DOE/NA-0046

National Nuclear Security Administration

Office of Research, Development, Test, and Evaluation

Stockpile Stewardship Quarterly

VOLUME 6 | NUMBER 2 | JUNE 2016

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

This issue of the *Stockpile Stewardship Quarterly* features a set of articles of particular interest to stewarding the nuclear weapons stockpile, with a focus on several of the efforts funded by the Engineering programs. The first article, from the Enhanced Surveillance program, describes contributions to nuclear weapon component reuse decisions and how this program has resulted in savings of millions of dollars. The next article, on survivability, describes research on understanding radiation-hardening in support of qualification of weapons system and components to radiation environments. The article on aeroballistics and reentry considers the factors that influence a vehicle's flight path, including the impacts of a harsh environment. The final feature article introduces the Advanced Simulation and Computing (ASC) Program's Trinity architecture, which is the latest mission-driven computing system designed to perform the most challenging, large-scale, capability-class simulations.

2016 Omega Laser Users' Group (OLUG 2016) Workshop. Pictured are the students, postdoctoral scholars, and young researchers who presented their high energy density physics research in three different workshop poster sessions. Their travel to the workshop was made possible by an NNSA grant. See page 6 for more information.

The 2016 Omega Laser Users' Group Workshop met recently. Their annual workshop provides a forum for students and postdoctoral scholars (pictured on right) to present their research and interact with members of the high energy density physics community. DOE/NNSA supports this annual event, which offers a variety of opportunities to future stockpile stewards. We are proud of the fact that a number of recent postdocs and new employees at the laboratories have been active participants in this community.

Also discussed in this issue is the Inertial Confinement Fusion (ICF) Program Framework, which was developed over 20 months in collaboration with the ICF and high energy density communities. The Framework describes the main goals of the ICF Program and the proposed program of work to enable programmatic prioritization.

Thank you for your hard work and have an enjoyable summer.

Inside

Comments

The *Stockpile Stewardship Quarterly* is produced by the U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) Office of Research, Development, Test, and Evaluation. Questions and comments regarding this publication should be directed to Terri Stone at terri.stone@nnsa.doe.gov.

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Large Return on Investment from Fitness for Reuse Evaluations for the B61 Life Extension Program

by R. Stinnett (Sandia National Laboratories)

As part of the early planning for the B61 Life Extension Program (LEP), Sandia National Laboratories' (SNL's) Enhanced Surveillance (ES) subprogram was asked to support Fitness for Reuse Evaluation of several components. This request was made because ES is the only program whose primary mission is prediction, detection, and assessment of aging issues in the nation's nuclear stockpile. During the following three years the ES team worked closely with the B61 Legacy and LEP groups as well as components and materials evaluation technical working groups to identify and evaluate components for which the value, both in terms of financial savings and for risk reduction, would be large if they could be reused in the B61-12.

Several B61 legacy components were selected for Fitness for Reuse Evaluation, including the Actuator and Pulsed Battery Assembly/ Pull-Out Switch Assembly, a rolamite switch, two thermal batteries, two igniters, as well as other components. Fitness for Reuse Evaluation is a term coined for the technical work done to determine if specific components used in the current B61 stockpile could be confidently reused in the B61-12 (see Figures 1 and 2). In order to make a decision to reuse a component, a strong technical basis and a thorough understanding of the relevant aging issues must be developed. These must demonstrate a high probability of meeting B61-12 LEP requirements for the planned life of the weapon system. This work was funded by ES at a level of approximately $2.6 million per year for three years with additional follow-up work in FY 2015 for an additional $1 million, resulting in a total ES investment of $8.8 million.

Partnership Between Enhanced Surveillance, B61 Legacy and LEP Groups in Fitness for Reuse Evaluations

The ES program, in partnership with the B61 legacy and LEP groups, organized efforts in several component and materials working groups to provide a solid technical basis for answering Fitness for Reuse Evaluation questions. For complex components

Figure 1. Technologists prepare a B61 bomb for inspection.

like the Actuator and Pulsed Battery Assembly/Pullout Switch Assembly, a 20-person team of materials experts from the corrosion, tribology, organic materials, metallurgy, diagnostics, and modeling areas worked together with component and surveillance engineers. This was required to provide the necessary science-based understanding of the component aging and performance issues to support reuse recommendations.

In most cases, all of the funding for the work was provided by ES, but in a few cases significant additional funding (several hundred thousand dollars) came from the B61-12 LEP program. This process and lessons learned from it are described in "Enhanced Surveillance Fitness for Reuse Evaluation for the B61 Life Extension Program," *Stockpile Stewardship Quarterly* Volume 3, Number 4.

The Fitness for Reuse Evaluations resulted in information that the B61 LEP group used to make reuse decisions regarding all selected components. Since FY 2014, the value and cost avoidance enabled by these evaluations has become evident. A few representative examples of return on investment (ROI) are discussed below.

- The rolamite switch (see Figure 3) was selected for reuse after extensive aging, mechanical and margin testing, and modeling. The estimated cost avoidance resulting from reuse of this component was $27 million.
- The decision was made to redesign and rebuild the two thermal batteries (see Figure 4 for an example) because of improved technology and materials available, but the information provided by positive Fitness for Reuse Evaluation results enabled confident extension of service life estimates to beyond 40 years versus the original 25 years and additional confidence in our thermal battery design techniques. One way to estimate this value is based on the

Figure 2. The B61-12 System.

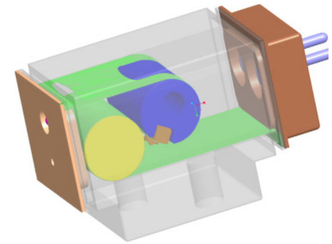


Figure 3. Rolamite Switch.

Figure 4. Thermal Battery.

approximately 50% longer active life of a battery that this enables. Conservatively, this would be approximately $3 million.

