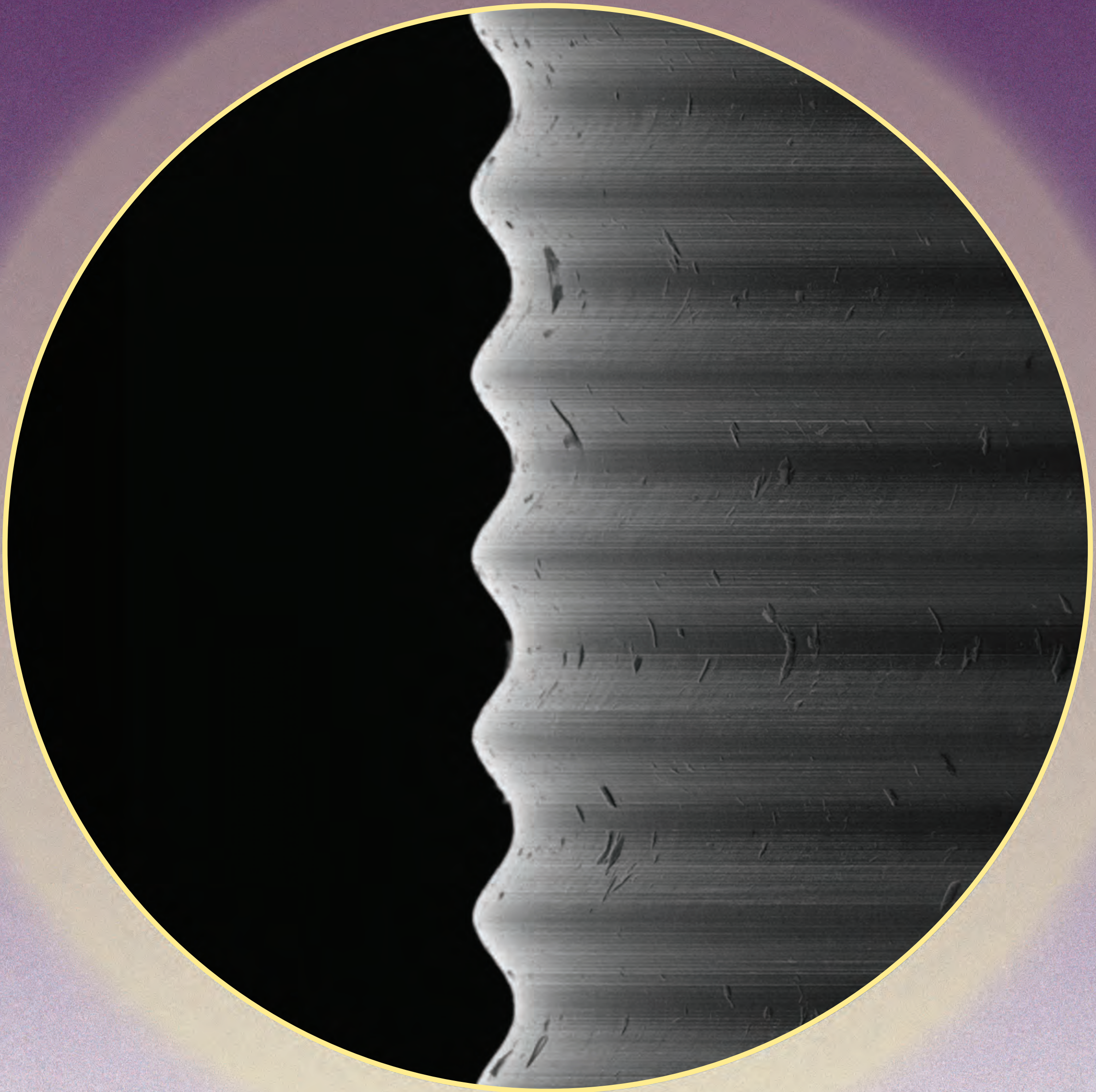
nuclear weapons journal



Winter 2004

☐ Validation Experiments ☐ Atlas ☐
☐ Shock-Driven Instability ☐ Ion Beam Analysis ☐
☐ Monitoring HE Aging ☐ Teflon Impact Response ☐

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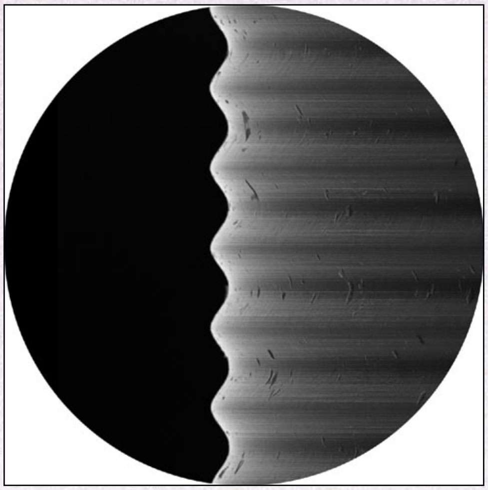

About the cover: Scanning electron micrograph (SEM) of the unstable interface in a Richtmyer-Meshkov hydrodynamic experiment performed using the OMEGA laser, showing a portion of the cylindrical target before the experiment. The laser strikes a layer of epoxy left of the figure and drives a strong shock into the cylinder, causing an implosion and initiating instability at this interface.The sinusoidal perturbations, machined into a thin aluminum layer, have a wavelength of 9 µm and peak-to-peak amplitude of 2 µm. *SEM courtesy of Norm Elliott, MST-7.*

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Correction: The "Backward Glance" in the September/October 2003 issue stated that George Gamov remained a Russian citizen after he fled the Soviet Union in 1933. In fact, he and his wife Rho (Luybov Vokhminzeva) became naturalized American citizens as soon as possible. They were proud of their American citizenship and traveled widely with their American passports. Only under Soviet law and in that territory did they remain Russian citizens. (We thank George's son, Igor, and his wife Elfriede for this information.)

Los Alamos
NATIONAL LABORATORY

NNSA
National Nuclear Security Administration

Point of View

John D. Immele
Deputy Director
National Security

The recent restructuring of responsibilities for the Laboratory's nuclear weapons activities will give us much stronger program integration and should help the people who run these programs set priorities more effectively. Because this is a fundamental change in the management of the Laboratory's key mission areas, I asked for this opportunity to set down some of my thoughts about why we are doing this and to discuss the benefits that the Senior Executive Team expects.

By now most of the Laboratory and its customers know that we have created an additional weapons directorate, headed by a Principal Associate Director for Nuclear Weapons Programs (PrADNWP). This new AD has programmatic responsibility for the entire nuclear weapons portfolio at the Laboratory and chairs the weapons Program Integration Board (PIB), reporting to Director Nanos and to me. The NWP Directorate, led by Don McCoy as acting AD, will take on several key roles, including overall allocation of resources for the nuclear weapons program and portfolio integration through the PIB. The new AD will balance priorities and ensure execution of program deliverables.

The directorates for Weapons Physics, Weapons Engineering and Manufacturing, and Operations continue to plan and carry out all the work in their line divisions. Importantly, the intellectual vision driving our nuclear weapons work will continue to come from these ADs and their division leaders.

What motivates this change?

In the year-plus since Pete Nanos became director, Laboratory management has increased its emphasis on project management and timeliness in delivering products, whether a key experiment, an important research finding, or a component manufacturing milestone. We believe the weapons program must transform itself into a structure in which managers make decisions more efficiently and effectively, manage programmatic risks with a clearer vision of outcomes, and provide clear, timely accounting to our customers and to ourselves. We want to see, within a very short time, major improvements in communications and in carrying out the program and line management missions.

> the **weapons program** must **transform** itself into a **structure** in which **managers manage programmatic risks** with a **clearer vision** of **outcomes**

Changing Structure and Responsibilities

Obviously, these are stretch goals, but I think they are attainable through better teamwork and the delineation of responsibilities offered by the new structure and the new AD position. Don McCoy, as acting PrADNWP, will be responsible for overall allocation of resources within the nuclear weapons program and for portfolio integration through the PIB; the Planning and Integration Office will report to Don. The new AD will balance priorities, using a risk-based approach, and then review the execution of program deliverables. In addition, the PrADNWP will oversee weapon-specific Directed Stockpile Work (D6), which includes the reliability replacement warhead (previously referred to as the robust warhead) and related work in the Office of Military Applications.

For the present, we are asking the Deputy ADs for Experimental Physics, Advanced Simulation and Computing, Manufacturing, and Operations to remain "dual-hatted" as program directors and line managers. Their new role will be to administer

Continued on page 31

RMI—The Study of a Convergent Hydrodynamic Instability

Inertial confinement fusion (ICF) is achieved by imploding a small, hollow sphere filled with a mixture of deuterium (D) and tritium (T) chilled to cryogenic temperatures. The implosion compresses and heats the DT fuel to the point that D-T fusion reactions occur and energy is released. In this multilayer system of shell, frozen DT, and DT gas, the interfaces between layers are hydrodynamically unstable when the interfaces are accelerated or shocked. These instabilities can prevent fusion by mixing colder shell material with the hot DT fuel, which dilutes and cools the fuel.

This shock-driven instability is called the Richtmyer-Meshkov instability (RMI) after former LANL staff member R. D. Richtmyer, who theoretically postulated its existence, and Soviet researcher E. E. Meshkov, who observed it experimentally. Planar measurements of the RMI have been made in conventional shock tubes and using large lasers (see *Nuclear Weapons Journal*, January-February 2003, p. 4). However, the RMI is expected to behave differently in a converging system such as an ICF capsule. The effect of convergence, generally referred to as the Bell-Plesset effect, theoretically amplifies the growth rate of instabilities during implosion. At Los Alamos, we measured the growth of the RMI in a cylindrical geometry to capture the effects of convergence while retaining the ability to measure the growth of interfacial perturbations with a line of sight along the interface.

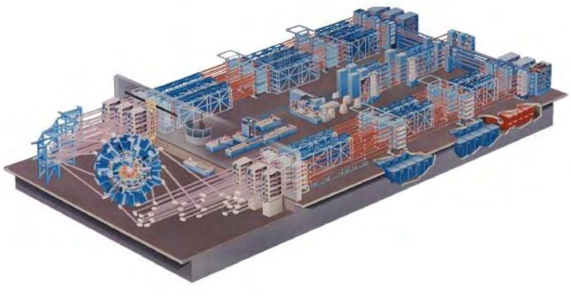

Figure 1. The OMEGA laser produces up to 30 kJ of 351-nm light in a 1-ns-long pulse. The target chamber is fully instrumented with diagnostic instruments from Los Alamos, LLNL, LLE, and others.

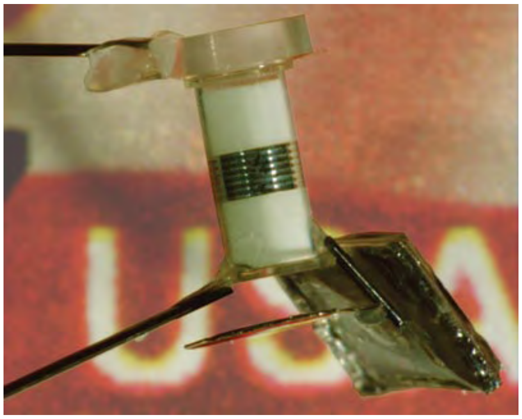

Figure 2. The target is a 2.25-mm-long x 1-mm-diameter cylinder. The outside is epoxy filled with low-density foam; the aluminum marker band is clearly visible. The target is mounted on a stalk for positioning within the target chamber. Additional backlighter foils are attached to the cylinder. Background is a postage stamp.

In collaboration with scientists from the UK's Atomic Weapons Establishment, we are conducting experiments on the OMEGA laser (Figure 1) at the University of Rochester's Laboratory for Laser Energetics (LLE). We use 50 laser beams with 18 kJ of energy to implode a small, hollow, epoxy

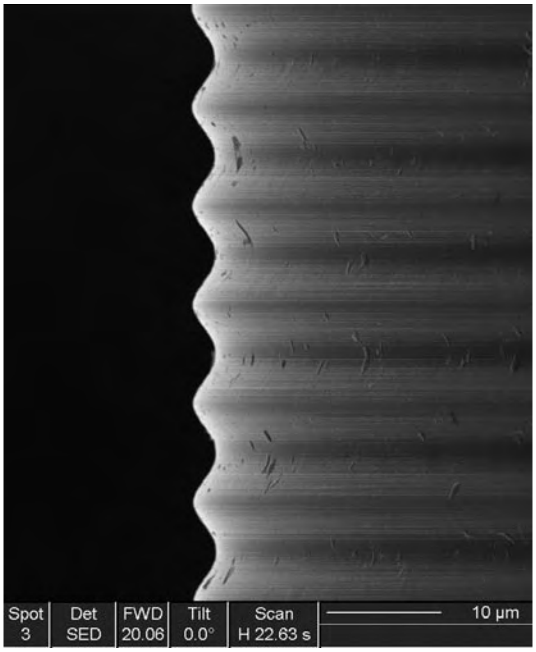

Figure 3. Scanning electron micrograph of the aluminum marker layer. A 9-µm wavelength sinusoid was machined into the marker layer. The cylinder axis is oriented vertically and is to the right side in the figure.

cylinder (Figure 2). Embedded within the cylinder is an aluminum marker band, and at the center of the cylinder is a low-density foam. The epoxy/marker and marker/foam interfaces are both RM-unstable.

observing perturbation growth with convergence in the **important turbulent regime** opens a **new area** of **research**

Instabilities grow from small but unavoidable imperfections that act as seeds. In this experiment, a controlled surface perturbation was machined into the outside surface of the aluminum marker layer (Figure 3). The surfaces tested ranged from a perfectly smooth surface (root mean square greater than 20 nm), to a sinusoid in either the azimuthal or lengthwise direction, to a randomly rough surface. Perturbation growth by RMI is induced by a Mach 10 shock launched by rapid (about 1 ns) laser heating of the outside of the cylinder. The cylinder implodes, reaching minimum volume (a convergence ratio of 5 to 1) in about 6 ns.

