecting this two-wave structure has been used to infer phase-transformation time scales. Recently developed ramp-wave-loading (RWL) techniques offer greater sensitivity over shock experiments in detecting phase transformations. Here, the authors use laser driven RWL of 20–50 micron thick preheated Bi foils to sample continuous paths in *P-T* space. These experiments represent, to our their knowledge, the first time multiple-wave features associated with phase transformations have been observed under laser-driven compression. The time scale for laser-driven RWL is several to tens of nanoseconds, substantially shorter than previously reported phase transition times for Bi I-II. By preheating the Bi (296–532 K) different paths through *P-T* space are explored to provide insight into the phase-transformation mechanisms. Under these rapid compression time scales, the equilibrium Bi I-II phase boundary is determined to be over-pressurized by $\Delta P \sim 0.3$–1 GPa. The onset of significant growth of $\Delta P/kT$ occurs at a threshold strain rate of 5x10-6 s-1. For higher strain rates, $\Delta P/kT$ increases logarithmically and is comparable to the new phase incubation period. The dependence of $\Delta P{=}kT$ on strain rate is consistent with a thermally activated transformation.

"Radiation Energetics of ICF-Relevant Wire-Array Z Pinches"

D.B. Sinars et. al., *Physical Review Letters*, 100, 145002 (2008)

The premise behind *Z* pinch plasma radiation sources is that the radiation energy is produced by the cylindrical implosion and compression of the wire mass by the Lorentz *jxB* force. However, the total energy radiated by some Al *Z* pinch plasmas on 7 MA facilities was in excess of the estimated kinetic energy of the implosion by factors of 2–4. Early two-dimensional simulations of 40-mm diameter tungsten array experiments explained the total radiation pulse as a combination of the implosionkinetic energy and subsequent additional plasma compression applied by the *jxB* force during stagnation. However, very large convergence ratios for the magnetic field (> 20) were needed to match experimental radiation powers and total yields with no systematic experimental data to corroborate such claims. In this Letter the authors estimate the *jxB* work done by using multiple diagnostics that include the first direct measurement of the imploding mass density profile of a wire-array *Z* pinch. In tests with a 1-mm on-axis rod the authors found that the radiation can be readily explained by the observable *jxB* work, but bare-axis tests require the equivalent of sub-mm convergence of the magnetic field (> 20 convergence ratio). Emissive, sub-mm plasma structures are not seen in soft x-ray diagnostics except at > keV energies. The systematic data set presented here (radiation power, size, spectrum, mass density profile) strongly constrains ongoing simulation efforts.

Awards and Highlights

SSGF 2008-2009 Awardees

Correction -- In last quarters newsletter new SSGF Fellow Richard Kraus was incorrectly listed as attending the University of Cambridge, UK. He is attending Harvard University.

2009 Glenn Seaborg Award

Kenton Moody, AX-Division at Lawrence Livermore National Laboratory won the 2009 Glenn Seaborg Award from the American Chemical Society Division of Nuclear Chemistry for his work in heavy elements and nuclear forensics. Congratulations Kenton!

2009 Ahmed Zewail Award

Henry Kapteyn and Margaret Murnane from the University of Colorado will share the American Chemical Society's 2009 Ahmed Zewail Award in Ultrafast Science and Technology. The purpose of the Ahmed Zewail Award is to recognize outstanding and creative contributions to fundamental discoveries or inventions in ultrafast science & technology in areas of physics, chemistry, biology, or related fields. Congratulations Henry and Margaret!

APS-DPP Selected Fellows

Congratulations to the 2008 APS-DPP Fellow selectees:

Christine Coverdale, SNL, for exceptional experimental achievements in both laser and z-pinch plasma physics, dedicated service to the professional community, and leadership in promoting laboratory and university collaborations.

George Kyrala, LANL, for outstanding experimental and theoretical contributions to understanding ionization and excitation processes in matter, and for pioneering efforts in developing and using x-rays produced by short-pulse laser matter interactions in ICF and high energy density physics experiments.

Andy Mackinnon, LLNL, for pioneering experimental studies of interactions of intense laser pulses with matter and in particular, the physics and applications of short pulse laser driven proton beams.

Experimental Investigation of High-Current LTD Cavities

NNSA's Science Campaign is funding research on the linear transformer driver (LTD) for flash radiography and dynamic materials applications. Extensive tests of the reliability of this technology are ongoing at Sandia's High Current LTD Laboratory. Both the prototype 0.4-MA LTD I cavity and an improved version, the 0.5-MA LTD II cavity, perform remarkably well. The LTD I cavity, composed of 40 capacitors and 20 switches connected in parallel, has operated at 85 kV for 13,000 shots. The reproducibility of the output pulse shape and amplitude had a variation of <1% (1σ). The pulse jitter has been as small as 2 ns and the repetition frequency has been up to 6 shots per minute. The LTD II cavity delivers 38% higher energy to a matched load than the LTD I cavity. The upgraded cavity is being operated at 100 kV to establish the optimum gas switch operating pressure for minimum prefires, fast rise and fall pulse output times, reproducibility, jitter, and longevity. To date, 8,000 shots have been fired at 100 kV, at 3 shots per minute, without component failures, with the switch pressure being varied from 40 to 55 psig. As the total number of shots on the LTD II cavity has increased, the optimum operating pressure has decreased because of switch conditioning and is now 43 psig. Our goal for the LTD II cavity tests is to conduct >20,000 shots and continue until the components start to fail. Michael G. Mazarakis, William E. Fowler, William A. Stygar, John L. Porter, Mary Ann Sweeney (Sandia National Laboratories), and Kevin Ward (Ktech)

Marx-Generator Improvement Leads to Increased Shot Rate on Z

The upgraded Marx generators in the refurbished Z accelerator have the same geometry as they did in the PBFA-II and original Z machines. A new orientation of the generators in the Z tank structure, however, led to water-resistor failures at the output end of the generators. The failures were a strong function of the Marx charge voltage: at 90 to 95 kV, an average of 8 of the 36 resistors failed each shot; at 80 to 82 kV, an average of 1.7 failed. The resistor failures were not detrimental to the downline shots, but required draining the oil to replace the resistors, thereby contributing to a reduced shot rate. A member of the Z Operations Crew in Org. 1676 observed a consistent failure mode of the resistors. This observation led to collaboration with members of Org. 1671 in designing new electric-field shapers. These shapers shield a sharp edge near the resistors that was causing the failures. The design solution, fully implemented on September 2 on Z in less than one week, has reduced the required inter-shot maintenance by six man-hours per shot (*i.e.*, it had taken three men two hours to complete the replacements at a 90-to-95-kV Marx charge level). We have had no resistor failures since this implementation. Brian Stoltzfus, Keith LeChien, Dave Artery, Dave Wolcott, Mike Baremore, Hans Wagoner, and Dale Hodgson (Sandia National Laboratories)

Comments

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

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