- Similarly the decision was made to rebuild the two ignitors with only minor design changes based on the positive Fitness for Reuse Evaluation results. Our energetics group estimates that the design cost for these components was reduced by approximately 30%, $1.8 million.
- Other component reuse decisions resulted in an estimated cost avoidance of $78 million.
- Based on mixed results from Fitness for Reuse Evaluation testing and modeling, the Actuator and Pulsed Battery Assembly/Pullout Switch Assembly was not reused. It is difficult to quantify the value of a negative reuse decision but arriving at the same conclusion late in system development or during production would incur additional costs exceeding $10 million. If an incorrect reuse decision was found to require all B61-12s to be returned to Pantex Plant for replacement, the transportation costs alone would be several tens of millions of dollars. Because the value of this decision is not directly quantifiable, it is not included in the avoided costs or ROI.

In addition to the value identified above, several other ES-funded projects were initiated due to findings from the Fitness for Reuse Evaluations. O-ring service life issues that were identified as part of the Pull-Out Switch Assembly evaluations resulted in the development of a new o-ring material that has more than 10 times the useful service life of the previously used o-rings. This new o-ring material was selected by the B61-12 and W88 ALT 370 groups for use in their systems. Similarly, electrical contact materials testing conducted as part of these reuse evaluations resulted in an ES-supported effort that developed new materials and processes to increase confidence in the electrical contacts to be used in all modernization programs. Finally, the degradation due to aging of caloric output of heat pellets used in the B61 thermal batteries was measured for the first time, with results that provide increased confidence in the service life of Li/FeS_2 batteries throughout the stockpile.

We have estimated the avoided cost and ROI of the Fitness for Reuse Evaluations by basing the estimates on the components for which we have quantitative estimates of the difference between the cost of reusing existing components and the cost of redesigning, requalifying, and producing new components. The estimates of cost avoidance and value were provided by subject matter experts in each area who have in-depth understanding of the relevant issues. Based on the above, the total quantifiable avoided cost resulting from the reuse decisions supported by our Fitness for Reuse Evaluations was determined to be approximately $110 million.

Return on Investment in Fitness for Reuse Evaluations and the Expertise That Made It Possible

The ES-funded Fitness for Reuse Evaluations for the B61-12 resulted in information to the B61-LEP team that helped inform their reuse decisions. The resulting $110 million cost avoidance supports a ROI for the ES investment of about 12 times and is approximately equal to a full decade of total SNL ES program funding. If the Fitness for Reuse Evaluations result in avoiding even one future B61-12 problem that would require bringing the weapons back to Pantex Plant, the ROI would be even higher.

In addition, this exercise makes clear the value of SNL's materials science expertise to the nuclear weapons program and its close integration with components and systems work. Whether used to evaluate the Fitness for Reuse Evaluation of selected components, to identify issues that need to be corrected in reused components, or to play a key role in the redesign of new components, SNL's materials expertise is a key enabler of the activities required to ensure stockpile health and effective stockpile modernization. •

Nuclear Survivability: Assuring Qualification by Advancing Technology, Experiment, and Modeling

by Bryan Oliver, Len Lorence, Fred Hartman, and Jim Bryson (Sandia National Laboratories)

Introduction

Maintaining the deterrence of the stockpile requires assuring that weapons can reach their targets and properly function in spite of current and evolving defensive capabilities of adversaries. In collaboration with the Department of Defense (DoD), radiation hardening requirements are set for warhead systems that could potentially face hostile nuclear-tipped anti-ballistic missile systems. The Nuclear Survivability Engineering Campaign (NSEC) assures that these survivability requirements can be met by funding fundamental research on weapon outputs and radiation effects, radiation-hardened technology development and maturation, and development of experimental testing platforms and validation data for models, particularly where testing capabilities do not exist. This is done in partnership with other campaigns such as the Advanced Simulation and Computing (ASC) campaign for modeling, the Science Campaign for facility enhancements for radiation sources at high energy density facilities, and the Readiness in Technical Base and Facilities (RTBF) program for facility support and technology maturation.

Hardening requirements for strategic weapon systems far exceed those of commercial space or other military systems. Radiation hardening often requires the use of unique materials and designs. For non-nuclear components, these can be significantly different from commercial products with similar functionality. The use of special technology to enable radiation hardness is a design choice. A recent example is the selection of heterojunction bipolar transistor (HBT) technology for arming, fuzing, and firing (AF&F) circuits in the B61-12 and W88 Alt 370, as well as the Mk21 fuze. This technology was developed and is being produced at the Microelectronics and Engineering Sciences Application facility at Sandia National Laboratories (SNL), which is providing trusted radiation-hardened microelectronics for stockpile modernization efforts.

NSEC-developed capabilities are being used to improve our understanding and models of adversarial weapon outputs (the hostile Redbook) as well as outputs from our own weapons (the fratricide Bluebook). Drawing on NSEC capabilities, efforts at Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL) are coordinated with DoD through the Defense Threat Reduction Agency. The weapon output models provide detailed definitions of radiation from weapons (fluence, spectrum, time history, etc.) Together with DoD operational constraints, these models set hardening requirements.

For a number of radiation effects, there are no radiation test capabilities adequate for qualification, even at the component level in some cases, given the underground test (UGT) moratorium (1992) and closure of the Sandia Pulsed Reactor (SPR) fast burst reactor (2006). Testing is utilized where possible, but modeling and experiments provide the qualification evidence for many radiation effects.

The NSEC also creates capabilities to assess the effect on electronics of both the low-intensity long-duration radiation from the decay of fissile material in the weapon system (internal radiation) as well as single event effects produced by cosmic rays.

X-ray Environments and Effects

The type of hostile environment that a strategic weapon encounters will depend on the stockpile-to-target sequence (STS) scenario, as shown in Figure 1. While sustained radiation from radioactive debris clouds can arise, the most significant radiation that impacts survivability is pulsed.

X-ray pulsed radiation is only a concern for hostile exo-atmospheric bursts. For endo-atmospheric bursts (both hostile and fratricide), the x-rays are absorbed in the atmosphere producing an air blast. Should a reentry system encounter a blast wave, structural vibrations can be produced that can damage internal components. Blast tube facilities are used to test weapon systems for this mechanical effect.