The signature of instability growth is the increase in marker-layer width during the implosion, as measured by x-ray radiographs. An extended source of x-rays is produced by five OMEGA laser beams striking a thin iron backlighter foil. The x-rays traverse the target, scatter, are absorbed, and result in a shadow image of the target. The image is captured by a fast framing camera (see Fast Framing Cameras, p. 4) that records up to 16 images within 1 ns. The marker band shadow is a dark ring in the image. The width of the ring, after correction for parallax effects, is a direct measure of instability growth (Figure 4).

the **signature of instability growth** is the **increase** in **marker-layer width** during implosion

Recent experiments show that the RMI behaves differently in a convergent geometry than in a planar geometry and is in qualitative agreement

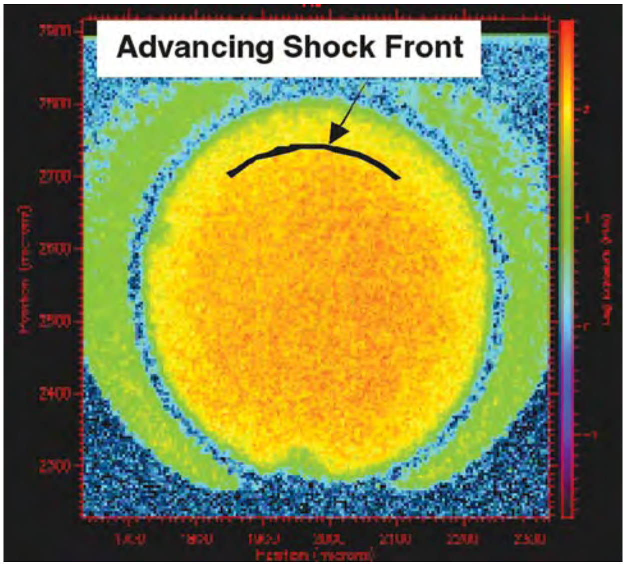

Figure 4. Sample radiograph of one frame of data. The dark band is the shadow of the marker band. The bright center area is the more transmissive foam, and the bright area outside the marker is the transmissive epoxy. The width of the dark band is a direct measure of instability growth.

with Bell-Plesset theory. In planar experiments, the growth of the RMI saturates and perturbation growth slows. In the cylindrical experiments, no evidence of saturation is seen; the perturbations continue to grow linearly. The instability growth rate also was observed to depend on initial perturbation wavelength. That is, shorter-wavelength perturbations grew faster than longer-wavelength perturbations, until the wavelength became very short, in this case only 2.5 µm. The growth rate of these short wavelength perturbations is retarded, which is characteristic of a transition to a turbulent regime early in time.

Laser-driven cylindrical implosions provide valuable data in the dense plasma regime in convergent geometry that is inaccessible in conventional shock tubes. The use of an initially solid marker band allows controlled engineering of a range of surface imperfections. Recent results suggest that convergence significantly modifies the way in which perturbations grow and the way in which their growth rate saturates. The ability to observe perturbation growth with convergence in the programmatically important turbulent regime opens a new area of research that has been little explored. The effect of convergence is postulated to amplify turbulent fluctuations (as do shock waves interacting with a turbulent layer), modifying the way in which growth proceeds.

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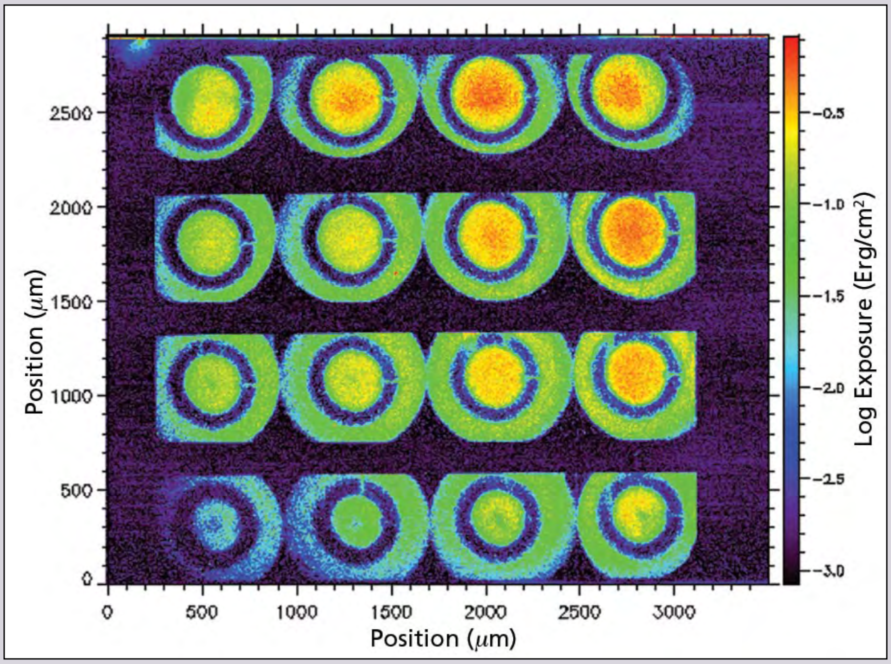
Fast Framing Cameras



Inertial confinement fusion experiments occur very quickly. The entire implosion is complete within a few nanoseconds. Fast framing cameras were developed to record multiple two-dimensional images of extremely short duration. The figure shows 16 images from the same laser shot. Each image was formed by a simple pinhole lens. The x-rays were converted to electrons using a microchannel plate. The electrons struck a phosphor that emitted light recorded on photographic film. The microchannel plate is energized, or gated, by a fast electrical pulse so that each image is shuttered open for only 60 ps. All 16 images were recorded in less than 1 ns. Fast framing cameras have become the standard diagnostic for ICF and high-energy-density physics experiments due to their high spatial resolution, fast time-gating, and ability to record x-rays with energies between 1 and 10 keV.

Pressure-Induced Phase Transitions in PTFE (Teflon)

Polytetrafluoroethylene (PTFE) was discovered on April 6, 1938, by Dr. Roy Plunkett at the DuPont Jackson Laboratory in New Jersey. This polymer resin was first marketed in 1945 under the DuPont Teflon trademark. PTFE is the most popular of the flouropolymers, finding applications ranging far beyond its well-known use on nonstick cookware.

Although PTFE is commonly used in industry and engineering, its mechanical response has received relatively little study in recent years. We designed an experiment to study PTFE's responses to impact. To analyze our test results, we need to take into account PTFE's complex characteristics and behavior.

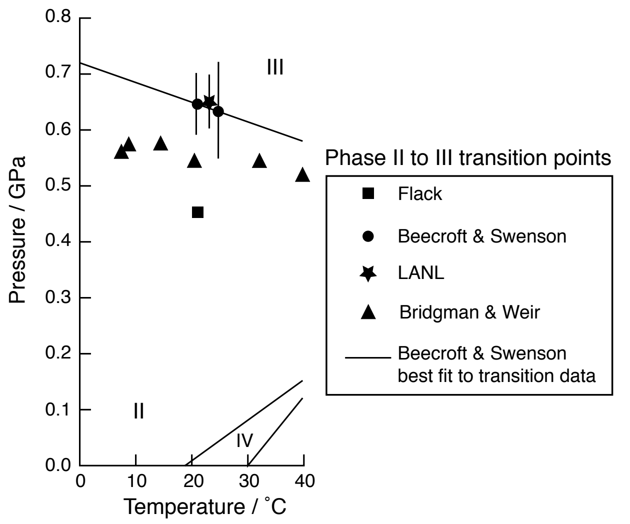
PTFE Material Properties

PTFE is an unusual plastic in many ways: it has the lowest coefficient of friction of any stable material and the lowest dielectric loss; its electrical resistivity is among the highest known in materials; and it retains some measure of ductility (~3% to 5%) at liquid helium temperatures. Under quasi-static loading at room temperature, PTFE will fail at 600% to 700% engineering strain in uniaxial tension. It is surprising, therefore, that such a ductile polymer should undergo an abrupt ductile-brittle transition when impact-loaded at quite modest rates. Previous authors have commented on the sometimes "brittle" nature of PTFE, but to our knowledge no explanation has been postulated until now.

In addition to PTFE's other complexities, it exhibits at least four phase changes, depending on combinations of temperature and pressure. In addition, PTFE always contains a mix of amorphous and crystalline regions, so it is not possible to manufacture fully amorphous or fully crystalline PTFE. At atmospheric pressure, below 19 °C, PTFE has a triclinic crystalline structure (II). Above this temperature, it undergoes a first-order phase transition into a hexagonal structure (IV), exhibiting a 1.8% volume increase. A second-order transition occurs at 30 °C into a pseudo-hexagonal (I) structure. From 30 °C until melting (321 °C for once-melted material, 341 °C for virgin moulding powder), a general relaxation of the crystalline structure occurs until, given infinite time, a fully amorphous state is reached.

> **we believe** these **Taylor shots** present **strong evidence** that a **pressure-induced phase transition** is **responsible** for the **brittle transition** in **PTFE**

A pseudo-equilibrium, pressure-induced phase transition (III) has been reported in PTFE at ~0.65 GPa at room temperature. This transition is strongly temperature-dependent; however, considerable hysterisis was noted, leading to large



Pressure-induced partial phase diagram for PTFE (Teflon). The phase transition is strongly temperature-dependent. The graph shows considerable variation in results from researcher to researcher.

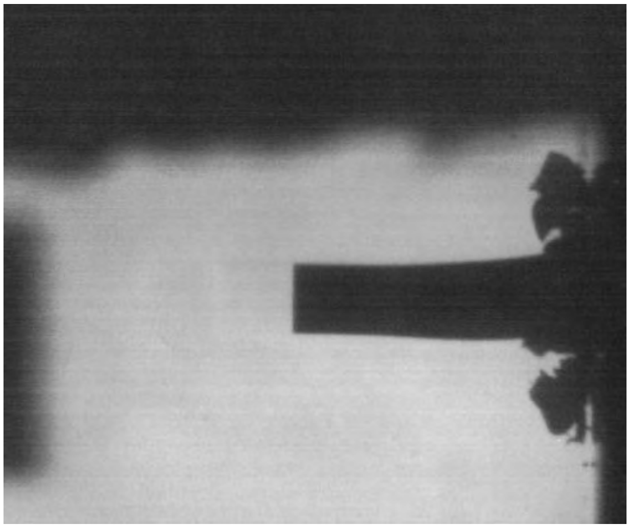
error bars. It is also evident that there is disagreement among researchers regarding the exact pressure at which the phase transition occurs. Recent work at Los Alamos, using a diamond cell anvil and Raman spectroscopy, suggests that the transition occurs at 0.65 GPa and exhibits around ±0.5 GPa of hysterisis. The pressure-induced phase transition results in an estimated 2% volume change.

Testing PTFE's Response to Impact

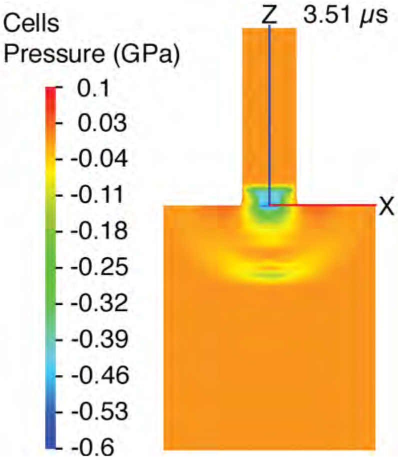
Several companies around the world manufacture PTFE. The material chosen for this study was DuPont Teflon, grade 7A. A single large billet was manufactured from 7A moulding powder, and all samples were machined from this billet. Prior testing had shown that the billet's isotropic properties were adequate to our requirements.

We chose the Taylor configuration to perform our controlled impact experiments. This setup involved firing a 2-in.-long, 0.3-in.-diameter right cylinder of PTFE at a large, flat-faced steel anvil. The front face of the anvil was highly polished and was lubricated with a thin layer of synthetic oil containing colloidal PTFE. This was done to minimise the frictional forces opposing expansion of the rod end that might otherwise prevent tensile cracking. The launching gun and anvil arrangement enables accurate alignment, velocity timing, and high-speed photography of the impact. In our Taylor gun the temperature of the sample may be altered from -100 °C to +200 °C.

An Imacon 200 high-speed camera was used to photograph the shots. This camera is capable of taking up to 16 frames at a maximum rate corresponding to 200 million frames per second. The exposure time and inter-frame time (IFT) of each exposure are fully programmable. In these experiments, 14 frames were used with a 500-ns exposure time and a 15-µs IFT. The sample velocity was measured using the time between interruption of two laser beams.



