Stockpile Stewardship Quarterly

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

Whether you have the image of an old-fashioned alarm clock with wings moving across the sky, as was used in numerous cartoons to indicate time 'flying,' or the image of a rapid progression of a solar eclipse captured with time-lapse photography, perhaps you share with me the sense that this quarter of the year has passed very quickly indeed. It seems not that long ago that I penned (or rather keystroked) my first introductory column for the *Stockpile Stewardship Quarterly.* I very much appreciated the feedback that I received from that initial effort of communicating with you.

I hope that your review of this issue will spur even more discussion among yourselves and with others. We, of course, appreciate direct feedback from you and also knowing that you thought enough about an issue or an article to send it on to others. If you think someone might want to be a regular recipient, please send us his or her contact information.

This issue brings into focus our core mission—keeping the U.S. nuclear arsenal safe, secure and reliable while maintaining the capabilities to do so for the indefinite future. Confidence in the effectiveness of these weapons and our infrastructure has helped make the United States—and the world—a safer place for nearly three quarters of a century.

A key to deterrence and to determining that our weapons are indeed safe, secure, and reliable is the Annual Assessment process, which you can read about starting on page 2. This issue examines not only whether the weapons are okay in 'storage' but also what happens if there are other factors to be considered. On page 4, there is an article on a hot topic, i.e., What happens to a component in an 'abnormal thermal environment'? (Did someone yell 'fire'?) One of the foundations upon which such assessments are based is the surveillance activities associated with each weapon type. Not only does this surveillance help determine the reliability of the weapon, but it can also help determine whether components from retired, dismantled weapons can be reused. The article addressing the contribution of surveillance to reuse decisions associated with the B61 bomb begins at page 5. Surveillance is one aspect of assessment and testing of materials, components and systems, and the facilities to perform tests is another. The articles beginning on pages 7, 9 and 11 delve a bit into this area. And now for the frosting on the cake—see page 8 for information on the Rand Corporation's Stanton Nuclear Security Fellowship opportunity!

Evolving Organization, Evolving Name: Office of Research, Development, Test, and Evaluation

As our organization continues to evolve, we are making improvements, enhancements, and changes. We've dropped the Capabilities from our name only. We will continue to demonstrate our many capabilities as we carry out our mission.

Inside this Issue

Comments

The *Stockpile Stewardship Quarterly* is produced by the NNSA Office of Research, Development, Test, and Evaluation. Questions or comments regarding this publication should be directed to Terri.Stone@nnsa.doe.gov.

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The Annual Nuclear Weapons Assessment Process by Dana Hunter (National Nuclear Security Administration)

Historical Perspective

In 1992, President George H. W. Bush approved a unilateral moratorium on underground nuclear testing. Prior to this moratorium, underground nuclear testing was essential in certifying the safety and performance of nuclear weapons. A year later, the Department of Energy's (DOE's) Office of Defense Programs proposed and implemented a Science Based Stockpile Stewardship Program, a robust program of scientific inquiry used to sustain and assess the nuclear weapons stockpile without the use of underground nuclear testing. The Stockpile Stewardship Program was accepted by both the U.S. Congress and the President and implemented by DOE.

In 1995, President William J. Clinton established an annual stockpile assessment and reporting requirement to ensure that the nation's nuclear weapon stockpile remains safe, secure and reliable without underground nuclear testing. Subsequently, Congress enacted into law (Section 3141 of the National Defense Authorization Act (NDAA) for Fiscal Year 2003) a requirement for annual stockpile assessments. This law was later amended by the FY 2010 NDAA and codified in 50 United States Code Section 2525.

The current Annual Assessment process requires the three national security laboratory directors (Los Alamos National Laboratory [LANL], Lawrence Livermore National Laboratory [LLNL], and Sandia National Laboratories [SNL]) and the Commander of the United States Strategic Command (USSTRATCOM) to annually assess the safety, reliability, performance, and military effectiveness of the active U.S. nuclear stockpile. The active U.S. nuclear weapons stockpile consists of seven weapon types seen below in Figure 1. Both NNSA and the Department of Defense (DoD) have responsibilities for nuclear weapons. NNSA is responsible for nuclear warheads and for nuclear bombs (including components such as parachutes). The DoD is responsible for the delivery systems.

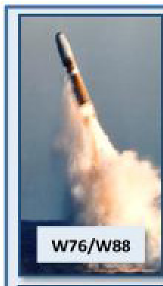
> ***"…I am today directing the establishment of a new annual reporting and certification requirement that will ensure that our nuclear weapons remain safe and reliable under a comprehensive test ban."***
>
> President William J. Clinton
> August 11, 1995

Additionally, the Secretaries of Energy and Defense are required to jointly submit a report to the President on the status of the U.S. nuclear stockpile and state whether an underground nuclear test is required to resolve anomalies.

Annual Assessment Reporting Process

The annual assessment reporting process (see Figure 2) takes approximately 14 months to complete. This process uses scientific and engineering assessments and stockpile surveillance to produce a series of high-level reports that make conclusions and judgments about the safety, performance, reliability, and military effectiveness of the weapons. These reports also act as a basis for determining whether there is a technical issue that requires resolution through underground nuclear testing. In total, the following seven types of reports are produced during a single annual assessment cycle:

Weapons Laboratory Annual Assessment Reports (AARs): AARs are prepared for each weapon type by the technical staff of the weapons laboratory responsible for the nuclear explosive package (LANL or LLNL) and their engineering counterpart at SNL. Each AAR contains technical information from the current cycle concerning the potential need for underground nuclear testing and whether each warhead type meets its required military



Warhead	Laboratory
W76-0/1	LANL/SNL
W88	LANL/SNL
W78	LANL/SNL
W87	LLNL/SNL
W80-1	LLNL/SNL

Bomb	Laboratory
B61-3/4/10	LANL/SNL
B61-7/11	LANL/SNL
B83	LLNL/SNL

Figure 1. Active U.S. Nuclear Weapons Stockpile and Supporting National Security Laboratories.