X-ray radiation can be further sub-divided into three classes of increasing photon energy: cold, warm, and hot

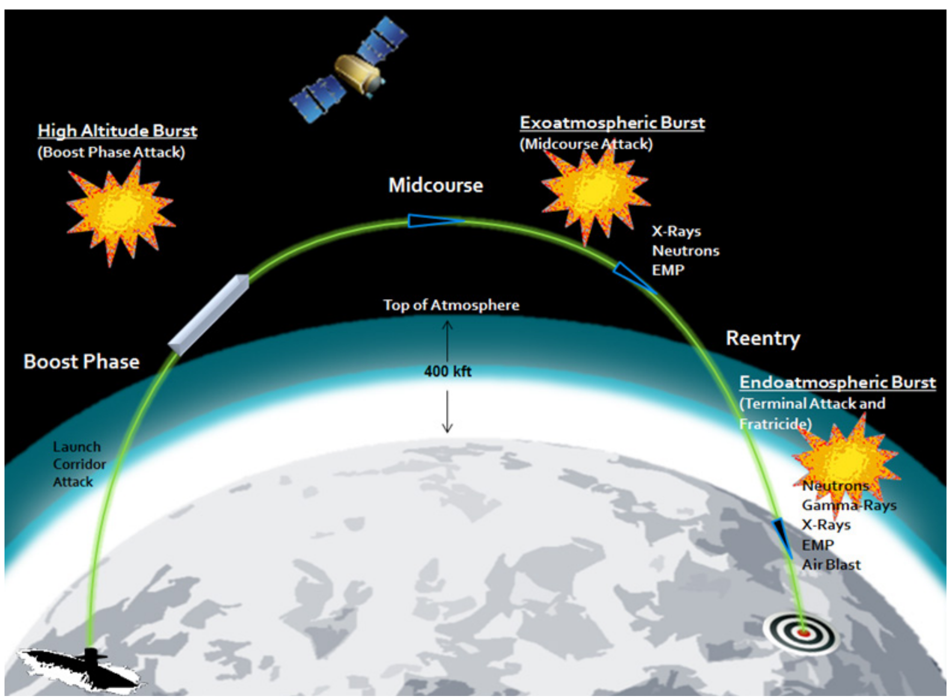


Figure 1. The hostile environment depends on the stockpile-to-target sequence scenario.

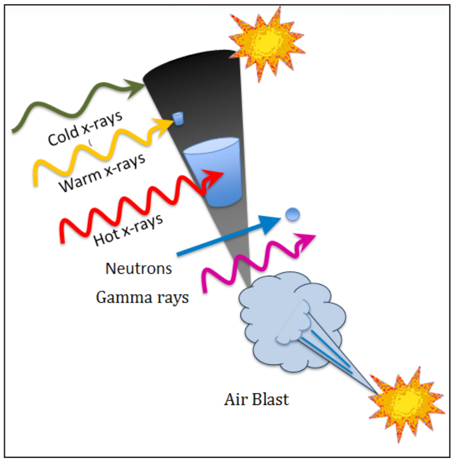


Figure 2. The hostile radiation environment in exo-atmospheric scenarios will involve x-rays with various penetration capabilities. In endo-atmospheric scenarios, air blast replaces x-rays as a concern.

(as shown in Figure 2). X-rays with different photon energy drive different types of radiation effects. Cold x-rays (photons below 10 keV) are absorbed in the aeroshell, vaporize its outer layers, and cause blowoff of material generating impulsive force into the system. Like blast, impulse can damage internal components of a weapon system. SNL's Z machine and LLNL's National Ignition Facility (NIF) can replicate this phenomenon for small-size material samples; however, they are not capable of irradiating an entire reentry vehicle. Such capability was lost when UGT ceased, although surrogate facilities such as SNL's Light-Initiated High Explosive facility can replicate system-wide impulse effects.

The most-energetic hot x-rays are the most penetrating and can effect electronics deeper in the system, including dose-rate-driven effects such as transient radiation effects in electronics (TREE)[1] and a class of electromagnetic pulse (EMP) called internal EMP (IEMP)[2] at the AF&F component level. The latter is produced by pulsed currents of secondary electrons which generate EMP internal to the weapon system itself.

SNL's Saturn facility can provide an x-ray environment for testing electronics for the radiation effects produced by hot x-rays. The Saturn facility generates x-rays via electron beam stopping in high atomic number targets, generating bremsstrahlung radiation. This same process is advantageous for generating gamma rays as well, as is done at SNL's HERMES III facility. Both Saturn and HERMES III are used extensively for electronics testing in these energy regimes.

Sources relevant to warm x-ray drives pose greater challenges. With the loss of underground testing, pulsed testing sources no longer exist for the warm x-rays that penetrate less deeply. The fluence from sources on SNL's Z machine and NIF diminishes as they are pushed from the cold x-ray regime to the higher energies of the warm x-ray regime. Unfortunately, a facility like Saturn that creates hot x-rays via the bremsstrahlung process also suffers decreasing fluence as one tries to generate x-rays in the warm regime. Hence, there is significant research devoted to creating high fluence warm x-ray sources.

Warm x-rays drive radiation effects that are different from those produced by cold and hot x-rays. They can produce thermomechanical effects[2] at both the system and component levels. Warm x-rays are also a concern for another class of EMP called system-generated electromagnetic pulse (SGEMP).[2] This is produced by both a pulse of secondary electron emission from cavity surfaces and direct x-ray interactions with cables. The result is a current surge through cables that can damage components to which they are connected.

To gather validation data for SGEMP models, both Z and NIF are being used. While the x-rays created on these machines are lower energy than ideal for testing, they can be used to validate aspects of physics in the codes. On both Z and NIF, a library of simple gas-filled cavity SGEMP responses as a function of photon energy is being assembled. In Figure 3, the experimental setup for a NIF shot is shown, including the SGEMP instrumentation designed to fit within NIF's Diagnostic Instrument Manipulator.

NSEC-developed capabilities are being used to improve our understanding and models of adversarial weapon outputs (the hostile Redbook) as well as outputs from our own weapons (the fratricide Bluebook).

The data obtained on these experiments are used to validate our multi-scale and multi-physics modeling and simulation capabilities that are supported by the ASC program. Radiation transport and environments are modeled with SNL's Radiation Analysis Modeling and Simulation for Electrical Systems (RAMSES) code suite and LANL's Monte Carlo N-Particle (MCNP) code. The RAMSES suite also includes codes to model electrical and EMP effects produced by the radiation. For modeling thermomechanical effects, radiation transport models are coupled with SNL's Sierra code suite and/or commercial mechanical response codes.