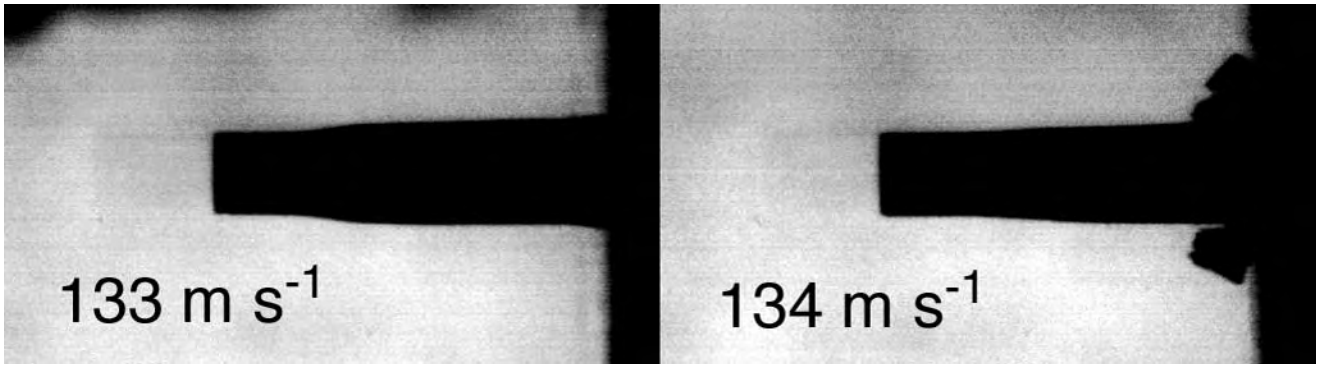
Typical impact of a cylinder of PTFE on a flat-faced steel anvil, recorded with an Imacon 200 high-speed camera with a 500-ns exposure time.



Results for a simple finite element analysis model of a PTFE Taylor cylinder traveling at 135 ms^{-1} 3.51 µs after impact. At that time, a local pressure of about 0.5 GPa develops at the front of the projectile—evidence that a phase transition is possible at velocities around those at which the ductile-brittle transition occurs.

Ductile-Brittle Transition

Taylor samples were found to exhibit an abrupt ductile-brittle transition. For example, a PTFE cylinder that is ductile at 133 ms^{-1} is suddenly brittle at 134 ms^{-1}. This marked change in response occurs with only a 1-ms^{-1} change in velocity at 21 °C. By firing a number of samples at close to the critical velocity, we can find a statistically valid threshold velocity. We decided to see whether the pressure-induced phase transition in PTFE might play a part in this behavior. To do this, we used the temperature capability of the gun. As previously described, the pressure-induced phase transition point is highly dependent on temperature. If the ductile-



Example of the abrupt ductile-brittle PTFE phase transition with change in projectile velocity at 21 °C. The transition occurs with only a 1-ms^{-1} increase in the velocity of the PTFE Taylor cylinder. Both frames were taken 165 µs after impact.

brittle response of the PTFE were related to the phase transition, a higher critical velocity would be expected as the temperature of the sample is lowered. In contrast, PTFE (like most polymers) generally becomes more brittle at lower temperatures; however, PTFE ductility is at a maximum at the 19 °C first-order transition. If the phase transition is not playing a role, then a lower critical impact velocity might be expected as the sample temperature is lowered or raised from room temperature.

The mechanical properties (for example, tension, compression, shear) of polymers are greatly influenced by temperature. To minimize this effect, we limited the tested temperature range to between 1 °C and 40 °C. The table below shows the ductile-brittle transition velocities that our experiment established. Clearly, the transition velocity is getting higher as the sample is cooled, implying that the phase transition is playing a role. To establish whether this explanation is physically possible, Brad Clements (T-1) carried out a simple dynamic finite element analysis simulation. In this order-of-magnitude calculation, simple elastic-perfectly plastic deformation was assumed at an impact velocity of 135 ms^{-1}. The results establish that approximately 3.5 µs after impact, a local pressure of ~0.5 GPa develops at the front of the projectile. This is evidence that a phase transition is physically possible at velocities around those at which the ductile-brittle transition is found to occur.

Sample Temperature (°C)	Ductile-Brittle Transition Velocity (ms^{-1})
1	139 ± 2
21	134 ± 1
40	131 ± 1

Definitive evidence of a phase transition during impact is difficult to obtain because flash x-ray crystallography would be required. Any post-experiment sample analysis is likely to be inconclusive because the phase transition is known to be reversible upon unloading. The ductile-brittle transition is certainly abrupt enough to be related to a phase transition. Given that the critical velocity of the Teflon 7A actually increased with lower temperature, the increase is further evidence of phase transition because, as reported, the fracture toughness of Teflon decreases at temperatures higher and lower than the 19 °C phase transition. While the strength of Teflon is increased at lower temperatures, the strain-to-failure is reduced.

In conclusion, we believe that these Taylor shots present strong evidence that a pressure-induced phase transition is responsible for the ductile-brittle transition found in PTFE, shedding light on the sometimes brittle nature of this fluoropolymer. ✹

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Ion Beam Analysis and Irradiation of Materials for Weapons Applications

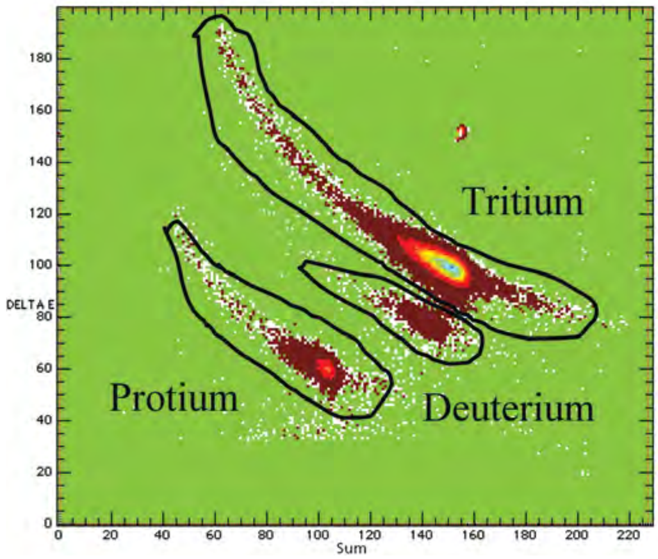
Ion beam analysis (IBA) is a nondestructive collection of analysis techniques that quickly—usually in minutes—measure elemental concentrations as a function of sample depth by irradiation with an ion beam. In addition to analyses, an ion beam also may be used to "treat" samples, so that the effects of irradiation on materials can be studied. This latter capability is particularly suited to the Laboratory's mission of stockpile stewardship because over time, radioactive decay can induce chemical changes that may jeopardize the stability of materials used in the nuclear weapons stockpile.

The Ion Beam Material Laboratory (IBML) of MST-8 uses a 3-MV tandem accelerator to generate alpha particles up to 9.6 MeV and protons to just over 6 MeV. This energy range permits analytical techniques that take advantage of scattering events between target and projectile ions in both coulomb- and nuclear-scattering regimes.

Analysis Techniques

Coulomb scattering describes the interaction of a projectile ion with the positive field generated by the nucleus of a target ion. At energies as low as approximately 2 MeV and with low-atomic-number projectile ions, this type of scattering is well predicted and can be used to deduce elemental concentrations as a function of depth in a sample. This type of analysis is known as Rutherford Backscattering Spectrometry (RBS). Other techniques include elastic recoil detection analysis (ERDA) to measure hydrogen content and particle-induced x-ray emission (PIXE) to measure element-characteristic x-rays. Above a certain energy, high-energy RBS (HERBS) is performed; HERBS allows enhanced elemental identification of light elements by using projectile ions to induce nuclear reactions. The IBML uses HERBS to perform measurements of many low-atomic-number elements that may be impossible with other techniques.

IBA gives immediate answers to questions about long-term effects of radioactive decay in the nuclear stockpile



Hydrogen isotope data from a fully loaded tritium film. The ERD measurement is made by impacting 9.4-MeV doubly charged hydrogen particles on the sample. To separate the isotopes, the energy-loss signal is plotted against the total energy of the scattered hydrogen nuclei. Trace amounts of deuterium and protium are caused by source gas and atmospheric contamination.

Material Irradiation

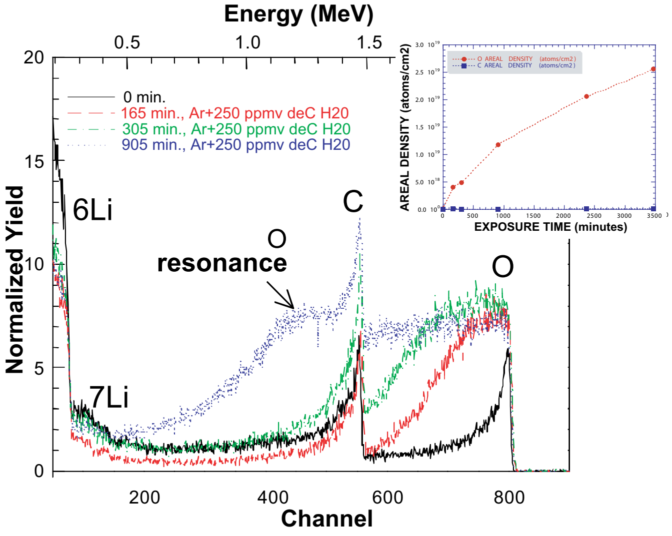
The accelerator's ability to produce helium ions at energies greater than 9 MeV allows researchers to mimic the effects of alpha decay as they relate to nuclear stockpile stewardship. For example, during the alpha decay of plutonium, an approximately 5-MeV alpha particle ejects from the nucleus, with the residual atom (now uranium) recoiling at approximately 70 keV. If the particle interacts with surrounding gases and materials, the chemistry and integrity of the material may change over time. The IBML can accelerate this aging process through the use of a high-fluence beam, as well as avoid the radioactive contamination and waste that are created by conducting nuclear weapon aging studies with traditional techniques.

> **experiments** were **conducted** in a **custom-built chamber,** where the **ion beam** was **passed** through a **thin window** of **titanium** before **interacting** with the **sample**

Neutron Tube Target Loading Verification

The ESA-TSE Neutron Tube Target Loading (NTTL) Program processes war reserve (WR) thin-film targets used in every weapon system in the nuclear stockpile; the targets are replaced periodically as part of the Limited Life Component Exchange Program. The NTTL process hydrides target films with a mixture of tritium and deuterium gas at a specific tritium-to-erbium ratio and at a total hydrogen isotope-to-erbium ratio. Hydrided targets are shipped for load verification to SNL/NM, where the total gas-to-metal ratio and the quantity of erbium on each target are quantitatively measured using destructive techniques, i.e., thermal desorption, mass spectrometry, chemical dissolution (wet chemistry), and atomic absorption spectroscopy. LANL determines these same quantities and more, using IBA. The ratio of total hydrogen to erbium and of specific hydrogen isotopes to erbium are measured to high precision, as is oxygen content as a function of erbium layer thickness. Three IBA techniques are involved: ERDA, RBS, and HERBS.

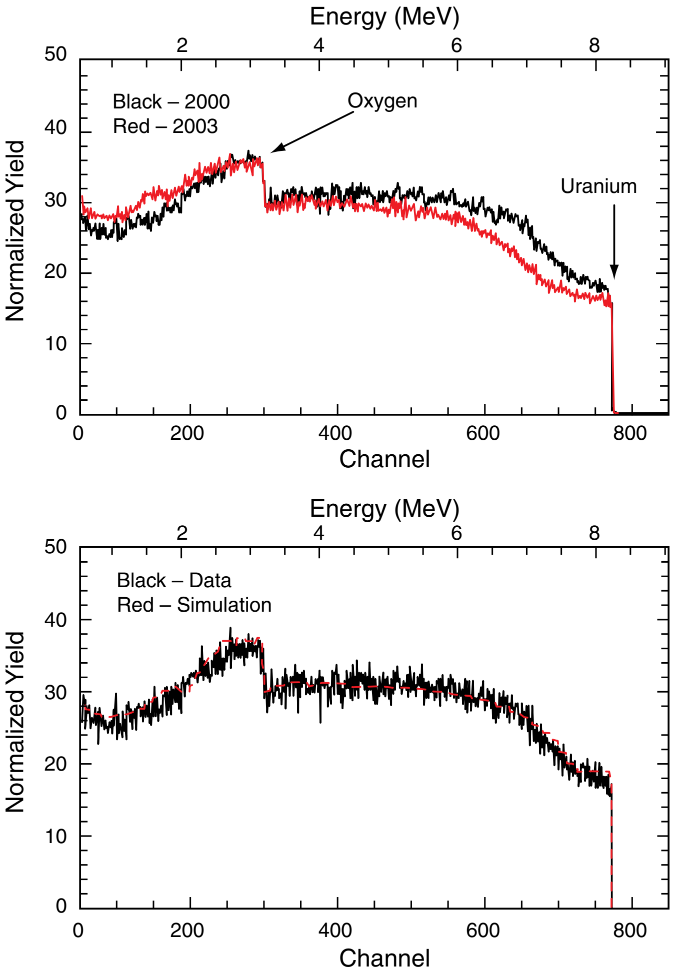
ERDA is used to measure hydrogen isotopes. In this technique, hydrogen is recoiled out of the sample and collected in a two-detector system. The first detector measures an energy-loss signal that is used to separate the hydrogen isotopes; the second stops particles and collects residual energy. An absorber foil placed between the ERDA detector system and the sample prevents the high flux of forward-scattered alpha particles from swamping the system with a huge, unwanted background. Simultaneous measurements of erbium from the RBS detector and hydrogen isotopes from the ERDA detector system provide yield ratios of hydrogen to erbium, which are converted to stoichiometric ratios by comparison to standards. A separate HERBS measurement performed at 7.6 MeV gives the oxygen-to-erbium ratio and the concentration profile of oxygen with depth.