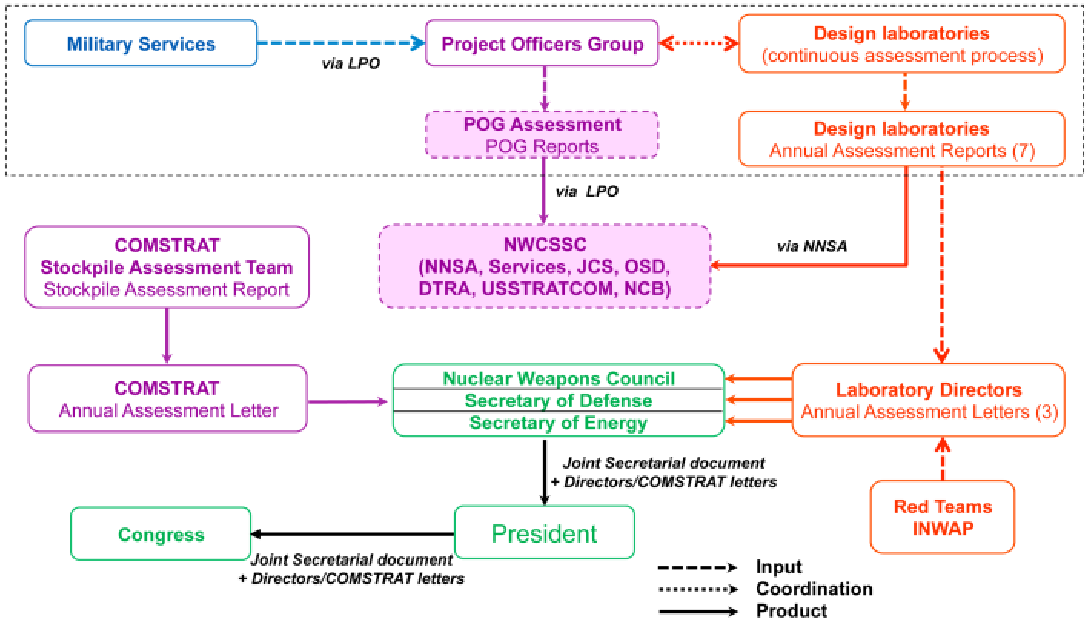


Figure 2. Annual Assessment Flow Chart.

characteristics, such as warhead yield, throughout its stockpile-to-target sequence.

Weapons Laboratory Red Team Reports: "Red Teams" (independent laboratory review teams, also known as Independent Weapon Assessment Teams) issue a report for the respective laboratory director's use that assesses the technical information contained in the laboratory's AARs and the potential need for underground nuclear testing.

Weapons Laboratory Director Annual Assessment Letters: Each laboratory director submits an independent assessment letter on the safety, performance, and reliability of the nuclear stockpile to the Nuclear Weapons Council (NWC) and the Secretaries of Energy and Defense by December 1 of each year.

Strategic Advisory Group Stockpile Assessment Team (SAGSAT) Report: The SAGSAT holds an annual conference that brings together all of the stakeholders involved in the annual assessment process. The SAGSAT prepares a report for the Commander of the USSTRATCOM that provides the technical underpinning for the Commander's assessment of the stockpile. This report expresses the SAGSAT's confidence that each warhead type will perform as designed and makes recommendations for USSTRATCOM action.

Commander of USSTRATCOM Report: The Commander of USSTRATCOM submits an independent assessment report on the safety, performance, reliability and military effectiveness of the nuclear stockpile to the NWC and the Secretaries of Energy and Defense by December 1 of each year.

Project Officers Group (POG) Reports: Each POG issues a technical annual assessment report to the NWC on the warhead type for which it is responsible. These reports are based largely on the weapon laboratories' AARs and also include additional information on military-service specific issues, including the results of surveillance testing performed by DoD and its contractors, operational issues such as deployment numbers, and logistical issues such as the status of work on weapons being done at military installations.

Report on Stockpile Assessments: The NWC prepares a report package, known as the "Report on Stockpile Assessments," on behalf of the Secretaries of Energy and Defense. This package includes an executive summary, a joint letter signed by both Secretaries, and unaltered copies of the weapons laboratory director reports and the Commander of USSTRATCOM report. This package is conveyed to the President by March 1 and forwarded to the Congress by March 15 of each year.

The directors of the national security laboratories base their Annual Assessment Letters on the individual weapon briefings and reports published by their respective laboratories. These reports document assessments derived from ongoing work associated with NNSA's Stockpile Stewardship Program as well as from feedback received from the Red Teams and Independent Weapon Assessment Teams. The Commander of USSTRATCOM bases his Annual Assessment Letter on the Stockpile Assessment Team Stockpile Assessment Report.

To close out the assessment process, the NWC coordinates a joint letter from the Secretaries of Energy and Defense to the President of the United States which summarizes the overall safety, security, and reliability of the nuclear stockpile. This letter also identifies if there is a need for underground nuclear testing to resolve any issues and is also forwarded by the Nuclear Security Council to the U.S. Congress.

Stronglink High-Voltage Bypass in Abnormal Thermal Environments by Thomas Blanchat, Scott Slezak, and Pat Brady (Sandia National Laboratories)

Directed by the Weapons Systems Engineering Assessment Technology Office, researchers at Sandia National Laboratories are performing tests that are providing new insights into the response of stronglinks (SLs) in abnormal thermal environments (fires) resulting from aircraft carriage or road transportation accidents.

SLs are robust hi-fidelity safety switches inside weapon system firing sets that are intended to provide electrical isolation during abnormal environments (i.e., accidents) consistent with SL/weaklink system safety requirements. SL/weaklink system safety requirements are based on the predetermined function/failure response of key components during representative time/temperature scenarios.

Historic SL high voltage hold-off qualification testing was based on placing bare components in ovens and verifying that the devices had very small leakage currents between input, case, and output terminals when heated to relatively high temperatures. Leakage current in these tests was due to contaminant gases and pryolysis products from decomposing organics (from coils, wires, and potting) producing benzene, toluene, acetone, heptene, heptane, octane, and many other complex compounds coating the inside surfaces of the SL. While these tests have shown that SLs were able to meet the required minimum isolation requirements, there was little margin.[1]

The qualification testing was not truly representative of what may occur in an accident. The SL is likely to perform worse than indicated by historic qualification testing. In a real accident environment, the atmosphere within the sealed firing set and the external SL surfaces will be significantly fouled with organic decomposition products (component potting, wires and connectors, phenolic case material, etc.) by the time the SL reaches its maximum required isolation temperature. This could potentially lead to reduced high voltage isolation performance as conductive soot and other materials coat the outside of the switch, shorting around the switch's internal open contacts. This is referred to as a high voltage bypass condition and is relevant to weapon assured safety.

A discovery experiment was performed in FY 2011 that tested SL hardware inside a modified firing set housing containing phenolic and Sylgard184/GMB organic materials. The test was based on a prototypic Stockpile-to-Target Sequence (STS) fire accident scenario. The heat source was a custom 6-panel radiant heater assembly automatically controlled to provide the expected heating rate to the firing set from a hydrocarbon fuel fire that fully engulfs the weapon. Increased SL leakage current was measured, likely due to electrically-conductive combustion gases and products adjacent to the SL.