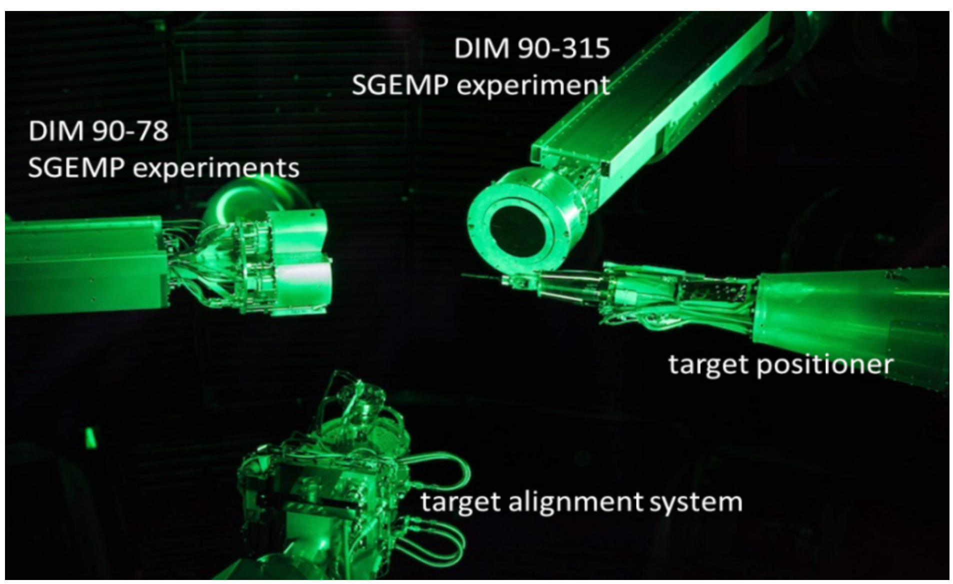


Figure 3. Cavity SGEMP experiments on NIF.

Neutron Environments and Effects

Neutrons are another form of radiation encountered in both exo-atmospheric and endo-atmospheric nuclear explosions (see Figure 1). Inside the atmosphere, air interactions cause the neutron spectrum to become less energetic and to arrive in a broad pulse. SNL's water-moderated Annular Core Research Reactor (ACRR) can be used to test for these environments. In space, neutrons are faster and more energetic. Until its retirement, the SPR fast burst reactor was used to replicate such environments for electronics testing. With the shutdown of SPR, the NSEC undertook, with its partners in ASC and RTBF, a new project called the Qualification Alternatives to Sandia Pulsed Reactor (QASPR). In addition to funding the research to create the radiation-hardened HBT microelectronics, the QASPR project has created physics-based models of neutron effects from the atomistic level of neutron displacement and damage to the response in transistors and circuits for both silicon[3] and III-V[4] electronics. To validate these models, the QASPR project has developed new experimental platforms and diagnostics on ACRR and the Ion Beam Lab (IBL). For the IBL, QASPR has demonstrated that ion beams can be used as a surrogate for neutrons to obtain validation data for fast radiation pulses and high damage levels equivalent to SPR, although over smaller exposure areas.

Summary

Nuclear survivability of reentry systems is essential to assure the deterrent value of the stockpile. Qualification of weapon systems and components to STS radiation environments involves testing on a range of facilities as well as modeling and experiment to understand a variety of radiation-driven mechanical and electrical effects. Such understanding enables radiation-hardened design, including improved radiation-hardness technology, and confidence in qualification.

References

[1]G.C. Messenger and M.S. Ash, "The Effects of Radiation on Electronic Systems," Van Nostrand Reinhold, 1986.

[2]B.C. Passenheim, "How to Do Radiation Tests," Ingenuity Ink, 1988.

[3]S.M. Myers, P.J. Cooper, and W.R. Wampler, J. Appl. Phys. 104, 044507, 2008.

[4]W.R. Wampler and S.M. Myers, J. Appl. Phys. 117, 045707, 2015. •

8th Omega Laser Users' Group Workshop

Attendees of the 2016 Omega Laser Users' Group (OLUG 2016) Workshop strike a pose at the University of Rochester Laboratory for Laser Energetics (LLE). Held from April 27-29, 2016, the workshop included three poster sessions with 78 posters, talks by world authorities, and lively discussions regarding upgrades and improvements to the Omega Laser Facility. This latter activity results in the Findings and Recommendations of the Users, which will be used by the LLE management to help keep the facility at the cutting-edge of high energy density physics (HEDP) research. The annual OLUG Workshop is made possible in part by the support of the National Nuclear Security Administration for travel expenses of students and postdoctoral researchers and the by the Department of Energy Office of Fusion Energy Sciences for support of general workshop costs. The 9th OLUG Workshop will be held April 26-28, 2017.

Aeroballistics and Reentry Environments *by Basil Hassan (Sandia National Laboratories)*

Aeroballistics typically refers to the flight of a body whose motion is influenced by aerodynamic forces and moments imparted to it. Ballistic vehicles, such as gravity bombs and reentry systems typically do not have an active control system or a propulsion system. A ballistic vehicle's flight path is influenced by its shape, initial velocity, flight path angle, angles of attack, body rates, and overall mass and mass distribution. Stockpile weapon systems such as the B61 and B83 family of gravity bombs, the Air Force reentry vehicles (RVs) such as the W78/Mk12A and the W87/Mk21, and the Navy reentry bodies (RBs) such as the W76/Mk4 and the W88/Mk5 are all examples of ballistic vehicles. The RVs and RBs, which travel at many times the speed of sound, are typically subjected to harsh environments which are characteristic of hypersonic flight. Initial velocities at reentry into the earth's atmosphere for these types of systems often exceed 13,000 mph and surface temperatures can reach values in the range of 6,000 to 8,000 degrees Farenheit. Having a firm understanding of these reentry environments is crucial towards understanding both the performance of the vehicle and its internal components.