Lithium hydride is exposed to a gas stream with 250 ppmv of decarbonated water for increasing amounts of time. The RBS spectra show growth of the oxygen layer and carbon contamination, and the diminishing peaks of the two lithium isotopes. Oxygen content and exposure time are plotted on the inset graph.

Lithium Hydride Corrosion Studies

Materials that are incorporated into nuclear weapons may not be at optimum compatibility with their surroundings. For example, lithium hydride is a highly reactive solid that generates several "products" when it is exposed to environmental contaminants; these products may have long-term effects. For example, hydrogen gas is generated from the reaction of lithium hydride with water, making the hydrogen available to react with other materials.



(top) A uranium sample was analyzed in both 2000 and 2003 to determine oxidation rate and extent. The RBS spectrum measures the in-growth of oxygen into the bulk of the uranium, as shown by the respective decrease of uranium and growth of oxygen in the 2003 spectrum.

(bottom)Total oxide content can be modeled to 5% concentration levels by fitting the oxygen diffusion profiles in a bulk uranium sample. This method compares oxygen concentration with depth.

The IBML uses IBA to determine the kinetics of reactions that occur as lithium hydride corrodes. While other techniques are available to perform these studies, IBA has two specific advantages: (1) it identifies the corrosion products and their thicknesses, and (2) the analytical depth and spot-size capabilities are on a scale consistent with the crystalline structure of the lithium hydride material. Lithium hydride grains can be many micrometers in diameter; ion beams show results for corrosion layers up to approximately 25 µm thick, depending upon measurement conditions.

Lithium hydride is stored and prepared in an inert environment glovebox that interfaces directly with a portable lithium hydride exposure chamber. The chamber is connected to a gas manifold that allows humidified gases to flow over the lithium hydride. The exposure chamber also is connected to an IBA chamber; thus exposures and measurements may be completed iteratively over long periods of time (days) without exposure to air. A range of water levels (as low as approximately 10 ppmv) and a variety of gases can be used for exposures. Elevated temperature capabilities have been developed for heating the samples. Although analyses are conducted in a "general purpose" chamber that is available to all users, the IBML has dedicated a port to the lithium hydride corrosion experiments.

RBS measurements are used for element identification, quantification, and product stoichiometric determinations. The RBS measurements may use varying beams and energies to maximize specific elemental sensitivities, e.g., analysis of carbon at 5.7 MeV with alpha particles. Other analyses include ERDA, to measure hydrogen isotope concentrations, and PIXE, to determine trace impurities.

Actinide Characterization

RBS techniques can be extremely sensitive when high-atomic-number elements are measured in a light matrix. In collaboration with NMT-16, experiments were designed to quantify small amounts of plutonium in a matrix of magnesium oxide. Magnesium oxide likely acts as an "environmental sponge," entrapping plutonium from aqueous solutions. The distribution of plutonium as a function of depth in magnesium oxide was determined in order to understand how magnesium oxide incorporates actinides into its crystal structure.

Simultaneous 3-MeV RBS and PIXE measurements showed a distribution of approximately nanogram quantities of plutonium extending into the first several thousand angstroms of the magnesium oxide matrix. The experiments were conducted in a custom-built chamber, where the ion beam was passed through a thin window of titanium before interacting with the sample. The thin window was used to isolate the chamber from the remainder of the accelerator, minimizing the potential for contamination. Samples were mounted in the chamber at the Chemistry and Metallurgy Research (CMR) Building and delivered to the IBML for analysis. Thus, no direct contact with the samples was needed outside the CMR controlled area.

HERBS is used to track the growth of oxide thickness on uranium. Using an enhanced cross section for oxygen at 7.6 MeV, the oxygen concentrations can be measured several micrometers into the uranium.

Material Irradiation Studies

Actinides can emit approximately 5-MeV alpha particles during radioactive decay; these particles may induce chemical changes or create voids in surrounding materials that may reduce the lifetime of materials used in WR applications. Conventional compatibility experiments expose a material to a radioactive source and monitor the results by a variety of techniques. For example, evolved gas species resulting from radiolysis can be measured by mass spectrometry at regular intervals, or the sample can be removed to measure physical properties. The disadvantages of these types of experiments are that their effects may not be observed for many years, even if a highly radioactive substitute source is used, and they produce radioactive waste and potential contamination.

In contrast, ion beam experiments can (1) accelerate alpha radiolysis so that studies are complete in hours or perhaps minutes, producing immediate answers to questions about potential long-term effects of radioactive decay in the nuclear stockpile; (2) eliminate radioactive waste and potential contamination, as solid radioactive sources are 0not used; and (3) provide in situ analytical information.

Ion beam experiments can accelerate **alpha radiolysis** in **hours or minutes,** eliminate **radioactive waste** and **contamination,** and **provide in situ** analysis

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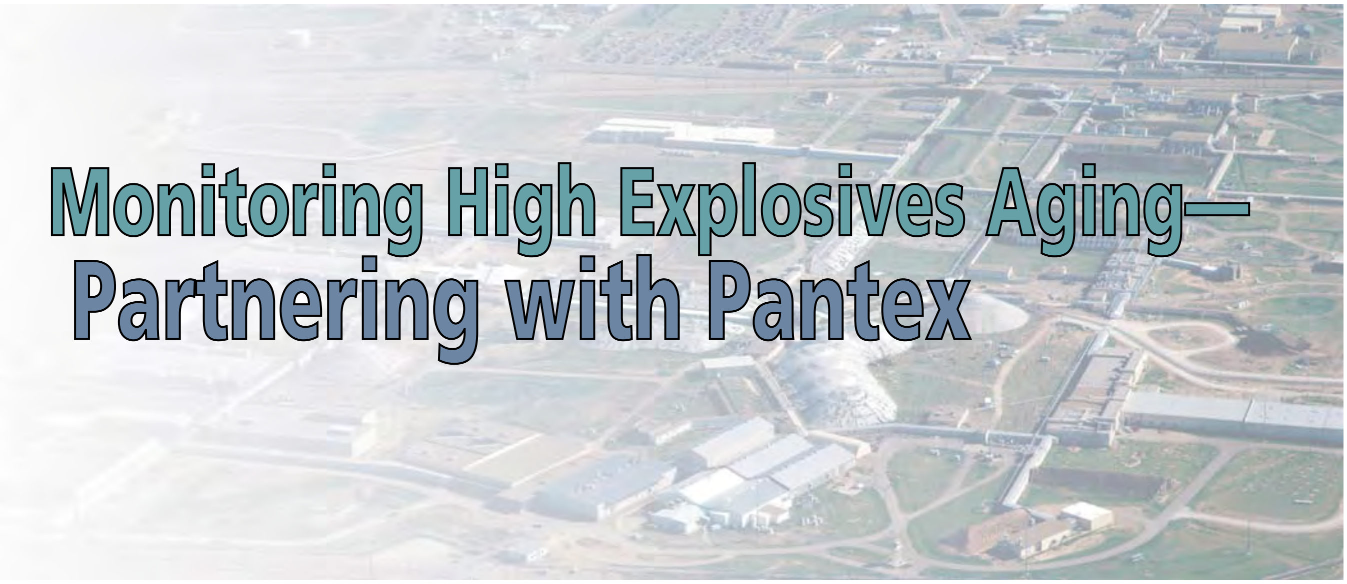


Monitoring High Explosives Aging—Partnering with Pantex

Stewardship of the nation's nuclear stockpile presents unique challenges as weapons age beyond their originally intended lifetimes. These challenges include identifying and monitoring age-related changes in weapon components and determining which aging phenomena will eventually affect safety, reliability, or performance.

> surveillance **provides information** on **how HE ages** that is **critical** to accurately **predicting aging** phenomena **inside nuclear weapons**

Surveillance activities, as executed under the Enhanced Surveillance Campaign (ESC) and Directed Stockpile Work (DSW), support Life Extension Programs and the Annual Assessment by determining when components must be replaced. High explosive (HE) surveillance under DSW is responsible for measuring properties of HE obtained from weapon systems removed from the stockpile explicitly for such purposes. The BWXT Pantex Plant near Amarillo, Texas, conducts surveillance on maincharge and booster HE according to LANL requirements. The HE in detonators and actuators is packaged and shipped to LANL, where surveillance on those components is carried out. This article focuses on HE surveillance activities at Pantex.

All the HE core surveillance tests described in this article take place at the BWXT Pantex Plant under LANL guidance and are the responsibility of the Directed Stockpile Work-Stockpile Evaluation Program.

LANL scientists and engineers first develop the test procedures, which are then implemented at Pantex. LANL scientists, engineers, modelers, and designers use the test results to assess the current health of the US nuclear weapons stockpile.

The test protocol for HE surveillance at Pantex includes nondestructive and destructive techniques. Several HE properties must be measured to ensure that all possible signs of aging are monitored. Design requirements call for charge shape, density, and composition to remain within specified limits. Additionally, HE must maintain structural integrity and mechanical strength.

Every main charge assembly is visually inspected as it is removed from the warhead. Technicians look for cracks, scratches, chips, discoloration, and any other irregularity. Handling during assembly and disassembly may cause some defects, while others are attributed to aging. All anomalies are photographed and recorded. Because conventional HE return charges (PBX 9501) are not reaccepted after surveillance, gross surface defects are detected with the aid of a blue dye solution. Insensitive HE charges (PBX 9502), however, can be reinspected and reused, so visual inspection is done without dye. Complete dye removal is difficult, and reaccepted charges cannot contain even traces of dye.

Survelliance identifies and examines signs of aging in components removed from weapons during disassembly at the Pantex Plant.

After each charge is visually inspected, its density is hydrostatically measured. The density is calculated by measuring forces present during "wet" and "dry" weighing. The dry weight is recorded first. Then a charge is placed in a wire basket and submerged in a water bath containing a small amount of wetting agent. Once the charge is submerged, the wet weight is measured. Booster densities are similarly measured using a smaller basket and water bath. Since densities are typically reported to ±1 mg/cm^3, a system capable of distinguishing density variations of ±0.1 mg/cm^3 is desired. To achieve this level of accuracy, several sources of systematic and random error must be minimized. This is done by thoughtful design of the measuring system to eliminate the influence of factors such as waves and water surface tension, by frequent calibration checks using a density master, and by operator diligence. Measured densities are compared to original values and accepted tolerances.

All charges are then gauged using a Coordinate Measurement Machine (CMM). Gauging is performed to examine whether forces applied during weapon assembly cause the HE to change shape over time. The CMM measures surface deviation from an ideal charge shape at a series of points covering the entire charge. Both inner and outer surfaces are gauged. Charges are machined to extremely tight tolerances, and the CMM can detect deviations of less than the thickness of a sheet of paper.

After gauging is completed, the forward and aft charges from two warheads are wet-machined to obtain specimens for additional testing. Common practice in HE machining is for water to continuously flow over the explosive and tooling to protect the safety of personnel and facilities. Mechanical test specimens must be thoroughly dried to eliminate the influence of absorbed water on mechanical strength. Quasi-static tensile and compression tests are run at low and high temperatures to evaluate mechanical properties near the stockpile-to-target-sequence temperature extremes. Ultimate stress, percent strain at ultimate stress, and elastic modulus are recorded. Mechanical properties vary from one HE lot to an-

An HE machinist gauges a tensile specimen to check for tolerance.

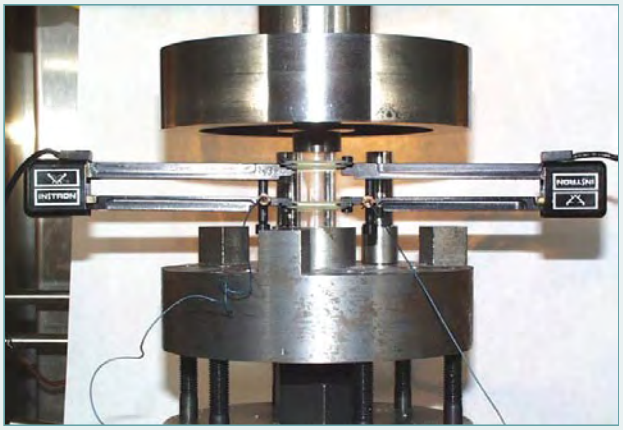
other and must be considered when examining data for aging trends.

Specimens for chemical composition and binder molecular weight determinations are machined from several different locations within each charge to check for variations throughout the HE. Many factors such as trapped water, radiation, and chemical compatibility can degrade the constituents in HE formulations over time. The high explosive (HMX, TATB, or RDX) composition is measured gravimetrically. Binder, plasticizer, and stabilizer compositions are determined using high-performance liquid chromatography. Binder molecular weight is determined using size exclusion chromatography/gel permeation chromatography equipped with a refractive index detector. Booster compositions and binder molecular weights are also measured. Changes in composition can alter the performance of the HE, while molecular weight changes can also influence the safety and mechanical strength.

In addition to chemical and mechanical analysis, three small-scale tests are implemented to detect changes in thermal stability (two tests) and impact sensitivity (one test).

To measure thermal stability, isothermal accelerated rate calorimetry is a measure of HE bulk thermal property, and differential scanning calorimetry (DSC) characterizes the HE and binder behavior. Operated in the modulated mode, DSC separates changes in heat capacity such as melting and glass transitions from kinetic transitions such as phase changes, decomposition, and binder endothermic relaxations. Both of these tests are used to identify if and when aged HE becomes less thermally stable.

Sensitivity changes can have consequences in the storage, transportation, handling, and deployment of weapons. Historically, surveillance chose not to measure HE sensitivity. The primary reason has been that HE sensitivity, as a measured property, is not well defined. Sudden decomposition can result from many different stimuli, and uncontrolled factors often challenge test reproducibility. During development, significant time, resources,



A cylindrical specimen machined from a main charge high explosive is ready for quasi-static compression testing.