Following the discovery experiment, a Phenomena Identification Ranking Table was formulated and a literature search was performed to examine the conditions under which electrical breakdown will occur and identify the specific mechanisms producing breakdown. Based on that work, a set of experiments described below was defined to provide thermal decomposition data for firing set housing and potting materials.

One important finding from the literature review was that smoke-induced leakage currents are highest during a fire when smoke is in the air, and these currents decrease as smoke settles. Smoke is attracted to static electric fields (direct current) and will deposit on high potential surfaces, building bridges between potential surfaces and making a direct connection that shorts the surfaces together. Higher voltages will make more rugged bridges because the higher voltages produce higher forces to hold the soot together. The conductivity that results from a certain amount of smoke in the air is not modeled simply by the smoke density, but is also dependent on the geometry of the surfaces, the electrical potential, and air currents that can break the soot bridges.

The historical data obtained in the early 1980s showed a correlation between electrical conductivity and thermal decomposition of condensed phase (solid) firing set phenolic and potting materials. This current study focuses on obtaining experimental data from mechanisms that may precipitate electrical bypass from non-condensed phase

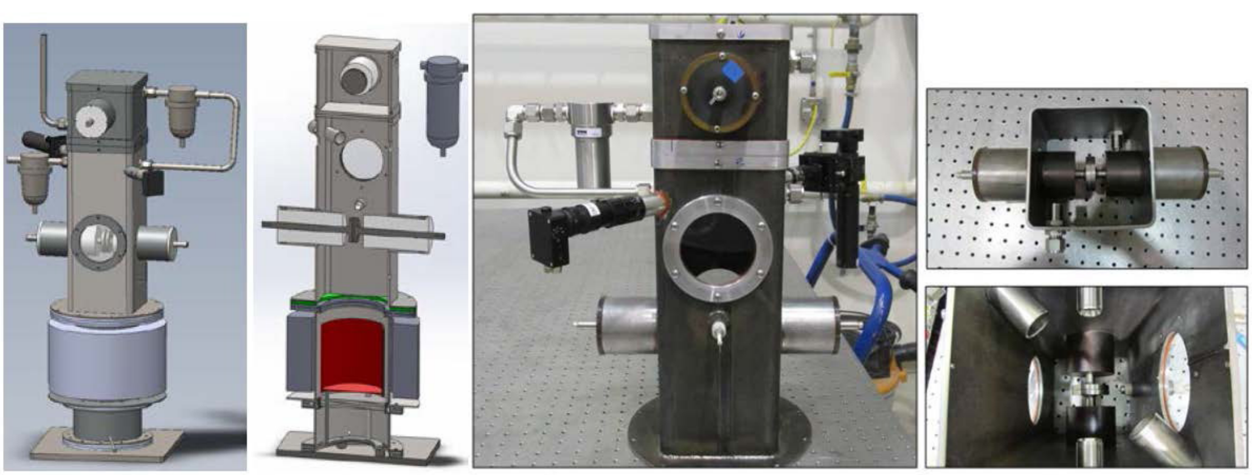


Figure 1. Material Decomposition Apparatus.

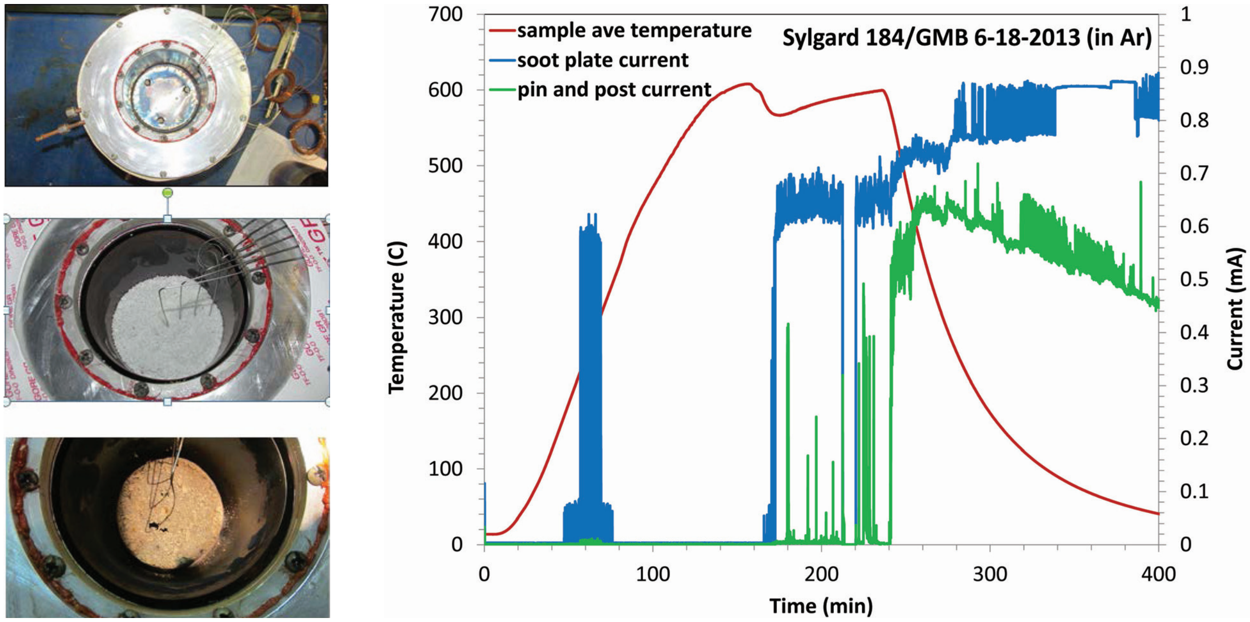


Figure 2. Sylgard184/GMB Potting Material Test Results.

decomposition products (smoke, soot, and gas), with the future goal of developing decomposition chemistry, soot and gas production, and material transport and deposition models to support electrical breakdown predictions.

Figure 1 shows the material decomposition test apparatus. It is designed to measure sample mass loss, smoke optical properties, gas species, and electrical conductivity of the smoke, soot, and gaseous products with STS accident voltages for SL-like physical configurations.

To date, four materials commonly found in SLs have been tested; polymethylene diisocyanate, Sylgard184/GMB, MXB-71 phenolic, and ethylene propylene diene monomer (EPDM) carbon-black rubber (similar to O-ring material). Electrical conductivity of the smoke-filled gases was observed in preliminary tests of all materials except for the EPDM rubber. This was evident from 1,500 volts of direct current shorting and arcing across 2-mm gapped soot plates and also a pin and post arrangement representing an electrical connector (located in the lower measurement chamber). The decomposing Sylgard in an argon environment produced the strongest arc effects. Electrical conductivity of the filtered gases was also seen in some tests using an air gap capacitor, located in the upper chamber. Figure 2 shows decomposing Sylgard material test results. Future work will involve a heated measurement chamber to provide more prototypic boundary conditions at the electrical measurement probes. This is necessary to prevent condensation of the pryolysis products.