In order to protect the warhead and its associated components, these reentry systems have a thermal protection system (TPS) which manages the heat transfer generated from the hypersonic flow. The TPS for ballistic RVs/RBs responds somewhat differently than a reusable TPS for vehicles like the retired National Aeronautics and Space Administration (NASA) Space Shuttle. Ballistic RVs/RBs fly trajectories which cause the outer portion of the TPS material to ablate, or be removed during flight. The ablation process, while changing the shape of the vehicle's external geometry, actually helps manage the thermal state of the inner components of the vehicle by removing heat with the ablated material. The amount and type of material for the TPS is carefully chosen to ensure that it protects the vehicle for any combination of design initial velocity and flight path angle entering the atmosphere. Understanding the shape change as a result of ablation is also important since it affects the aerodynamic forces and moments imparted on the flight vehicle. These forces and moments, which influence how a body flies, depend on a variety of factors, including the vehicle shape, initial velocity, and vehicle angle/rates; local temperature and pressure conditions at any point along the trajectory; and the mechanical properties of the geometry (mass and moments of inertia distribution).

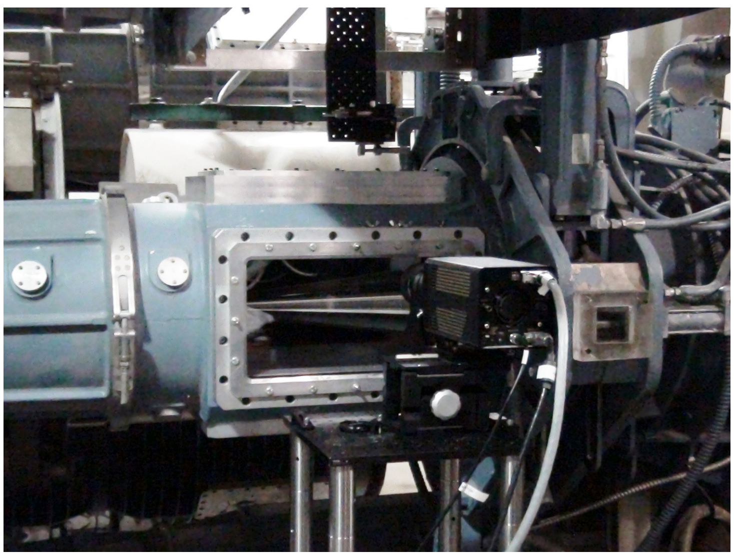


Figure 1. SNL's Hypersonic Wind Tunnel. A generic ballistic flight vehicle is in the test section.

While the Air Force and the Navy are responsible for the thermal protection systems (nose tip and aeroshell) associated with the stockpile delivery systems, Sandia National Laboratories (SNL) and its sister NNSA laboratories (Los Alamos National Laboratory and Lawrence Livermore National Laboratory) are responsible for understanding how the external flow field environments affect our internal components. The surface pressure and temperature loads caused by the high speed flow field will transmit through the TPS and its substructure to the internal components. The pacing environments for SNL components during reentry are Normal Environments and Hostile Environments. In Normal Environments, we are concerned with the loads transmitted to the components during regular reentry flight. This includes understanding effects like random vibration of components during reentry. Hostile Environments, which occur when a reentry system is exposed to a nearby explosion or detonation, can impart a thermo-structural response due to x-rays and blast effects. Like the random vibration, it is important to quantify the hostile effects on system components.

The external environments experienced by a RV/RB in hypersonic flight must be quantified over the range of reentry velocity and flight path angle (the V-gamma map) and are determined using many techniques. The classical way of determining the aerodynamic forces and moments and the aerodynamic heating is testing in wind tunnels. Wind tunnels, like the two that are operated at SNL, attempt to replicate the flow environment seen during flight. The wind tunnels at SNL (see an example in Figure 1), like the larger facilities operated by organizations such as NASA and the Air Force, are typically unable to reproduce the entire flight environment combination of vehicle scale, vehicle velocity, and flow enthalpy (measure of energy in the flow). In general, one may be able to match two of the three depending on the facility and the size of the vehicle. The approximations to the flight environment as well as test equipment errors lead to uncertainties in the resulting forces and moments from wind tunnel testing. An additional way to determine the aerodynamics forces and moments is via numerical methods, such as computational fluid dynamics (CFD). CFD computer codes

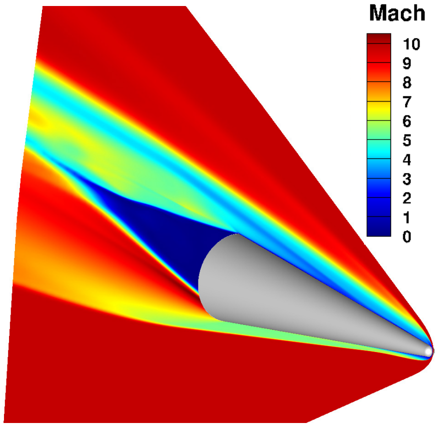


Figure 2. Computational Fluid Dynamics solution of hypersonic flow around a generic ballistic flight vehicle. (Color contours represent Mach number, which is a measure of the local velocity of the flow surrounding the vehicle). Mach 10 is equal to ten times the speed of sound.

solve a set of coupled partial differential equations that model the conservation of mass, momentum, and energy of a gas (or fluid) flowing past geometries of interest (see an example CFD solution in Figure 2). While CFD codes can model the salient combinations of vehicle scale, velocity, and flow enthalpy, uncertainties exist in many of the physics models that are inherent in the governing equations. The key sources of uncertainty occur when modeling chemical reactions in the hypersonic flow and when the flow transitions from laminar to turbulent flow during the high speed trajectory. Therefore, our ability to model these flows and accurately predict the aerodynamic forces and moments will depend on the accuracy and assumptions inherent in the physics models and how well these models can be validated by associated ground tests or available flight tests. The final method of determining aerodynamic forces and moments is directly from flight tests. The aerodynamics models used for ballistic systems have historically been developed from combinations of all three capabilities. A trajectory code uses this aerodynamic information to integrate the equations of motion to model the flight along a given trajectory.