A mechanical testing technician closes an environmental chamber door and sets temperature before initiating a quasi-static tension or compression test.

High-explosive "dog bone" specimens after quasi-static tension testing.

A chemical technician measures binder molecular weight using size exclusion chromatography/gel permeation chromatography.

and expense were devoted to characterizing the sensitivity of HE used in nuclear weapons. Experts felt that as long as the chemical and physical properties did not change with time, sensitivity also remained unchanged. Although this assumption has held, the operational environment under which weapons research is now conducted has changed significantly over the years. In response, surveillance has implemented a small-scale sensitivity test.

The drop-weight impact test examines changes in sensitivity due to mechanical impact. Many tests are employed in an attempt to characterize HE response to mechanical forces such as crushing, pinching, and scraping. All have advantages and drawbacks. In the test, a small amount of HE is placed on a steel anvil, and a steel striker is dropped onto the HE. A microphone determines whether the HE reacted when the striker made contact. Subsequent drops are repeated, each time with a new HE sample and with the striker hoisted to a different height depending on the previous test result. Statistical analysis determines a 50% height, which is a height at which half of the samples would react if drops were repeated at that height. This drop-weight test establishes a good beginning on testing HE sensitivity.

A chemical technician loads the accelerated rate calorimetry chamber.

Through strong collaboration with HE Enhanced Surveillance, DSW core surveillance activities are continuously being revised to establish a comprehensive program. New diagnostics are under development to detect aging effects as early and as accurately as possible. For example, efforts in ESC focus on developing additional sensitivity tests, especially those pertaining to safety and assessing changes with age. Surveillance provides LANL scientists, engineers, modelers, and designers with information on how HE ages inside weapons that is critical to accurately predicting HE aging phenomena and their impact on nuclear weapon performance. ✹

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All photos courtesy of the BWXT Pantex Plant. The dedicated individuals at Pantex are committed to maintaining the health of the nation's nuclear weapons stockpile by providing quality measurements of the properties of high explosives.

Sustaining Our Credibility: Balancing Experiments and Calculations

The quest to do science-based prediction in support of nuclear weapons stockpile stewardship is an enormous challenge for two reasons: the complexity of the physics in the weapons and the current prohibition against testing full systems. A major issue in nuclear stockpile stewardship is the need to develop computer codes that accurately simulate weapons behavior. Developing predictive capability in these codes requires validation science, which is a combination of experiments, theoretical physics models, and computer simulations that improve our understanding of weapons physics phenomena. Validation science examines one or several phenomena at a time to improve physics models or computational algorithms; in contrast, an integrated test examines many weapons phenomena simultaneously to adjust code parameters.

Credible Predictions

The credibility of our predictions depends on how well we do our science and interpret our calculations. Computer calculations designed to simulate weapons physics have limitations that must be determined accurately by science. As we all know, the scientific method is the *sine qua non* of increased understanding, and this methodology continues to be the essential tool we use to ensure our credibility about nuclear weapons computer codes. Well-designed scientific experiments—the cornerstone of the scientific method—produce data that stringently test a hypothesis based on a physics model. Such experiments not only enable us to test whether the model explains physical reality, but also help determine the limits of applicability of particular models and computational methods.

Computer Simulations

To effectively use computer simulations for stewardship, we balance baselining and code upgrading. Modern simulation codes are baselined (calibrated) primarily against nuclear test data and largely are used to calculate intermediate states of a system, up to and beyond criticality. Large-scale experiments to test precritical states are costly, integrated, explosive tests such as hydrodynamic tests (hydrotests). In addition to nuclear tests and nonnuclear integrated tests, we can perform less costly experiments that directly explore relevant weapons physics in the context of validation science. We design these experiments to upgrade codes and assess limitations. Because these smaller-scale nonnuclear experiments vigorously support science-based prediction by improving individual models and algorithms in the codes, they are essential to stewardship. A validation experiment frequently provides a definitive evaluation of a hypothesis and consequently becomes part of the bedrock of predictive science. In contrast, integrated tests usually are engineering tests that provide data used to adjust code parameters to fit those tests. However, they say little about the validity of individual physics models or computational methods. To ensure the physical reality of the final simulation, we must supplement baselining with an aggressive validation program specifically targeted at individual physical effects, such as fluid instability. Only in this way can we ensure credible science-based predictions that support our statutory responsibility for current and future stockpile stewardship.

Supporting Stockpile Stewardship

In summary, the validation experiments must underpin science-based predictions that support the Laboratory's nuclear stockpile stewardship mission. The health of such experiments is essential for invigorating the science within the Laboratory weapons program and for fostering a culture of collaborative and cross-disciplinary research that is the heart and soul of Los Alamos.

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Validation Experiments in Support of the Nuclear Weapons Stockpile

Experiments to validate physics models are the fundamental testing ground for science-based prediction, the Laboratory's first goal for national security. These experiments are essential to the Laboratory's mission of stockpile stewardship because they provide data needed to test and improve models, algorithms, and computational methods in large-scale simulation codes. These codes are used in the annual assessment and certification of the nuclear stockpile and to address significant findings (problems that require further investigation), as needed. Apparent improvements in simulation codes, achieved with more powerful computers and new and improved models, must be evaluated scientifically to determine their applicability to stockpile stewardship requirements. For example, the fluid dynamics algorithm in a hydrodynamics code must track the progression of fluid flow from an unstable but deterministic flow, through a more complex flow with both deterministic and stochastic components, and subsequently through transition into turbulence. High-resolution model-testing data must challenge the code over a wide range of spatial scales and as a function of time (Figure 1). Experimenters must develop relevant diagnostic techniques and acquire data that will help code developers and designers determine model validity and the limitations of the code that uses the model.

Figure 1. When a planar shock wave impacts three gas cylinders, it creates the three vortex pairs, seen in cross section, by illumination with a thin sheet of laser light. These successive snapshots of the vortex pairs at an earlier time (left) and later time (right) show how the flows become highly distorted en route to turbulence.

Gas Shock-Tube Experiment

The gas shock tube is an excellent example of a validation experiment that is used to investigate fluid dynamics relevant to weapons physics by investigating fluid instability at interfaces between fluids of different densities as they mix and become turbulent after impact by a shock wave (Figure 2). A gun-like apparatus launches a shock wave that becomes planar before accelerating one or more gas columns. Each column is made of slowly flowing sulfur hexafluoride, a heavy, nontoxic gas that serves as the target. The interface between the sulfur hexafluoride and surrounding air becomes unstable and distorts rapidly as the gases mix and become turbulent. Such instability growth, known as Richtmyer-Meshkov Instability, is a weapons physics issue known since the Manhattan Project. Today's experimental techniques and modeling capabilities provide better quantification of the instability process, so our goal is to demonstrate the predictive capability of such flows that occur in weapons.

Current experimental techniques include the flow system that creates the sulfur hexafluoride column, laser-sheet illumination of the post-shock flow, velocimetry based on particle tracking, and high spatial resolution (using large image chips) that is comparable with computed images. The application of particle image velocimetry (PIV) is an especially important advance in our fluid-instability studies. PIV is a diagnostic method used extensively with low-velocity flows, but it is rarely used with flows accelerated by shock wave. The technique involves adding microscopic tracer fog particles to the flow and illuminating the traced flow with a thin sheet of light to photograph a cross section of the flow. Two photographs taken stroboscopically in rapid succession produce a double exposure with observable discrete particles. Using a correlation-based analysis of tracer-particle clusters, we map the flow during the time between exposures. Using the measured time interval between photos, we determine the velocity vector of each particle cluster and thereby produce a two-dimensional (2-D) map of the velocity field for a Mach 1.2 flow.

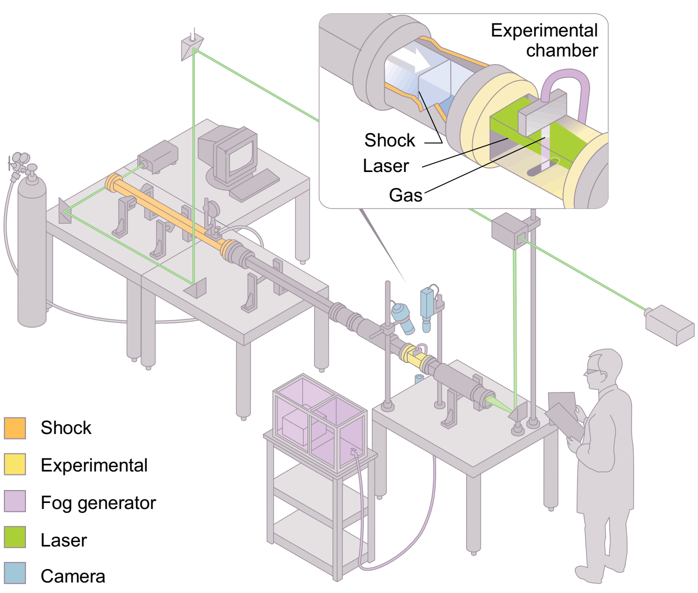

Figure 2. The shock-tube apparatus consists of a long, gun-like tube to produce the shock wave; a laser and cameras to measure the flow; and gas-handling equipment to prepare the gas targets.

This velocity-field measurement significantly enhances the value of the experiment for validation because testing a velocity field calculated by fluid simulation is a more sensitive evaluation of fluid dynamics modeling than comparing only the experimental and simulated density fields. Figure 3 compares measured and simulated velocity fields and vorticity fields that capture the flow swirl. Note that the simulation accurately calculates the velocity field at large spatial scales (several millimeters), but fails to calculate the experimentally observed submillimeter structure, the microvortices. Consequently, this validation experiment has been used to determine a code limitation; improved modeling ensures the needed improvements.

Planar laser-induced fluorescence (PLIF) is yet another experimental validation technique. Using a fluorescent vapor to trace the flow, PLIF dramatically increases spatial resolution, as seen in the PLIF images of three heavy-gas cylinders accelerated by a planar shock wave (Figure 1). These experiments with PLIF have demonstrated science-based prediction by revealing a subtle effect in the two-cylinder experiments that was predicted theoretically but was not detected earlier with fog-traced flow.

Shock-Tube Analysis Methods and Data Interpretation

Advanced analysis methods are being developed to quantify the comparison between high-resolution data and simulation results. We are moving beyond the "viewgraph norm" that involves subjective visual comparison of experimental and calculated images. For example, air-sulfur hexafluoride boundaries can be analyzed with fractal-dimension analysis, which quantifies the complexity of this interface. Another useful technique is the separation of the deterministic (predictable) flow from the stochastic (variable) portion of the flow, which can be predicted only statistically. This decomposition of shock-tube flows into deterministic and stochastic features is possible because the flows are sufficiently reproducible that we can do ensemble-averaging of dozens of data shots. Such decomposition is especially helpful to theorists because the deterministic portion of the flow is susceptible to calculation by Euler equations, whereas the stochastic features require a turbulence model. Wavelet analysis also examines flow morphology. Other physics-based analysis methods are being developed as part of a Laboratory-Directed Research and Development project. These methods are being applied to radiographic data.

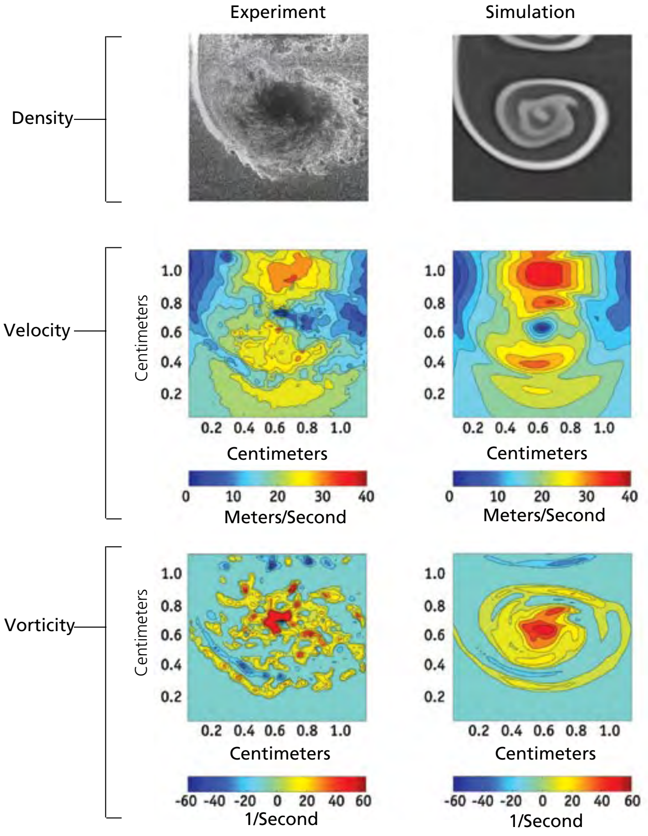

Figure 3. Experimental data are compared with code output by using 2-D density, velocity, and vorticity fields. Large scales (several millimeters) show good agreement but significant differences appear at small scales (submillimeters), where experimental data show more structure than the code results.

One important physics model validation study with the shock-tube preceded the investigations of heavy-gas cylinders. Instead of sulfur hexafluoride cylinders, we used a thin layer of sulfur hexafluoride with corrugations on both up- and downstream sides of the layer. This experimental target, a "gas curtain," evolved into a complex flow (Figure 4). Before the advent of PIV capability, we developed a physical model—the Jacobs model—to describe the growth rate of this pattern. Flow "circulation," a measure of swirling motion, is the adjustable parameter used to fit the Jacobs model to experimental data. Measuring the circulation with PIV showed excellent agreement with values estimated from the Jacobs model, thereby producing a showcase example of model validation.