This new research will enhance our understanding of SLs that have such a critical role in nuclear weapon safety.

Reference

[1]*Combined Voltage and Thermal Environments Test Results for the MC2969 and MC2935 Stronglink Switches*, M.A. Dinallo and P. Holmes, Electromagnetic Test Report EMTR-002, Sandia National Laboratories, August 1997.

Enhanced Surveillance Fitness for Reuse Evaluation for the B61 Life Extension Program

by Regan Stinnett (Sandia National Laboratories)

As part of the process for reuse, an assessment is made whether to reuse, rebuild, or redesign a weapon component. Reuse means the assessment has shown that the component in question is fit for the lifetime of the future weapon. In discussing reuse for the B61 Life Extension Program (LEP), we will provide an approach, process, and lessons learned.

In January 2012, several B61 components were identified by the B61 legacy and LEP groups as candidates for fitness for reuse evaluations to be conducted by the Electro-Mechanical, Thermal Battery, and Energetics Components and Materials Evaluation (CME) Working Groups at Sandia National Laboratories (SNL). The SNL Surveillance Governing Board asked the Enhanced Surveillance (ES)/C8 Sub-Program to use its non-nuclear component and materials expertise to help evaluate the fitness for reuse of B61 components as candidates for reuse in the B61-12. This work was to be conducted as part of ES/C8 Sub-Program's role in providing understanding and assessment of aging issues in the stockpile.

Science-Based Approach to Fitness for Reuse Evaluations

The fitness for reuse evaluations began with clear direction from the B61 legacy and LEP groups as to which components were to be evaluated and the requirements that must be met for reuse. Because our CME Working Groups are made up of members with in-depth expertise

Figure 1. B61 Weapon System.

in component engineering, surveillance, materials, systems, and assessment, this collaboration resulted in a high level of experience and broad technical expertise being applied to the question of how best to design a science-based program to identify and answer crucial fitness for reuse questions.

The working groups deliberated on requirements to be met, the best, science-based approach to accomplish each task, and the right combination of expertise that needed to be engaged to be successful. For all components, the working groups created technical teams with broad expertise to help determine the right science-based questions and identify the most effective approaches to answering questions regarding remaining life of the components.

Technical Activities

For each component to be evaluated, the three CME Working Groups assigned an accountable component engineer together with a team of engineers and materials scientists to plan, execute, analyze, and interpret the combination of multiple functional and materials tests needed to determine fitness for reuse. All teams determined that detailed materials analysis of the components was essential to enable a science-based understanding of component state of health and predictions of remaining life.

For one especially complex component, the Electro-Mechanical Working Group enlisted the expertise of 15 materials scientists to help identify potential aging- and reliability-related issues to be addressed as part of evaluating fitness for reuse. This team identified potential ways for materials aging to result in component performance degradation, including aging of electrical contacts, corrosion, fatigue, hermeticity, and age-related degradation of seals, coatings, and lubricants. One example of materials aging in o-ring seals is shown in Figure 2.

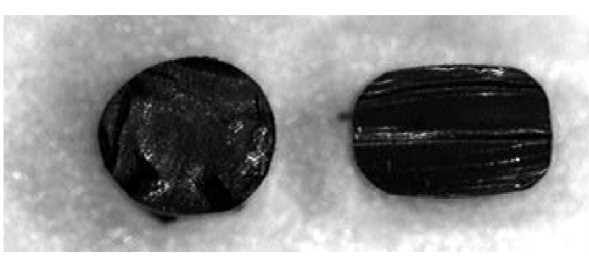


Figure 2. O-ring Compression Set.

The results, interpretations, and models developed were essential in providing aging information and science-based predictive lifetime estimates that were incorporated into the evaluation reports together with results from functionality, margin, and lifetime testing done at the component level.

The results of these investigations were a primary component of the information provided to the B61 LEP group for fitness for reuse decisions.

Real World Issues: Communications, Changing Priorities, Hardware Issues, and Schedule Risk

After beginning the fitness for reuse work, the Working Groups and the B61 LEP and legacy group representatives attended quarterly status meetings. By August 2012, the B61 groups had decided that some of the previously identified components would not be reused but that it was still important to evaluate the fitness of the existing components as a validation of the existing design.

It soon became clear that obtaining hardware for testing was a serious problem and that the NNSA owners of the B61 hardware should have been included in planning meetings to communicate the importance of these tests and the urgency of the need for hardware. Also, the process to obtain the hardware from different sites required several months to complete, much longer than planned. Hardware delays totaled at least 6 months, resulting in serious time pressure on the working group's evaluation activities.

Summary of Fitness for Reuse Results

The results of the ES-sponsored fitness for reuse work were presented to the B61 LEP and legacy groups in April and May 2013. In addition, due to the hardware delays, there were several areas in which follow-up work was required.

Results to date from the ES-sponsored fitness for reuse work are as follows:

- Some components were selected for reuse based, in part, on our input.
- For some components potential fitness for reuse issues were identified, making reuse unlikely.
- Decisions were made early to build some new components rather than reusing old ones. In several of these cases, the fitness for reuse evaluations have provided positive results to support reuse of existing designs and materials.

The process was educational and resulted in lessons learned. Among the key lessons learned are the following:

1. Direct involvement of LEP and legacy system customers with CME working groups was critical to ensuring effectiveness.
2. Hardware availability is a dominant driver of schedule. It is important to ensure that all stakeholders are on-board in planning and act on hardware delays early.
3. The involvement of science-based materials experts working together with component engineers in planning the required evaluation activities and in providing and analyzing data is crucial to effectiveness of the fitness for reuse evaluation process.
4. Fitness for reuse evaluations should be scheduled to allow a period for follow-up on issues resulting from the evaluation before the final date for decisions.

Facilities Used by the Division of Nuclear Experiments by Paul F. Ross (National Nuclear Security Administration)

Within the Office of Research, Development, Test, and Evaluation, the Office of Test and Evaluation's Division of Nuclear Experiments supports the Stockpile Stewardship Program by conducting experiments with special nuclear and surrogate materials. This Division oversees planning, budgeting, and execution for a range of projects with a focus on experiments and associated operations at the Nevada National Security Site (NNSS), the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility, and other firing sites. It manages the plutonium experiments and hydrodynamic experiments components of the Dynamic Materials Properties, Advanced Certification, and Primary Assessment subcampaigns, along with the portfolio of plutonium, hydrodynamic, and subcritical experiments formerly part of Directed Stockpile Work, Research and Development (DSW R&D).