Like the aerodynamic environments, thermal environments are typically determined via testing in arc jet facilities or through computational methods. As with wind tunnels, arc jets cannot replicate the complete hypersonic environment that a TPS material will experience. The associated computational methods are also dependent on the accuracy of the CFD codes and the thermal response models which attempt to predict the ablation process. Ultimately, flight testing is extremely important in determining response of the TPS during flight, though it is often too expensive to test at all points of interest in the velocity/flight path angle trajectory space.

The internal structural response of the components in RVs/RBs is also determined via a combination of ground testing, computation, and flight testing. Structural response ground testing facilities also suffer from an inability to replicate all loads experienced in hypersonic flight. Combinations of facilities which subject the vehicle and components to acoustic and vibration environments can only reproduce part of the spectrum experienced in flight. Like their aerodynamic and thermal counterparts, the structural response codes are only as good as their physics models and input they receive via the aerodynamic and thermal loads. While flight tests can be conducted to understand the structural response during re-entry, typically only limited data are obtained for full model validation.

Through investments from NNSA's Advanced Simulation and Computing (ASC) and Engineering Programs (formerly known as Campaign 6/WSEAT), SNL is actively improving its computational and testing capabilities to accurately replicate these reentry environments. The ASC Program is investing in enhanced computational physics models and taking advantage of advances in computational architectures to make these multi-physics simulations tractable. Additionally, the Engineering Programs are investing in fundamental physics discovery, advanced diagnostic techniques, and facility improvements to provide better understanding of the underlying physics and validation data for the prediction codes. As an example, SNL is combining state-of-the art experimental and computational methods to better predict the boundary layer state of vehicles in flight. As a vehicle flies through the air, the state of the vehicle's boundary layer, the thin region surrounding the vehicle where viscous forces are important, can have a significant effect on the vehicle's performance. Understanding when the transition from laminar to turbulent boundary layer flow occurs allows engineers to more accurately predict vehicle flight path and environmental loads. These investments, coupled with available flight test data for validation, will allow SNL's computational and testing capabilities to be more predictive in replicating the environments experienced during hypersonic flight. Enhanced predictive capabilities will result in improved science-based methods to better understand and predict component performance for both the existing stockpile and for any future modifications via Life Extension Programs (LEPs). Subsets of these capabilities are currently being used in the design and qualification of the B61-12 LEP and will be used for the W80-4 LEP. •

Contact Us

What do you think about this issue of the *Stockpile Stewardship Quarterly*? We want to know. Please send your comments and suggestions for future issues to Terri Stone at terri.stone@nnsa.doe.gov. Requests to be added to our mailing list should include your full name, email address, and affiliation/organization.

The Trinity Supercomputer: The Advanced Simulation and Computing Program's First Advanced Technology System *by Mark C. Anderson and Bill Archer (Los Alamos National Laboratory)*

The Advanced Simulation and Computing (ASC) Program, and its predecessor the Accelerated Strategic Computing Initiative (ASCI), have provided the simulation and computing resources necessary for stockpile stewardship since its inception in the late 1990s. ASC and ASCI have provided a number of leadership class supercomputers beginning with the Red machine through today's Sequoia platform. These machines have satisfied both capability (largest scale machines for the most challenging problems such as Q, Purple, and Cielo) and capacity (moderate scale, commodity technology machines for production work such as Luna and Zin) computing needs, and explored advanced computing architectures (Roadrunner, BlueGene/L, and Sequoia). The present ASC platform strategy consists of two platform lines: Commodity Technology Systems for capacity-class production simulations and Advanced Technology Systems (ATSs) for the most challenging, large-scale, capability-class simulations and to explore advanced architectures.

The Trinity platform is the first in the ATS line. Cray Inc. won the contract to design, integrate, and build the system for the New Mexico Alliance for Computing at Extreme Scale (ACES), which is a joint effort between Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL). The Trinity architecture is based on Cray's XC40 supercomputer architecture using Intel processors. Trinity is being delivered in two phases governed by the availability of Intel parts. The first phase contains Intel's Haswell (XEON E5-2698v3) processors, and is shown in Figure 1. The second phase contains the first production Intel Knights Landing (KNL) Xeon Phi™ processors. Trinity introduces a number of other technological firsts, including Multi-Channel Dynamic Random Access memory (MCDRAM), burst buffer, and advanced power management. MCDRAM is high-speed stacked memory that is faster than previous memory architectures. Burst buffers enables application access to disk storage with minimal slow down. Advanced power management effectively slows down processors depending on application demand to minimize power consumption.

Figure 1. The Haswell partition of the Trinity system installed at Los Alamos National Laboratory.

Table 1. Trinity System Architecture.

Trinity System			
	Overall	**Haswell Partition**	**KNL Partition**
Memory Capacity	~2 PB	1.15 PB	~1 PB
Memory BW	>6PB/sec	>1 PB/s	>1PB/s +>4PB/s
Peak FLOPS (est.)	>40 PF	11 PF	>30 PF
Number of Nodes	19,000+	9,432	>9,900
Number of Cores	>760,000	301,952	>570,000
Parallel File System Capacity (Usable)	78 PB (1.45 TB/s sustained)		
Burst Buffer Capacity (Usable)	3.7 PB (3.3 TB/s sustained		

Table 2. Trinity Node Architecture.

Compute Nodes	
Intel "Haswell" Xeon E5-2698v3	Intel Xeon Phi™ "Knights Landing"
9436 nodes	>9,500
Dual socket, 16 cores/socket, >0.5 Tflops/Haswell	1 socket, 60+ cores, >3 Tflops/KNL
128 GB DDR4	96 GB DDR4 + 16GB HBM

The overall Trinity architecture is detailed in Table 1. Table 2 provides the details of the nodal architecture. All of the technologies will be provided as part of a fully integrated system consisting of compute nodes, memory, high speed interconnect, and parallel file systems.

Delivery of the Haswell partition began in mid-2015. This phase of Trinity is scheduled for general user availability in July 2016. The KNL partition will be available for users in FY 2017. Trinity

Figure 2. Water cooling infrastructure for the next several generations of supercomputing.

will have at least eight times greater applications performance than Cielo, the current NNSA supercomputer sited at LANL. Given the pioneering nature of the system, it is named after the first nuclear weapon test, the Trinity event in July 1945.