Scaling and Uncertainty Quantification

Obviously, the parameters of a shock-tube validation experiment are far from those of a nuclear detonation test, which is prohibited by international treaty. However, our fluid-instability experiments are designed to address only the fluid dynamics of simulation codes for which the relevant scaling parameter is the Reynolds number, the ratio of inertial to viscous forces. Because the Reynolds number in experiments is well above laminar-to-turbulence transition, the experiments can be used to validate codes that calculate this transition in highly distorted flows driven by shock waves.

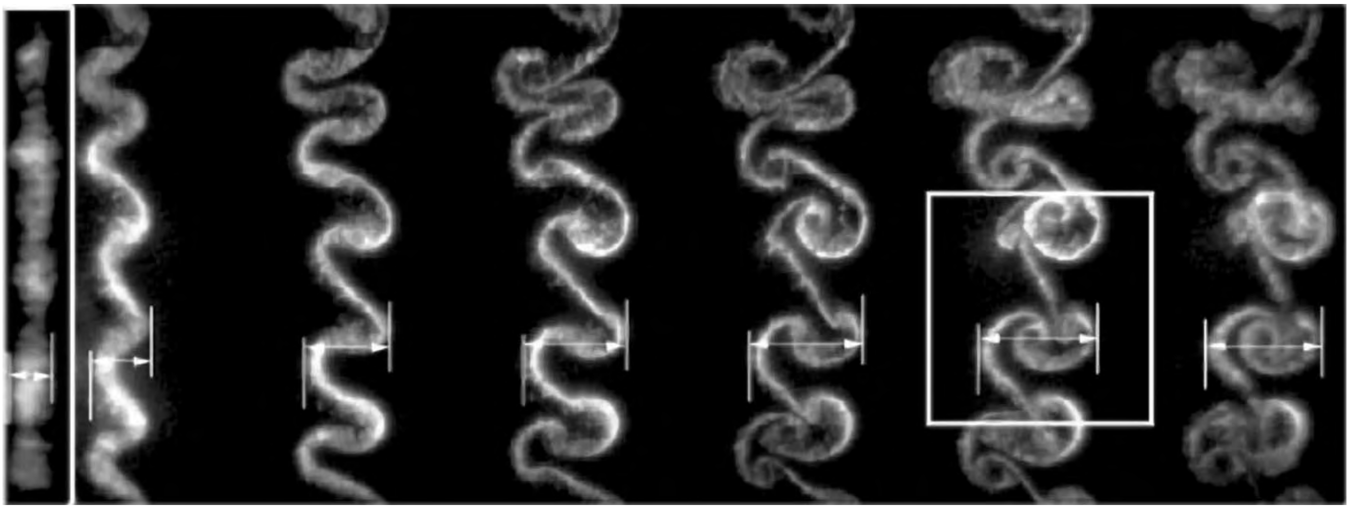

Figure 4. Series of experimental images of the cross section of a heavy-gas flow driven by a shock wave (i.e., gas-curtain experiment) showing how the swirling motion becomes highly distorted just before it becomes turbulent.

Shock-tube experiments do address the current emphasis on uncertainty quantification. Because fluid instability is highly nonlinear and because we perform hundreds of experiments with nearly identical initial conditions, we produce large quantities of data by applying ensemble-averaging and statistical analyses to determine the variability of important quantities and the sensitivity of one variable to another. These data enable precise determination of error and uncertainty, unlike most integrated experiments (that utilize only one or a few shots) that rely on calculations to assess uncertainty. Thus, simulations of these validation experiments can assess code uncertainties—another benefit of validation exercises.

Uncertainty quantification is especially important for phenomena that are highly nonlinear, including much of the physics of a nuclear weapon. Thus, effective validation science must include experimental data for which subtle changes in initial experiment conditions produce profound changes in observable phenomena. Ultimately, we are concerned about subtle changes in the initial state of a weapon that could lead to significant changes that could lead to nuclear detonation. An example of phenomena with high sensitivity to initial conditions is a "bifurcated flow," in which distinctly different flow patterns are observed when initial conditions change microscopically.

This phenomenon of flow bifurcation is clearly evident in the simultaneous acceleration of three heavy-gas cylinders by a planar shock wave. Typical data in four experiments with the same nominal initial conditions show markedly different flow features (Figure 5). Computer simulations have calculated one of these four patterns, and work is ongoing to learn which subtle initial differences can lead to large differences in postshock flow. As researchers learn how to simulate the other three flow patterns, they will have increased confidence in their fluid dynamic algorithms. This work will lead to greater awareness of code uncertainties, which they will quantify. Thus, this experiment not only challenges the hydrocodes but leads to increased confidence in code credibility and in quantitative understanding of code uncertainty.

Figure 5. Flow bifurcation. Each pair of images shows the flow evolution of three heavy-gas cylinders that are accelerated simultaneously by a planar shock wave. Each of the four image-pairs shows flow during an experiment that has nearly the same initial conditions as the others. The strikingly different shapes of the flows demonstrate the extreme sensitivity of the flow on initial configuration. This sensitivity and strong nonlinearity produces a flow bifurcation that constitutes an outstanding code validation experiment.

Identifying strong nonlinear phenomena and quantifying uncertainty have other important benefits for the weapons program. The researcher performing the calculations—whether designer, code developer, or analyst—will be calibrating his or her judgment about nonlinear fluid dynamics and about the code itself. Thus, a validation exercise that has challenging data like the triple-cylinder experiment validates both the code and the researcher, who learns the code's capabilities and limitations in addition to learning the physics of the experiment. Therefore, validation science is the cornerstone of predictive capability.

Detonation Shock Dynamics Experiment

We can conduct yet another type of validation experiment in support of the detonation shock dynamics (DSD) model. DSD is an approximation to the reactive Euler equations that allows computationally efficient tracking of curved detonation waves. DSD bypasses poorly known attributes, such as equation of state for the reacting explosive mixture and the reaction rate law, in favor of a direct experimental calibration. The resulting mathematical function describes the relatively simple net effect propagation of many complex processes on the detonation shock.

The classic experiment in these studies is the rate stick, a long cylinder of high explosive that is initiated at one end. Measuring the detonation velocity through the charge and observing the detonation as it emerges from the cylinder end, we can reconstruct the curved wave shape in the stick. Ideally this procedure is repeated for a range of charge diameters. Wave shape information for this particular geometry is used to calibrate a propagation law, which the DSD model processes to compute general geometries. These data have validated a DSD model that has been implemented in a programmatically important code at Los Alamos.

Silver Jet Experiment at pRad

A third example of a validation experiment is the silver jet experiment. Driven by high explosives, it creates a metallic (silver) jet and is diagnosed at the proton radiographic (pRad) facility. Code predictions about the shape of a 2-D, blade-shaped jet of silver showed good agreement with pRad images. However, the code also was tested by applying PIV analysis to the pRad images, interpreting persistent features in the images as tracer particles. This analysis produced velocity-field data even though the experiment was not designed for PIV. The result is in good agreement with velocity profiles in the data and simulation codes. Consequently, we have greater confidence in the code's ability to calculate these flows.

Validation Science

In conclusion, validation science compares data from simulation results with data from low-cost experiments in order to validate models and codes, particularly Advanced Simulation and Computing (ASC) codes. Because validation science strongly impacts the credibility of our codes, it is a growing field. The basis for successful validation science is vigorous collaboration among experimenters, analysts, theorists, and code simulators. It is important to note that the three validation experiments discussed here are only a few of the numerous collaborations that Los Alamos and other researchers are using to support science-based validation of the nation's nuclear stockpile. ✹

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Validation experiments have provided enormous benefits to the Laboratory, both scientifically and in academic interaction. The fluid instability project began by collaborations with Jeff Jacobs (University of Arizona) and his students. Then a series of postdoctoral researchers pushed the frontiers of scientific understanding and diagnostics expertise: John Budzinski, Sanjay Kumar, Mark Marr-Lyon, Kathy Prestridge, Paul Rightley, Chris Tomkins, and Peter Vorobieff. Most of them continued their careers as Laboratory staff. Other Los Alamos collaborators on the fluid instability work have been Matt Briggs, Cherie Goodenough, Jim Kamm, Bill Rider, and Cindy Zoldi. John Bdzil, Tariq Aslam, Larry Hill, and many others conducted detonation shock dynamics research. Eric Ferm and Larry Hull performed the silver jet experiments that were analyzed by Kathy Prestridge.

The contributions of many national laboratory and university researchers have promoted a strong culture of science-based prediction at Los Alamos, helping initiate and sustain our validation experiments and science-based predictions. For example, the structure of validation science has been described well by our SNL/NM colleagues, Tim Trucano and Bill Oberkampf. Jeff Jacobs' (University of Arizona) pioneering work on laminar jets and biacetyl-based PLIF led to early gas-curtain experiments; his theory provided the first test of model validation. The shock-tube team at the University of Wisconsin provided validation data for higher flow speeds, as requested by X-Division researchers. The contributions of the University of New Mexico's Peter Vorobieff have been invaluable in conducting experiments and developing innovative approaches to data analysis.

Atlas
Completes Move to NTS

Atlas is the world's first pulsed power system designed from the ground up to perform high-precision hydrodynamics experiments using electromagnetic drive. For more than a year now, Atlas has been involved in a major move. On October 7, 2002, a team from Bechtel Nevada (BN) arrived at Los Alamos to begin disassembling and packing and then shipping Atlas to the Nevada Test Site (NTS)—all 20,000 pieces of it. After the relocation is complete, BN will operate Atlas under Los Alamos direction and ownership. Los Alamos will lead the multi-laboratory physics program.

Most of the final construction details of the new Atlas facility in Building 6-922 at Area 6 of the NTS were completed in December 2003. The construction of a new high bay facility has been completed; mechanical installation of the pulsed power system has been completed; and electrical testing of the subsystems has begun. Experiments will resume in the new location later this year.

Atlas seems comfortably settled in its new home.

- Metal tankage and the oil system are complete.
- Most of the dielectric insulating oil has been delivered.
- The 24 electrical energy storage (Marx) units, the heart of Atlas, have been reassembled and temporarily installed in their tanks.
- The load protection switches, vertical transmission lines, and the current convoluting center section have all been assembled and installed.
- The modular charging supplies and high-voltage trigger systems have been installed, and final reconnections are being made.
- The new electromagnetic enclosure for the machine controls is complete, and the control system is being installed and reactivated.
- New laboratories for target support and imaging diagnostics are ready for engineers, technicians, and diagnostics scientists.

The next major step in the recommissioning process is the high-voltage testing of the energy storage units. These subsystem tests are to be followed by the electrical test of the full machine using a test load. After about 6 weeks of preparation in November and December 2003, testing of individual Marx units began in early January 2004, and about 20 units—five-sixths of the machine—had been successfully tested by the end of February.

In its new location Atlas, the world's most energetic laboratory pulsed power system, will continue to provide the capabilities for hydrodynamic experiments in high-precision, converging geometry in support of science-based stockpile stewardship. The system will support a range of experimental goals, especially those designed for validation of both legacy codes and new computer codes in the Advanced Computing and Simulation Program.

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The final details of the new home for the Atlas pulsed-power system are nearing completion. The painters are gone, and the landscaping is almost finished. As with a move into a new home anywhere in the nation, the joint LANL/BN Atlas team is unpacking the final boxes, storing the off-season clothes in new closets, arranging (relatively large and sophisticated) furniture, and getting dinner on the stove. The building is taking on a "lived-in" look.

The Atlas test program is conducted by the Bechtel Nevada operations team under the direction of Clark Thompson of Group P-22 (back row, center). Clark has been with the Atlas program since 1994.

Atlas is getting settled in its new home at the Nevada Test Site. In the outer ring of the assembly are the 24 Marx electrical energy storage units. The firing point is at the center of the assembly. The workers (bottom right) provide scale for the size of Atlas.

Nested Safety and Security Committee Process

The Nested Safety and Security Committee (NSSC) is a line-organization management system that drives continuous improvement in environment, safety, and health (ES&H) and security in the workplace. A vehicle for communications and problem solving, the NSSC process is an excellent decision-making tool that line management uses to establish and maintain ES&H and security standards, goals, and priorities at the Laboratory.

Structure/Meeting Levels

The Laboratory defines five levels in the NSSC process, in terms of attendance at meetings: team, group, division, directorate, and Director's Central Safety and Security Committee (DCSSC). Because NSSCs occur at all organizational levels, every Laboratory worker is included in at least one level.

"Team level" includes any subgroup of employees that report to a group-level manager. All workers on a team attend team-level meetings, which are chaired by a team leader. "Group level" includes all team leaders, others who report directly to the group leader, and all subcommittee chairs (e.g., the group may have established a subcommittee to look into criticality issues); group leaders chair the meetings. "Division level" includes all group leaders and others who report directly to the division leader, and subcommittee chairs (e.g., the division may have a subcommittee handling ergonomic issues); division leaders chair these meetings. "Directorate level" includes all division leaders, others who report directly to the associate director, and subcommittee chairs. The associate directors chair meetings at this level.

Dave Herbert, a Laboratory management/safety consultant and a member of the National Safety Council, is supporting the Laboratory's initiative to revitalize the NSSC process. He met with the DCSSC on January 8, 2004, and has briefed managers and supervisors of HSR, ESA, and NMT Divisions about the philosophy and implementation of the NSSC process. Herbert is available to meet with your team, group, or division to discuss the NSSC process; contact Linda Salazar at 667-4218, or e-mail lindasalazar@lanl.gov.