The Division of Nuclear Experiments provides the key plutonium experimental data and integrated surrogate hydrodynamic experimental data to support stockpile stewardship and national security needs, without nuclear explosive testing. These experiments also provide valuable learning opportunities for the new designers of the modern nuclear stockpile. To carry out its mission, the Division utilizes several facilities throughout the NNSA Nuclear Weapons Complex, including the U1a Complex and the Joint Actinide Shock Physics Experiment Research (JASPER) facility at NNSS, DARHT at Los Alamos National Laboratory (LANL), and the Contained Firing Facility (CFF) at Site 300 at Lawrence Livermore National Laboratory (LLNL).

These four facilities provide a range of environments in which to study material behavior and associated physics phenomena. U1a is an underground laboratory designed to execute subcritical experiments. These integrated experiments support the assessment of current and modernized weapons. JASPER is a high power gas gun used to study material properties at high pressures, temperatures and strain rates which emulate nuclear weapon conditions. JASPER experiments complement U1a experiments; DARHT and CFF complement both U1a and JASPER. DARHT and CFF are described in the companion article about Hydrodynamic Testing at LANL and LLNL on page 9. U1a and JASPER are discussed in the following paragraphs.

JASPER Facility

The JASPER facility is a Hazard Category 3 non-reactor nuclear facility that conducts dynamic properties experiments on materials in extreme states of shock pressures, temperatures, and strain rates similar to those

Figure 1. The JASPER two-stage gas gun is comprised of a breach, barrel, and containment chamber system (including fast-closing valves). Projectile velocities from 1 km/sec to ~8 km/sec are used to generate Mbar-level shocks.

Figure 2. The removable JASPER Primary Target Chamber (PTC) (blue) is located inside the Secondary Containment Chamber (white). The high-velocity projectile enters through the front of both chambers and shocks a Pu sample inside the PTC.

Figure 3. The JASPER Secondary Containment Chamber provides the infrastructure for supporting samples and experiments inside the PTC, including diagnostic feedthroughs, vacuum ports, x-ray ports, and trigger and timing systems access.

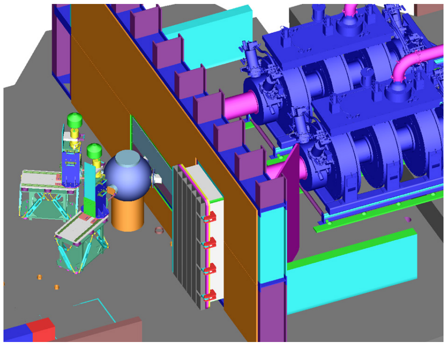


Figure 4. "Zero Room" illustration depicting (right to left) Cygnus machines (blue), containment barrier wall (brown), spherical confinement chamber, and radiographic cameras.

Figure 5. Three-foot-diameter subcritical experiment spherical confinement chamber showing radiographic ports (side) and diagnostic feedthrough cover (top).

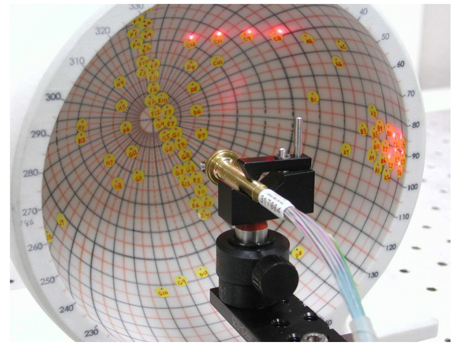


Figure 6. Metrology alignment of advanced optical probe head showing lasers from multiplexed PDV system sampling selected spots on the inner surface of a shell to be imploded.

in a nuclear weapon when it is exploded. JASPER is a two-stage gas gun that utilizes gunpowder and high pressure gas to launch a projectile into a test sample (see Figures 1-3). Since 2001, JASPER successfully has produced data of unparalleled precision over the course of many experiments on both surrogate materials and plutonium (Pu). These experiments are an essential part of the shock physics database that provides high-precision, multi-phase Pu equation of state data at high pressure necessary to assist assessment of the current nuclear stockpile and certification of weapons undergoing modernization of the nuclear explosive package. JASPER experiments have the ability to characterize and compare how weapon and other national security materials of various compositions, manufacturing processes, surface preparation, ages, and phases behave under weapon-like conditions. Modern JASPER diagnostics include inflight x-ray radiography, photon Doppler velocimetry (PDV), and shorting pins to characterize shock and ramp loaded compressions, and radiometry to infer dynamic temperatures. Both types of measurements can be performed along complex loading paths that can be generated by advanced flyers.

U1a Complex

The U1a Complex is an underground experimental laboratory housed in a series of horizontal tunnels and alcoves 960 feet below the desert at the NNSS (see Figures 4-6). The close proximity of U1a with the Device Assembly Facility (DAF) enables the efficient and flexible assembly of components—some involving special nuclear materials—for experiments that study the early-time hydrodynamic behavior of weapon materials in the nuclear explosive package. These materials, both surrogates and Pu, can be driven to the extreme states (pressures and velocities) they would experience in a nuclear weapon by using high explosives (HE) arranged in a variety of geometries, including scaled weapon shapes. Experiments enhancing the ability to assess current weapons and to certify modernized weapons include those focused on answering specific material or structural issues and those providing integral performance of primary-like systems. U1a is the only facility in the U.S. national security enterprise authorized to conduct experiments with both HE and weapons-relevant quantities of Pu and to entomb these materials in the underground environment with no further processing. Major diagnostic capabilities for subcritical experiments on imploding systems include the following: high resolution flash radiographs provided by the Cygnus dual-axis x-ray machines; approximately 180 channels of PDV to capture the continuous motion of surfaces under shock conditions; continuous direct imaging of moving surfaces; and innovative optical and electrical techniques for characterizing HE shock characteristics.

Rand Corporation's Stanton Nuclear Security Fellowship Program

Rand Corporation will be accepting applications for the 2014-2015 Stanton Nuclear Security Fellowships through February 10, 2014. Candidates may be post-doctoral students, junior faculty members, and doctoral students with dissertation topics in the field of nuclear security. Prior experience will include disciplines such as nuclear policy, security, engineering, physics, and related fields.

The purpose of the Stanton Nuclear Security Fellows Program is to stimulate the development of the next generation of thought leaders on nuclear security-related topics by supporting interdisciplinary research that will advance policy-relevant understanding of the issues. Up to three fellowships will be awarded in 2014.