The Trinity technical specifications and the request for proposals were developed as part of a joint effort between ACES and Lawrence Berkeley Laboratory, which is under the DOE Office of Science. Trinity will be used by LANL, Lawrence Livermore National Laboratory, and SNL, and will be housed at LANL's Metropolis computing center. Trinity was sized to run many of the largest and most demanding simulations of stockpile stewardship, helping assure the safety, security, and effectiveness of the U.S. nuclear deterrent without the use of underground testing.

"Trinity will serve the needs of the men and women who play an important role in solving extremely complex calculations that underpin the success of our nation's stockpile stewardship program," said Bob Meisner, former ASC Program Director. "A very powerful mission-computing system, Trinity begins the transition to new exascale architectures. How well we make that transition has huge impacts on the future of stockpile stewardship."

An often-overlooked aspect of the ASC computing capability is the vast infrastructure necessary to support it. In addition to the floor space and the building housing these machines is a complex infrastructure to provide the electrical power, thermal cooling, network connectivity, and associated medium- and long-term storage. For example, Trinity will draw an average of between 9 and 10 MW of power and requires enormous thermal cooling resources. The system will be the first LANL system to use water-cooling. Some of the equipment for water-cooling is shown in Figure 2.

Application performance and increases in geometric and physics fidelities are key drivers for Trinity. As part of the procurement, a Center of Excellence has been established to ensure application success. A collaboration of the ASC tri-labs, Cray, and Intel, the Center is essential for ensuring applications successfully perform on the Trinity architecture.

A process similar to that used on previous machines such as Cielo and Sequoia will govern usage of the Trinity supercomputing resource. That process is broken into six-month chunks and referred to as an Advanced Technology Computing Campaign (ATCC). The ATCC includes 180 days for general usage, plus some time for use at program discretion. Each weapons laboratory is allocated a total of 60 days during an ATCC, that is, each laboratory is allocated one-third of the resource. The laboratories run independent proposal-based selection processes for each campaign. Winning proposals are chosen based on programmatic priorities.

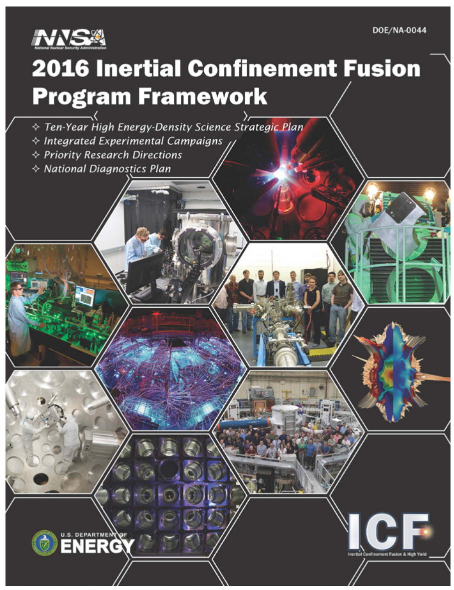
ATS systems such as Trinity are intended to primarily accommodate the largest, most complex simulation problems necessary for stockpile stewardship. Trinity introduces several new technologies, including the KNL processors, MCDRAM, burst buffers, and advanced power management. The Trinity homogeneous many-core architecture, along with the new technologies represent significant steps on the path to exascale computing. •

Inertial Confinement Fusion Program Framework

The Inertial Confinement Fusion (ICF) Program's mission is to provide the most extreme temperature and pressure conditions spanning states of condensed matter to very hot and dense plasmas for the National Nuclear Security Administration's Stockpile Stewardship Program. This mission requires some of the most advanced experimental and computational capabilities in the world. Most important to the success of this mission are the highly trained scientists, engineers, and technicians that dedicate their lives to this mission, and are a key part of the intellectual capital that underpins the nuclear weapons stockpile. The ICF Program has developed a goal that, by 2020, we will determine the efficacy of reaching ignition on the National Ignition Facility (NIF) and of achieving credible physics scaling to multi-megajoule fusion yields for each of the three major ICF approaches, i.e., Laser Indirect Drive, Laser Direct Drive, and Magnetic Direct Drive. The program of work to achieve this goal is described in the integrated ICF Program Framework. This program document was principally motivated by the following four needs:

- The post-National Ignition Campaign ICF Program needed a clear five-year goal to understand if ignition may be achieved on the NIF (and if not, why not); and, although Z and OMEGA were not built to achieve ignition, these facilities are home to two of the three major approaches to ignition. Therefore, a science program was needed that could explore physics scaling arguments to fusion yield for the approaches and as a means to compare the approaches.
- The distinction between focused physics experiments and integrated performance experiments needed to be clearly delineated to enable scientific debate regarding the balance between them, given the state of understanding and fixed facility resources.
- The visibility into program activities needed to be increased to enhance scientific peer review within and among the laboratories, and to subject those activities to healthy criticism from institutions outside of the laboratories in an effort to strengthen the scientific foundation of the ICF Program and the basis for program decision making.
- Clear milestones, metrics, and deliverables needed to be established that may be achieved for transparency during the intervening years and to track progress.

"...by 2020, we will determine the efficacy of NIF for achieving ignition and the credible physics scaling to multi-megajoule fusion yields for each of the major ICF approaches."



http://www.nnsa.energy.gov/icf

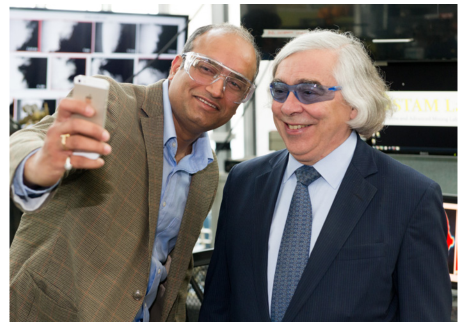
This ICF Program Framework was developed over 20 months using input from hundreds of technical staff, program managers, and academic partners from more than a dozen institutions with direct interest in the ICF and related high energy density (HED) aspects of the National Nuclear Security Administration (NNSA) Stockpile Stewardship Program (SSP) It is structured into four major elements:

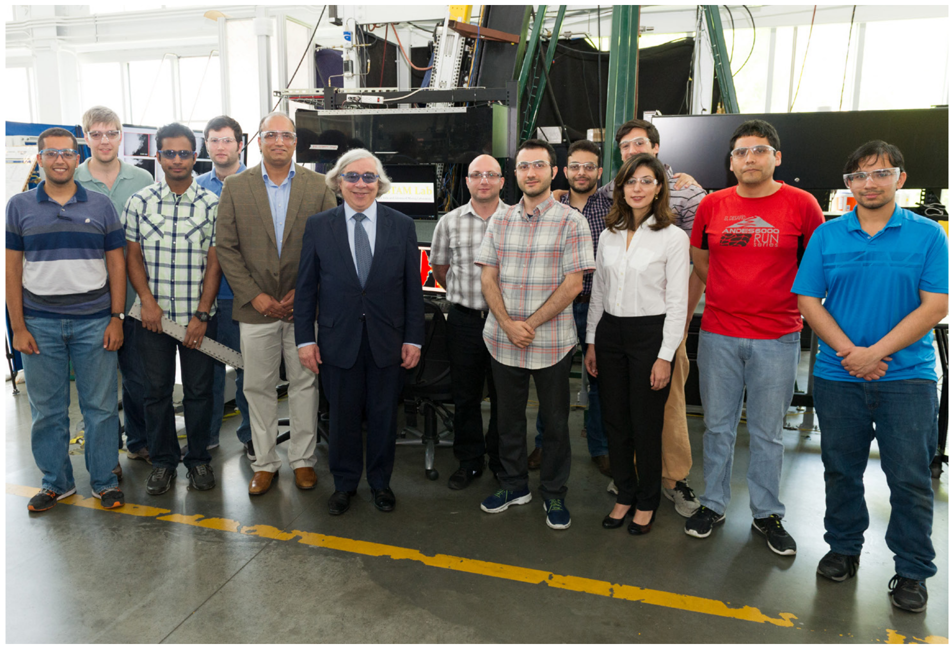
- *The Ten-Year High Energy Density Science Strategic Plan.* This fundamental requirements document outlines the three-, five-, and 10-year deliverables for the HED weapons science portfolio, including the major ICF Program deliverables. Requirements are derived from the annual 25-year Stockpile Stewardship and Management Plan (SSMP) and from the emerging stockpile responsiveness requirements in the National Defense Authorization Act for Fiscal Year 2016.
- *The Integrated Experimental Campaigns.* This element involves an approach-specific set of implosion experiments with the primary objective to baseline performance, demonstrate scaling, test new design features or capabilities, and/or test new target concepts. Performance metrics are highly integrated quantities such as total neutron yield, and milestones are generally spread over multiple years.
- *The Priority Research Directions.* This element involves fundamental and focused research to develop and improve models, codes, and simulations (i.e., predictive capabilities), and to set detailed, physics-based milestones for experimental research and computational efforts. The PRDs are designed to enable cross-cutting coordination and basic research opportunities for external collaborations.
- *The National Diagnostics Plan.* This resource-loaded plan describes a suite of advanced diagnostics to be delivered through 2021 that are cost-shared among LLNL, LANL, SNL, LLE, and NRL. The plan includes contributions from 17 institutions.

Visit www.nnsa.energy.gov/icf for more information.

Secretary of Energy Ernest Moniz Visits Stewardship Science Academic Alliances Partner

Department of Energy (DOE) Secretary Ernest Moniz delivered the keynote address for the second installment of the Quadrennial Energy Review, held at the Georgia Institute of Technology on May 24, 2016. While at the campus, Secretary Moniz also toured the NNSA-supported Shock Tube and Advanced Mixing (STAM) Laboratory and met with a number of postdoctoral researchers and graduate students working in the laboratory and with the laboratory director, Professor Devesh Ranjan. The laboratory features the gas tunnel experiment supported by the Stewardship Science Academic Alliances program which studies Rayleigh-Taylor (RT) instability, a fluid instability that occurs at the interface between two fluids of different densities under a gravitational force at extreme conditions. As a key hydrodynamic process during the inertial confinement fusion (ICF) implosion, STAM Laboratory studies of RT mixing directly impact fundamental understanding of the flow physics, and validation of engineering models for ICF target design and energy deposition. Other STAM Laboratory facilities toured were the inclined shock tube which studies the shock-driven Richtmyer-Meshkov instability and several experimental setups researching supercritical carbon dioxide Brayton cycle components for next generation nuclear reactors. Secretary of Energy Moniz was pleased to hear about the strong ties between the researchers at the STAM Laboratory and DOE/NNSA National Laboratories (Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Sandia National Laboratories). Secretary Moniz encouraged Professor Ranjan to continue sending students to these laboratories in the summer as they can be future hires for these labs. Secretary Moniz also congratulated Dr. Ranjan for receiving the prestigious 2016 DOE Office of Science Early Career Research Program award. •





DOE Secretary Moniz toured the Shock Tube and Advanced Mixing Laboratory at the Georgia Institute of Technology and spent time with Professor Devesh Ranjan and the postdoctoral researchers and graduate students working there. Top: Professor Ranjan is photographed taking a "selfie" with Secretary Moniz. Bottom, from left to right: Mark Mikhaeil, Stephen Johnston, Sandeep Pidaparti, John Carter, Professor Ranjan, Secretary of Energy Moniz, Vladimer Tsiklashvili, Mohamad Mohaghar, Miad Karimi, Benjamin Musci, Dorrin Jarrahbashi, Diego Vaca, and Prasoon Suchandra.

Associate Director of SSAA Center of Excellence Instrumental in Discovery of New Element

Stewardship Science Academic Alliances (SSAA) Center of Excellence Associate Director Robert Grzywacz is part of the team associated with the discovery of the new element Tennessine. Grzywacz, who is Director of the University of Tennessee (UT)-Oak Ridge National Laboratory Joint Institute for Nuclear Physics and Applications and a professor at UT, developed a process that measures the decay of nuclear materials down to a millionth of a second. That process was vital in proving the existence of this new superheavy element.

On the periodic table, Tennessine (element 117) will join Group 17, commonly known as the halogens. Other members of that group are fluorine, chlorine, bromine, iodine, and astatine.

Grzywacz worked with UT postdoctoral researchers David Miller and Nathan Brewer to refine the testing device so that it could be used to accurately detect elements. •