For more information about NSSC meetings and issues, see the March/April 2003 issue of Nuclear Weapons Journal*, p. 14.*

The DCSSC includes all associate directors and others who report directly to the director and subcommittee chairs. The Laboratory Director chairs the DCSSC; DCSSC subcommittees research issues and develop potential solutions for issues. To enhance communication flow, all nested committees meet monthly; information cascades both up and down the line-management chain.

All issues are created, recorded, prioritized, and tracked to closure in accordance with the Laboratory Issues Management Program, LIR 307-01-05.

Responsibilities

At all levels, committee members establish performance expectations, review performance against expectations, review incidents for lessons learned—individually or collectively—and assign corrective actions, and review subcommittee reports on accomplishments. At the group, division, directorate, and DCSSC levels, committee members review new or modified requirements that are applicable to the Laboratory and recognize noteworthy and awardable accomplishments.

Team-level committee activities also include

- reviewing walk-around findings,
- soliciting employee ES&H and security concerns and ideas for improving ES&H and security performance, and
- reporting on the status of previously identified issues.

Group-, division-, and directorate-level committee activities include

- developing and implementing plans for reducing ES&H and security incidents in the various organizations and
- reviewing new or modified requirements, as they are applicable to the organization.

The DCSSC is tasked with establishing and implementing ES&H and security plans and establishing NSSC performance expectations. It also

- reviews incidents that occurred since the last DCSSC meeting and corrective actions adopted by the lower-level organizations, and if necessary, assigns institutional corrective actions and champions to ensure implementation of the actions;
- reviews the status of issues that pertain to ES&H and security from the Issues Management System; and
- addresses new institutional issues, using a formal decision-making process.

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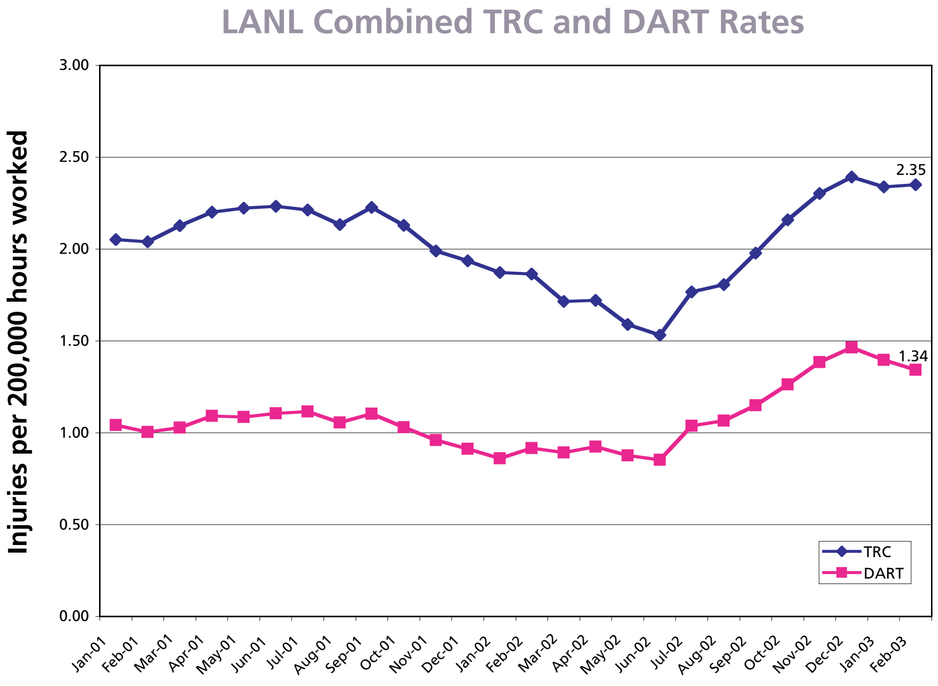
The Laboratory's combined injury and illness rates reflects 12-month rolling averages, normalized to 200,000 hours, to equal 100 full-time employees. The TRC line documents total recordable cases; DART data include days away from work, restricted work activity, or transfers to another job.



Sustainable Design

Sustainable design may appear to have little practical application in the nuclear weapons program. However, substitute the term with “design of high-efficiency buildings,” and the benefits of such a process are more readily apparent. Structures that are designed to maximize energy conservation and minimize waste ensure a better future for the institution and for individual programs. In addition to being worker and environmentally friendly, the rationale is simple—energy conservation and waste minimization reduce operational costs, leaving more resources available for the dual Laboratory missions of stockpile stewardship and scientific research. Currently, plans for nine strategic facilities are in progress at Los Alamos; one of these facility plans included a study of sustainable design principles.

Conserving Energy Equals Cost Savings

Sustainable design ensures energy conservation by incorporating energy-efficient features and systems during facility planning. These measures may include induction electric lighting and occupancy sensors, energy-efficient chillers, and high-performance windows. Taking advantage of natural site features such as topography, sunlight, and shade optimizes a building’s orientation and can save thousands of dollars in energy-related operational costs. A successful example of sustainable design is the National Renewable Energy Research

NREL’s thermal test facility is an example of good sustainable design

Laboratory (NREL) in Golden, Colorado. This 10,000-square-foot thermal test facility is an open-space laboratory/office building that utilizes many passive solar and energy-efficient features. Its design significantly lowered its energy-related operational costs, which are 63% less than if the building met only Federal Energy Code (10 CFR 35) requirements. This cost saving includes a 50% energy reduction and a 30% peak power reduction; approximately 75% of the building's lighting needs are met by daylight.

Minimizing Waste Maximizes Efficiency

Senior management requested an evaluation of the impact that eliminating specific waste streams would have on Laboratory operations. In response, a case study was developed using the proposed Characterization of High Energy Materials (CHEM) Laboratory, part of the DX Division strategic facility plan. The study was undertaken to determine whether sustainable building design could significantly reduce or eliminate waste streams and lead to substantial cost savings and increased worker productivity over the lifetime of the building. The results of the study were significant.

- Because operations in a building like the proposed CHEM Laboratory typically produce approximately 14,000 gallons of high explosive (HE)-contaminated wastewater annually, designing the building to minimize or eliminate waste streams would create substantial cost savings. Although most sustainable design studies examine only energy efficiency and the recycled materials used during construction, this study involved designing the building such that wastewater containing trace HE and perchlorates could be cleaned on-site and reused in the lab equipment washer.

- A "waste-free" building could increase employee productivity, as workers would spend less time in cleanup-related activities. Employee salaries account for more than 80% of the estimated lifetime budget of any facility and dwarf expenditures for utilities, construction, maintenance, and equipment. By eliminating or recycling just the aqueous part of the HE waste stream, DX-2 could realize lifecycle savings of up to $1.7 million (not discounted) due to gains in worker productivity.

- The proposed CHEM Laboratory design is "flexible," meaning that different treatment technologies for the various waste streams could be installed inside the building without drastic reconfigurations as technologies change or become available. Instead of sealing all piping underneath a concrete slab base, the planned design features a watertight basement where equipment could be accessed easily, as needed. Because it is watertight, the basement would contain all spilled or leaked liquids, preventing liquid waste spills into the environment and reducing the level of involvement with state and federal regulators. Savings could be realized in potential cleanup and regulatory compliance costs.

The DX Division case study shows that the cost savings of sustainable design will pay for the building within nine years. Numerous other demonstrations and studies have shown that energy conservation and waste minimization—both key considerations of sustainable design—are two simple business practices that cut the ever-rising costs of facility operation throughout the lifetime of a building. Such savings translate directly into improved worker efficiency and cost containment, the heart of sustainable design. ❋

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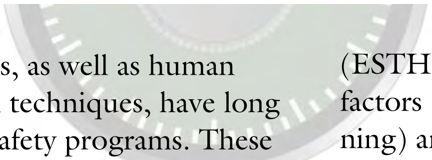
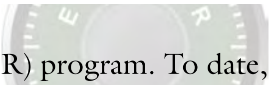
For more information on the CHEM Laboratory case study, see J.R. Stine et al., *Waste Minimization or Elimination Through Sustainable Building Design: The Characterization of High Energetic Materials (CHEM) Laboratory Building: An NNSA Waste Stream Elimination Case Study,* Los Alamos National Laboratory report LA-UR-03-2317.

Security and Safety
Tools that Work to Improve Both





Hazard- and risk-assessments, as well as human error analysis and mitigation techniques, have long been mainstays of effective safety programs. These and other safety tools reveal that worker errors contributing to or resulting in accidents are often the consequence of ineffective system configurations, process conditions, or individual employee characteristics that combine to create the proverbial "accident waiting to happen." As a result, state-of-the-art safety management approaches don't automatically regard employee error as the cause of system failures; instead, they evaluate such errors as potential symptoms of trouble elsewhere in the system or organization. While it's undoubtedly true that human errors can never be completely eliminated, the good news is that those "induced" by various system/process/employee features can be identified and controlled through traditional systems analysis, hazard assessment, and human error mitigation techniques.

Recognizing the many commonalities between good safety and security practices, LANL leveraged its Integrated Safety Management (ISM) and Integrated Safeguards and Security Management (ISSM) programs and formed a team of safety, security, human error, and organizational experts from S and D Divisions to review past LANL security incidents. This team concluded that many of the *system-induced human errors* that make accidents more likely could also be contributing factors to security incidents and that by identifying the factors that make errors and incidents more likely, mitigation strategies that effectively target these contributors could be developed.

These findings led to creation of the Enhanced Security Through Human Error Reduction (ESTHER) program. To date, 16 situational factors (e.g., distractions and failures in work planning) and 12 human factors (including fatigue and poor judgment) have been identified as potential contributors to 4 kinds of errors:

- unintentional acts ("I didn't mean to do that"),
- unintentional failures to act ("I forgot to do that"),
- intentional but incorrect acts ("I thought that's what I was supposed to do"), and
- intentional but incorrect failures to act ("I didn't think I was supposed to do that").

In addition, ESTHER can account for *breaches*—that is, the deliberate, nonmalevolent circumvention of required procedures or practices ("I knew I wasn't supposed to do it that way, but..."). ESTHER analyses can be applied retrospectively following a security incident as well as prospectively to discover and eliminate error-likely conditions. From both these uses, lessons learned will be developed and shared to reduce the likelihood of future errors/incidents.

ESTHER targets safety and **security breaches** and **practices**

In some cases, ways to minimize the influence of discovered contributing factors—such as workplace distractions and clutter, deficient work planning, and failure to ensure that required materials are available before starting the task—will be obvious and within the employees' control. In other situations, line management must become involved to control factors such as improving procedures that are believed to be deficient, recommending fitness-to-perform evaluations when employees take certain prescription medications, or deciding if skill refresher training is needed. More complicated interventions involving job re-design to eliminate overly complex tasks, improving inappropriate local security cultures and practices, and dealing with management system deficiencies will probably require the support of error assessment experts, human resource professionals, and perhaps a senior management representative.

ESTHER enhances security not only by minimizing the inadvertent release of classified information through error but also by reducing the security resources devoted to these activities, thereby enabling limited resources to be directed toward prevention of—and response to—other security threats. Moreover, by defining error-likely conditions, ESTHER provides the basis of constructive action and positively motivating staff through rewards and recognition programs.

ESTHER analysis services are available at no cost to conduct or guide assessments of errors and incidents and reduction efforts across the Laboratory. ✸

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di0206400091

Avoid distractions. Take extra precautions—have a co-worker double check your work—when you're preoccupied with other matters but are required to handle classified information.

di0206400191

Don't put deadlines before safety or security. Plan ahead and work with your manager to avoid or resolve conflicts that can place classified information—and perhaps your job—at risk.

Reduced clutter reduces the potential for security violations. Arrange and maintain your work area so that it's easy to keep track of classified information and materials.

Note: These photos were staged solely to illustrate safety/security hazards in the workplace.

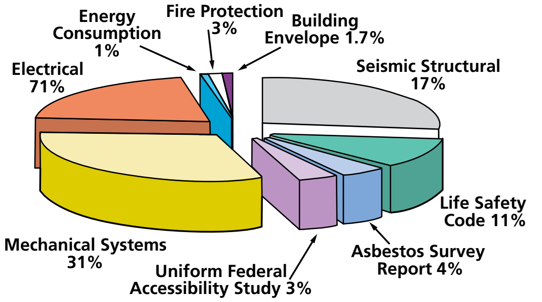
NSSB construction site, with the Nicholas C. Metropolis Center for Modeling and Simulation in the background.

NSSB Replaces Aging SM-43

The aging process has taken its toll on SM-43, the Laboratory's 45-year-old Administration Building. No longer reliable, the building has significant functional, security, and safety issues, and is expensive to operate. All these deficiencies potentially jeopardize the Laboratory's mission of nuclear weapons stockpile stewardship.

Not only are most major systems in the old building inadequate for today's needs—unforeseen in the 1950s—they do not comply with current DOE or uniform building code standards for office and light laboratory use.

Built long before the phenomenon of worldwide dependence on office- and security-related electronics, SM-43 is not configured to meet the requirements of today's high-powered, high-speed communication, research, and security systems. In short, SM-43 is no longer a reliable location for the Laboratory's high-tech, electronically dependent systems. It also is expensive to operate; energy costs are $445,000 more per year than for a modern building of similar size.



As early as 1996, the costs of modernizing SM-43 were an estimated $9.45M, not including seismic upgrades.

Artist's rendering of the completed National Security Sciences Building.