Fellows will be located at one of Rand Corporation's three U.S. locations (i.e., Santa Monica, California; Washington, DC; or Pittsburgh, Pennslyvania) for a full year, beginning in September. In addition to their independent research, fellows will support Rand client-sponsored research. Each fellow will receive a stipend: $50,000 (doctoral students), $75,000 (post-doctoral students), or $100,000 (junior faculty members). Visit http://www.rand.org/about/edu_op/fellowships/stanton-nuclear.html for more information.

Hydrodynamic Testing at Los Alamos National Laboratory and Lawrence Livermore National Laboratory by David Bowman (Los Alamos National Laboratory) and Bryan Balazs (Lawrence Livermore National Laboratory)

In the era of underground nuclear tests (UGTs), the performance of the nuclear phase of a nuclear weapon could be directly measured and assessed by performing tests on working devices at the Nevada Test Site. Since the establishment of NNSA's Stockpile Stewardship Program in the early 1990s, both the Los Alamos National Laboratory (LANL) and the Lawrence Livermore National Laboratory (LLNL) predict and assess weapons performance by using expert judgment guided by past UGT data, scientific judgment, and weapon codes and models. In the absence of underground nuclear tests our work focuses on hydrodynamic test data derived from driving mock nuclear weapons and emulating key aspects of weapons performance. In order to provide reliable and accurate simulations of weapon performance, weapon codes and models must be informed and validated by UGT data, modern scientific data on material and nuclear properties, and hydrodynamic test data.

Testing to Emulate Weapon Performance

Hydrodynamic testing utilizes high explosives (HE) to drive mock nuclear weapons so that the behavior of components driven by the explosives can be measured in a controlled manner, and the results compared against computer models of the experiment. In the early days of such testing, it was generally believed that metals being driven by explosives at very high velocities (10 to 20 times faster than a bullet) exhibited behavior that was very much like that of liquids; hence the term "hydro." Today's understanding of material behavior under explosive drive conditions is more nuanced; however, the term hydrotesting continues to be used to refer to these types of experiments.

At both LLNL and LANL, a hydrotest generally refers to a full-scale mock up of a nuclear weapons system in which non-fissile simulant materials are used in place of highly enriched uranium or plutonium. At both laboratories, several types of diagnostics are used to measure the hydrodynamic behavior of the experiment; the diagnostics range from x-ray radiography with high-speed cameras and high-resolution film packs to electro-mechanical position measurements to advanced velocity measurement techniques such as photon-Doppler velocimetry (PDV).

Explosive Facilities to Study Primaries

A component known as the "primary" is one of the most crucial components within a nuclear weapon, and it is the performance of the primary that is generally the main focus of a hydrotest. Scientists are interested in understanding and predicting the characteristics of the implosion of the mock "pit," which is the core of the primary. Depending on the type of data being sought, stockpile assessments by both LANL and LLNL will use either the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility at LANL, or at the Contained Firing Facility (CFF) at LLNL. Both DARHT and CFF have the ability to combine high-energy x-radiography with the other diagnostics mentioned above. These facilities are complementary, in that DARHT provides two lines of sight along with multiple images of the core of a primary implosion, while CFF provides wide field-of-view (FOV) radiography simultaneously with multiple types of advanced diagnostics and the ability to operate with larger HE loads. The capability of two complementary facilities also increases the hydrotesting throughput for both labs.

The DARHT facility consists of two Linear-Induction Accelerators (LIAs), whose mechanical axes are orthogonal to one another. Each LIA accelerates a beam of electrons to end-point energies of up to 20 MeV (for Axis I) and 17 MeV (for Axis II). The electrons strike a thin foil of heavy metal, typically Tantalum, and the slowing of the electrons by the heavy atoms in the foil produces x-rays. These types of x-rays are known as Bremsstrahlung radiation. Axis I of DARHT produces a 60-nsec-long pulse of x-rays, resulting in 550 rads of x-radiation, equivalent to 55,000 chest x-rays. Axis II produces a single 1.6-µsec-long pulse that can be broken up into four distinct shorter pulses, with the potential to deliver 1,000 rads of x-radiation to the test device. The intersection of Axis I and II allows LANL scientists to take up to five radiographs of the hydrotest from two different angles (see Figure 1).

CFF (see Figure 2) is designed for blasts with HE charges as large as 60 kilograms, a capability requiring 3,200 cubic meters of concrete and 2,000 metric tons of steel—enough concrete and steel to build the frame of a 16-meter by 18-meter, 60-story office building. This containment enables isolation of the environment from hazardous materials in hydrotests of our largest devices. To image the HE implosion, CFF uses the Flash X-Ray (FXR), a Linear Induction Accelerator (LINAC) that provides a single 65-nanosecond, 3,000 ampere pulse of 17 to 18 MeV electrons that are converted, via a tantalum target, into an x-ray pulse. This x-ray pulse has a dose of over 450 rad at a distance of one meter with a spot size of approximately 2 millimeters, providing the ability to image very high-density objects. FXR also has the largest format radiographic capability (84 cm x 72 cm) in the complex, which enables images of interactions between the outer boundaries of the device and external components.

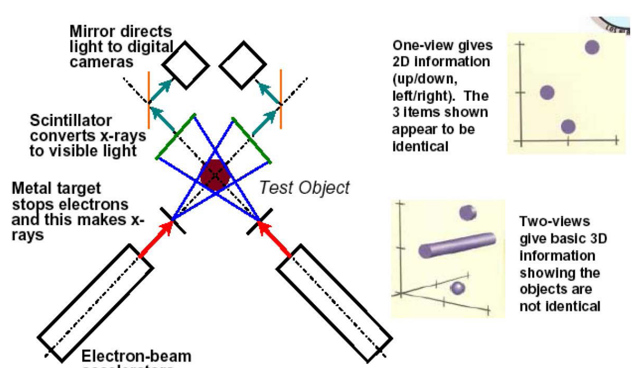


Figure 1. Typical DARHT dual-axis radiography configuration; the inset views address the benefits of having different views of the test objects.

Types of Hydrotests

There are two basic types of hydrotests performed at DARHT and CFF. One type of experiment is known as a JOPIN shot, for JOint PIN and radiography experiment. For a JOPIN shot, the principal diagnostic is an array of electro-mechanical shorting pins protruding from a small sphere that is located inside the weapon's pit. As the high explosives drive the pit implosion, the surrogate material strikes the tips of the shorting pins, and an electrical impulse is generated that is used to track the position of the pit material as a function of time. A large FOV radiograph is typically taken of this experiment, to investigate other features of interest. Recently, both LANL and LLNL are exploring the use of optical PDV probes (see Figure 3) as partial or even full replacements for pins. The optical signals generated give information on both position and velocity of the imploding pit, a much richer (and more detailed) dataset than with just pins alone.

Figure 2. The Containment Chamber and the FXR at the Contained Firing Facility at LLNL's Site 300.

A second type of hydrotest is known as a "core punch" experiment. A core punch experiment captures radiographs of the pit geometry as it implodes, providing information about material locations at critical times. A radiograph (or, in the case of DARHT, multiple radiographs) of the imploding pit are the principal diagnostic for core punch hydrotests. Ancillary diagnostics such as shorting pins or PDV probes provide additional data for core punch hydrotests.

While LANL and LLNL each has its own facilities for hydrotesting, each lab regularly brings one of their experiments to their sister laboratory's facility to take advantage of each facility's unique capabilities. LANL scientists have executed JOPIN experiments at CFF, and LLNL scientists have used DARHT's capabilities for core punch experiments.

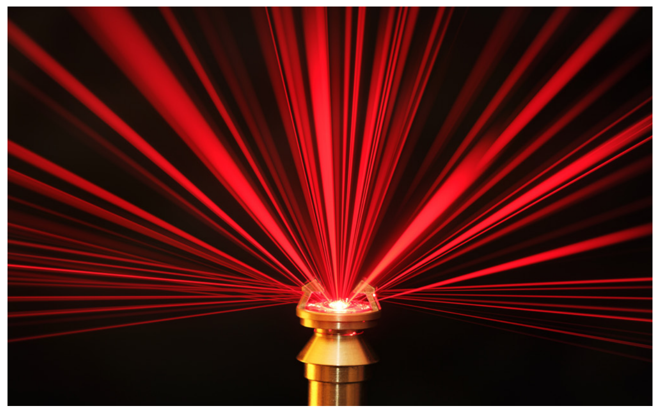


Figure 3. A multiplexed PDV probe used to record the velocity of pit surface during the implosion.

Simulations of Hydrotests

Data from hydrotests at CFF and DARHT are compared with our computer simulations to identify areas of overall weapon behavior that are not well understood and thus worthy of further investigation. These experiments and the codes they validate are the two fundamental tools used by our scientists to ensure the long-term viability of the U.S. nuclear deterrent, well into the future, without having to resort to additional underground nuclear tests.

Save the Date — 2014 Stewardship Science Academic Programs Symposium

The NNSA Office of Research, Development, Test, and Evaluation is pleased to announce the 2014 Stewardship Science Academic Programs Symposium will be held at the Bethesda North Marriott in Bethesda, Maryland on February 19-20, 2014. The Symposium will feature overviews of work to date from ongoing grants and cooperative agreements from the following programs: Stewardship Science Academic Alliances, High Energy Density Laboratory Plasmas, National Laser Users' Facility, and the Predictive Science Academic Alliance Program. Registration is required, but there is no registration fee. The registration deadline is January 24, 2014. For more information and to register, visit www.orau.gov/ssap2014/.

Advancing Qualification Alternatives to the Sandia Pulsed Reactor Activities

by Steven J. Sampson (National Nuclear Security Administration)

Background

Nuclear weapons contain sensitive electronics harmed by weapon effects radiation. Weapon systems require qualification to ensure their ability to survive within a hostile radiation environment. This work addresses this qualification need for nuclear weapon electronics. In 2006, Sandia National Laboratories (SNL) shut down the Sandia Pulsed Reactor (SPR) as part of its effort to reduce its security footprint for onsite special nuclear materials and relocated its fuel to the Nevada National Security Site. Since SPR provided hostile radiation environments for qualification, then a need developed to find an alternative approach to the qualification process. To compensate for the loss of the SPR after 2006, the Qualification Alternatives to the Sandia Pulsed Reactor (QASPR) project started. QASPR uses computational modeling to simulate exposure environments, testing regimes to confirm component performance and for model verification and validation, plus technology to improve circuit radiation hardening approaches and develop advanced semiconductor devices.

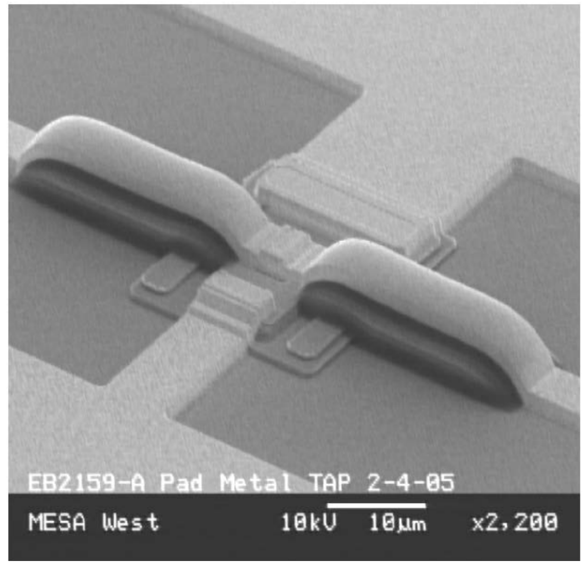


Figure 1. Heterojunction Bipolar Transistor.

QASPR Modeling

The QASPR project estimates neutron damage in electronics using nuclear explosion simulations. These simulations augment historical electronic circuits' radiation exposure data by accurately addressing circuit model shortcomings. Recalibration using historical data and data gathered by the QASPR project improves the analysis process by expanding the range of conditions and by adding relevant physics such as photocurrent and photoconductivity to the calculations. These calculations lead to newly defined radiation performance metrics for the circuits. To date, these simulations enabled a 'ranking' of the circuits in terms of vulnerability and this 'ranking' can determine which circuits need more thorough investigation by simulation. These simulations, along with experimental data, provide evidence for the technical basis for qualification. These simulations correlate with other circuits' performance of similar functionality in another warhead system. Circuit designs represent functionality in the radar, fireset, missile interface and controller module plus path length module. Prioritized QASPR circuit analysis will focus on qualification evidence ultimately generated by QASPR for all warhead applications.

As part of SNL's weapon system circuitry simulation effort, the SNL Radiation Analysis Modeling and Simulation of Electrical Systems (RAMSES)/Charon code team recently started performing two-dimensional (2D) simulations of heterojunction bipolar transistors (HBTs) (see Figure 1), which serve as critical radiation-hardened components for stockpile modernization. The QASPR project develops predictive capability to assess how these devices perform in a radiation hostile-threat environment. It's first use will be as part of a new qualification capability for warhead electronic systems in FY 2016. The 2D capability to simulate neutron damage, unique to Charon, allows the QASPR team to assess the quality of the 1D simulations typically used. If necessary, these simulations will establish if extensions to the 1D models must occur for full Quantification of Margins and Uncertainty or Uncertainty Quantification (QMU/UQ) analysis. As a risk-mitigation strategy, the full 2D simulation capability will perform QMU/UQ analysis in the event that the 1D models prove insufficient in capturing all the relevant physics for devices operating in saturation mode. This assessment compares validation predictions with experimental data. A single 2D simulation will take on the order of a few hours and full 2D simulations for QMU/UQ analysis will involve thousands of simulations requiring several days of computation time.