National Security Sciences Building

SM-43's replacement, the new National Security Sciences Building (NSSB), will provide efficient, modern, productive research and office facilities. Intended for occupancy in 2006 and equipped with 21st-century electronics, the new NSSB will be an eight-story structure of approximately 275,000 square feet; it will include a lecture hall and a new 600-vehicle parking garage. Most important to the Laboratory's Stockpile Stewardship Program, the new facility will provide a safe, reliable location for DOE's cyber-based weapons program, with state-of-the art cyber security and electronic resources that will accommodate changes in priorities and work flow.

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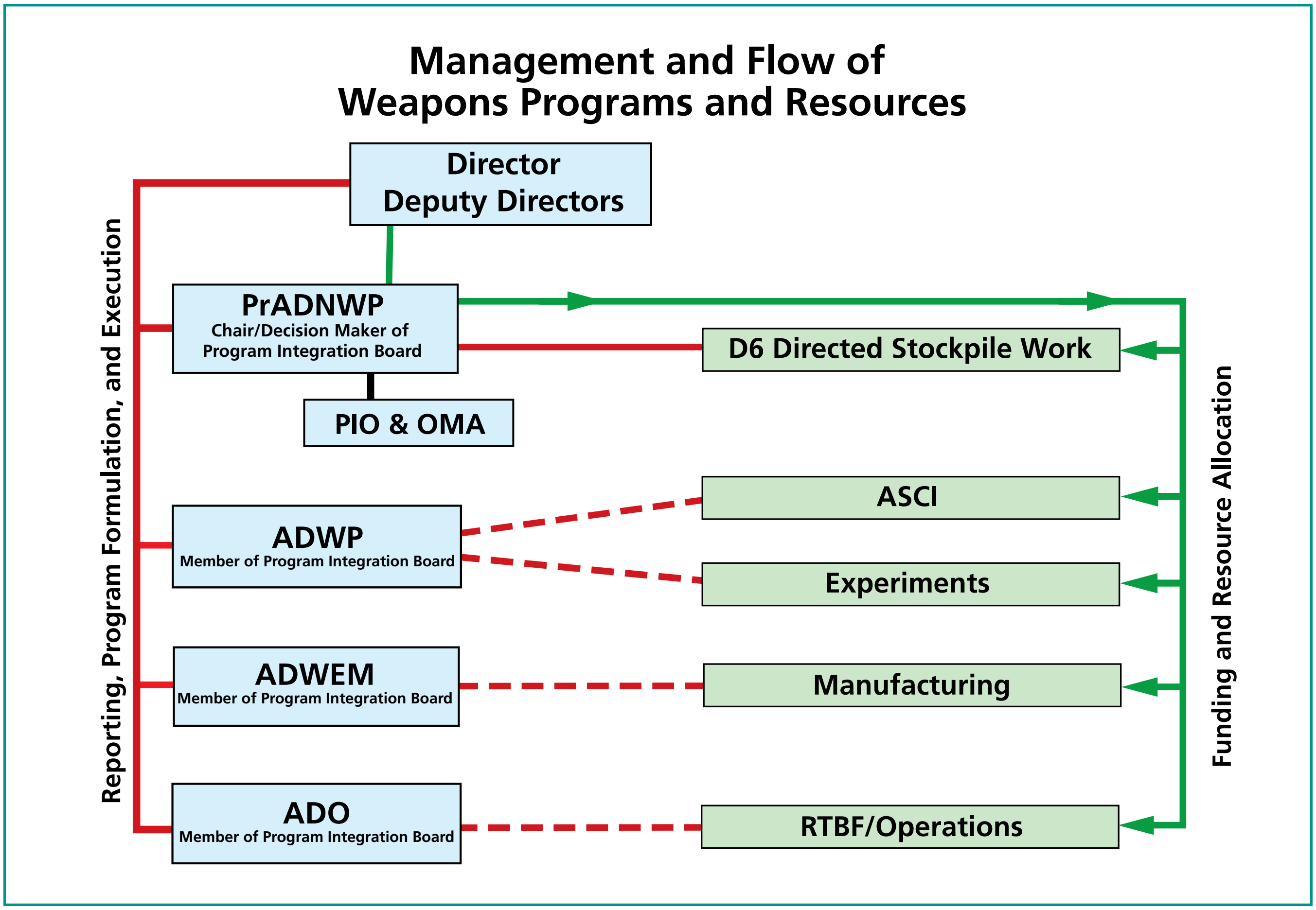
Point of View *continued from page 1*

and manage project funds allocated from the new directorate, while still supporting the program formulation and line functions in the Weapons Physics, Weapons Engineering and Manufacturing, and Operations Directorates. The Deputy ADs want to move quickly to merge the current program boards under the PIB—Stockpile Assessment and Certification, Experimental Assessment and Validation, Simulation Capability, and Manufacturing—into a single coordination board linking program directors and division leaders for all sectors of nuclear weapons work at Los Alamos.

The job of the Weapons Physics Directorate, currently led by Sue Seestrom as acting AD, will continue to be certification. Weapons Physics line managers will determine the resources needed for that job on an annual and on a continuing basis, and the new PrADNWP will balance the needs of the entire weapons program and the rest of the Laboratory against those requirements. The Weapons Engineering and Manufacturing Directorate, led by Rich Mah, will continue to focus on engineering and manufacturing for the stockpile. A similar balancing is at the core of the relationship involving the line managers within Weapons Engineering and Manufacturing and PrADNWP. This give and take between line and program management will provide clear allocation of resources, project scope, and most importantly, expectations.

Balancing Inherent Risk

When Director Nanos and I presented these changes to Laboratory managers recently, we were asked whether this is a return to matrix management. Fundamentally, it is. Without some ongoing tension between line and program management, an organization as large and complex as the Laboratory cannot operate effectively. Every other successful large technical organization is built around a matrixed structure; there is simply no other way to properly balance the inherent risk in our program. We want to retain the strong, direct, and creative contributions of our division and group managers in setting the course and making the program work.


Management and Flow of Weapons Programs and Resources

At the same time, we need better overall strategy, accountability, and risk-based leadership from a program organization that represents the Laboratory to our customers.

By the time you read this, Rich Mah will have begun the process of improving how we accomplish our important manufacturing work. As the Laboratory's manufacturing role has increased in recent years, it has become clear that managing materials, engineering, and manufacturing activities across several divisions and directorates may not be optimal and that our Laboratory can do much more to align itself with the quality revolution that has taken place in US manufacturing. The goal of this realignment is to ensure that everything we make for experiments in the stewardship program or for replacement of stockpile components is of the highest quality and is produced on time and within budget, using the quality processes that will prevail in the 21st century.

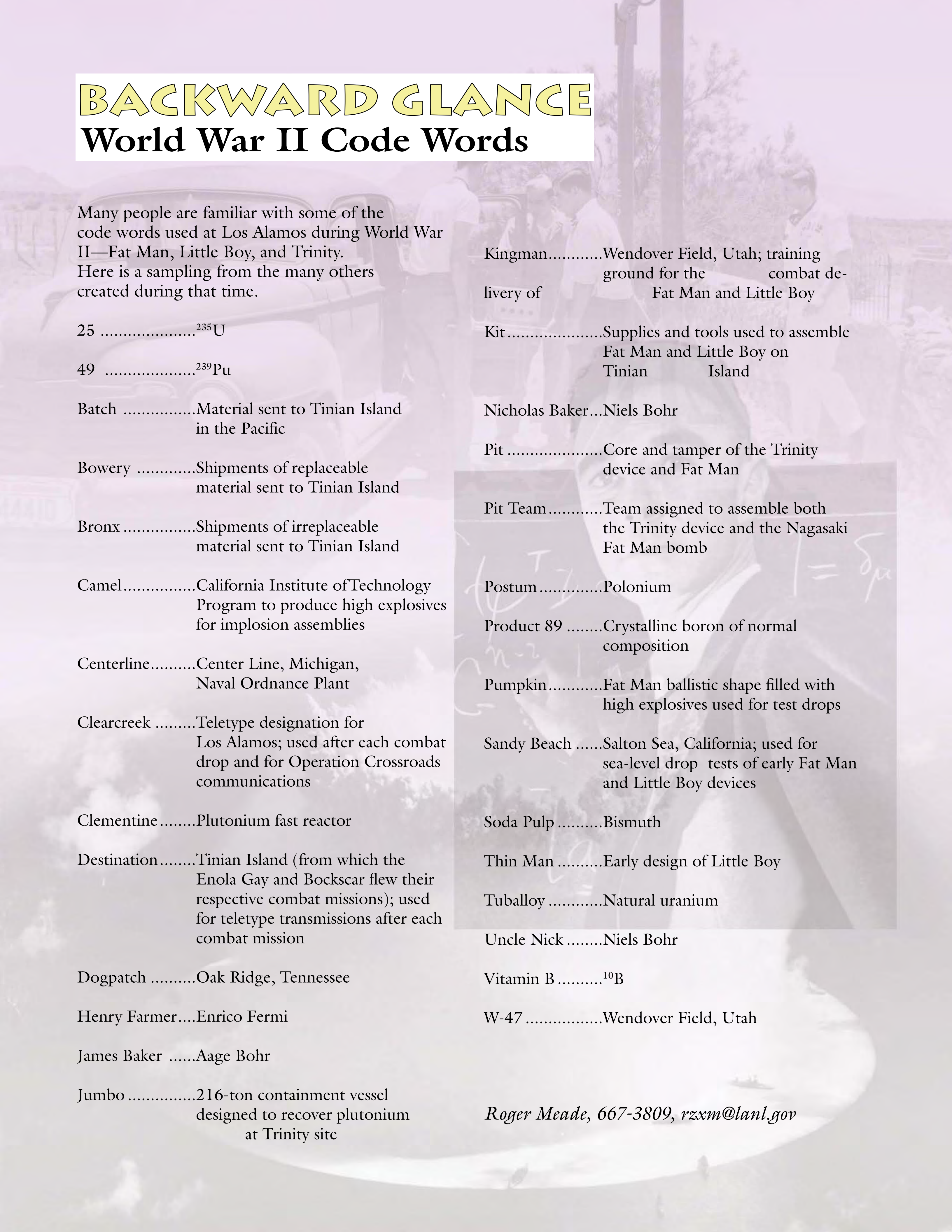
I hope all of you working directly within or indirectly supporting the weapons program take the time to examine these changes and identify how you can contribute to making this transition both smooth and truly innovative. I look forward to hearing your comments and especially your suggestions on how we can more effectively and efficiently carry out the mission entrusted to us in sustaining the nuclear deterrent.

Organizational Acronyms and Abbreviations

ADO	Associate Director for Operations
ADWEM	Associate Director for Weapons Engineering and Manufacturing
ADWP	Associate Director for Weapons Physics
BN	Bechtel Nevada
BWXT	BWX Technologies, Inc.
D	Decision Applications Division
DOE	US Department of Energy
DX	Dynamic Experimentation Division
ESA	Engineering Sciences and Applications Division
ESA-TSE	Tritium Science and Engineering Group
HSR	Health, Safety, and Radiation Protection Division
LANL	Los Alamos National Laboratory
LLE	Laboratory for Laser Energetics, University of Rochester
LLNL	Lawrence Livermore National Laboratory
MST	Materials Science and Technology Division
MST-7	Polymers and Proteins Group
MST-8	Structure/Property Relations Group
NMT	Nuclear Materials Technology Division
NMT-16	Nuclear Materials Science Group
NNSA	National Nuclear Security Administration
NREL	National Renewable Energy Research Laboratory
NTS	Nevada Test Site
P	Physics Division
P-22	Hydrodynamics & X-Ray Physics Group
PrADNWP	Principal Associate Director for Nuclear Weapons Programs
S	Security and Safeguards Division
SNL/NM	Sandia National Laboratories/ New Mexico
T	Theoretical Division
T-1	Theoretical Chemistry and Molecular Physics Group
UC	University of California
UK	United Kingdom
X	Applied Physics Division

BACKWARD GLANCE

World War II Code Words



Many people are familiar with some of the code words used at Los Alamos during World War II—Fat Man, Little Boy, and Trinity. Here is a sampling from the many others created during that time.

25	^{235}U
49	^{239}Pu
Batch	Material sent to Tinian Island in the Pacific
Bowery	Shipments of replaceable material sent to Tinian Island
Bronx	Shipments of irreplaceable material sent to Tinian Island
Camel	California Institute of Technology Program to produce high explosives for implosion assemblies
Centerline	Center Line, Michigan, Naval Ordnance Plant
Clearcreek	Teletype designation for Los Alamos; used after each combat drop and for Operation Crossroads communications
Clementine	Plutonium fast reactor
Destination	Tinian Island (from which the Enola Gay and Bockscar flew their respective combat missions); used for teletype transmissions after each combat mission
Dogpatch	Oak Ridge, Tennessee
Henry Farmer	Enrico Fermi
James Baker	Aage Bohr
Jumbo	216-ton containment vessel designed to recover plutonium at Trinity site
Kingman	Wendover Field, Utah; training ground for the combat delivery of Fat Man and Little Boy
Kit	Supplies and tools used to assemble Fat Man and Little Boy on Tinian Island
Nicholas Baker	Niels Bohr
Pit	Core and tamper of the Trinity device and Fat Man
Pit Team	Team assigned to assemble both the Trinity device and the Nagasaki Fat Man bomb
Postum	Polonium
Product 89	Crystalline boron of normal composition
Pumpkin	Fat Man ballistic shape filled with high explosives used for test drops
Sandy Beach	Salton Sea, California; used for sea-level drop tests of early Fat Man and Little Boy devices
Soda Pulp	Bismuth
Thin Man	Early design of Little Boy
Tuballoy	Natural uranium
Uncle Nick	Niels Bohr
Vitamin B	^{10}B
W-47	Wendover Field, Utah

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