HBT simulations with Charon will improve through a new model for the recombination of carriers with displacement damage in gallium arsenide (GaAs) and related materials. This model provides a basis for atomistic simulation of transient gain recovery in HBTs after pulsed neutron irradiation. This new model implemented in an exploratory code will migrate to Charon, including drift-diffusion of the carriers and reactions with defects within a radially symmetric average defect cluster. These simulations follow the concentrations of charge carriers and defects versus position and time, and provide the rate of carrier recombination which evolves with time as the defects react. The initial radial distribution of defects comes from pair-correlation function analysis of defect maps obtained from simulations with the Cascade binary collision code, as well as from molecular dynamics simulations. Rate equations for reactions use energies of formation and migration diffusivities for defects in GaAs provided by simulations made with Density Functional Theory codes. The reaction model underwent extensive verification by comparison with analytic solutions. Verification tests ran simulations designed to test various functionalities of the code with analytical solutions, such as the electric field created by charged defects, carrier transport by diffusion and drift, carrier recombination at defects, and defect transport by diffusion.

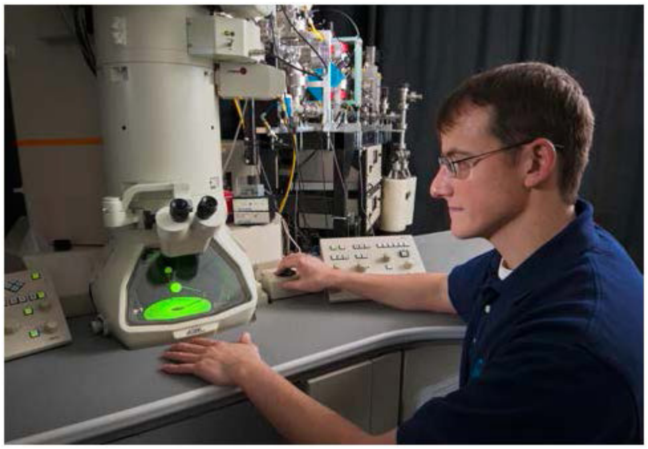


Figure 2. Ion Beam Laboratory experiment with HBT.

Validation simulations for conditions corresponding to the p-doped base of the negative-positive-negative (NPN) HBT agree with observed recovery of gain degradation in irradiated HBTs.

With fewer minority carriers, corresponding to lower current injection in a device, defects react and carrier recombination decreases more slowly, consistent with the experimental observation of current-induced HBT gain recovery. According to the model, arsenic interstitials react with carbon dopants very quickly to produce carbon interstitials through a kick-out reaction. Subsequent reaction of the carbon interstitials produces time-dependent carrier recombination in the time regime of interest. Excess minority carriers increase the population of the more mobile neutral charge state of the carbon interstitial, thereby increasing their rate of reaction. Efforts to validate the code continue, including comparison to carrier emission and capture from Deep Level Transient Spectroscopy (DLTS) measurements. Recombination in n-doped material and the influence of internal electric fields on carrier recombination continue to be studied.

QASPR Testing

The QASPR project team established ion-to-neutron damage equivalence through experiments at the Ion Beam Laboratory (see Figure 2) involving HBTs to gather data for the calibration and validation of HBT models. In the past, silicon ions demonstrated this purpose, but these experiments require devices with thin metallization covers that are specially fabricated by Microsystems and Engineering Sciences Applications (MESA). Recent experiments demonstrated that carbon ions can pass through the full metallization layer of a production HBT to produce the appropriate displacement damage in the emitter-base region of the transistor. Validation and calibration data for HBT models can now be acquired with the same devices that MESA produces for the stockpile which simplifies the requirements and reduces costs for MESA to deliver test articles for QASPR.

The QASPR project team also subjected positive-negative-positive (PnP) HBTs with a new semiconductor material, fabricated in the MESA facility, to their first radiation-hardness tests at the Annual Core Research Reactor (ACRR). As a result of recent design changes, MESA now produces PnPs with collector material composed of indium-aluminum-arsenide (InAlAs) rather than indium phosphide (InP) for stockpile applications. Preliminary examination of the data reveals that the PnP HBTs with InAlAs collectors exhibit greater radiation hardness than devices with InP collectors. Electron displacement damage experiments with the linear accelerator at the Little Mountain Test Facility at Hill Air Force Base helped to understand the physics of neutron damage in these new HBTs. These electron irradiations used for DLTS experiments study defect formation in the HBT materials. The new HBTs with InAlAs collectors received irradiation for gain and annealing factor studies at damage levels equivalent to the degradation produced by the White Sands Missile Range (WSMR) Fast Burst Reactor (FBR). Due to the temporary shutdown of the SNL ACRR, the QASPR experimental team recently investigated and determined that the WSMR FBR could surrogate for the ACRR with the purpose of gathering data to develop and validate the QASPR models for how HBT electronics respond to neutrons. This approach, which requires operating the WSMR FBR in steady-state mode for an hour, requires more expensive and time-consuming experiments than at ACRR. The neutron damage factors obtained at WSMR agree well with previous measurements at ACRR for a variety of HBT transistors, establishing this approach as viable to use as an alternative to the ACRR should that reactor ever be shut down for a lengthy period of time.

The QASPR project achieved great success over the years modeling and testing for silicon-based circuitry and expanding the scope of radiation-hardened physics, modeling, and testing for advanced HBT materials. The establishment and certification of the QASPR approach as the basis for qualification for weapon system survivability leads an important development for the future of our weapons program.

Omega Laser Facility Conducts Record Number of Experiments

The Omega Laser Facility at the University of Rochester's Laboratory for Laser Energetics (UR/LLE) recently completed its 25,000th experiment. One of the thousands conducted to create and study extreme states of matter, this milestone shot was a science experiment to study the properties of liquid deuterium at high pressure.

The Omega Laser Facility produces the most target shots of NNSA's large high energy density facilities. In addition to answering vital physics questions, these experiments support the development of diagnostics and experimental platforms for the National Ignition Facility at Lawrence Livermore National Laboratory. Also, LLE educates advanced students in fields of study critical to NNSA's mission.

Congratulations to UR/LLE!