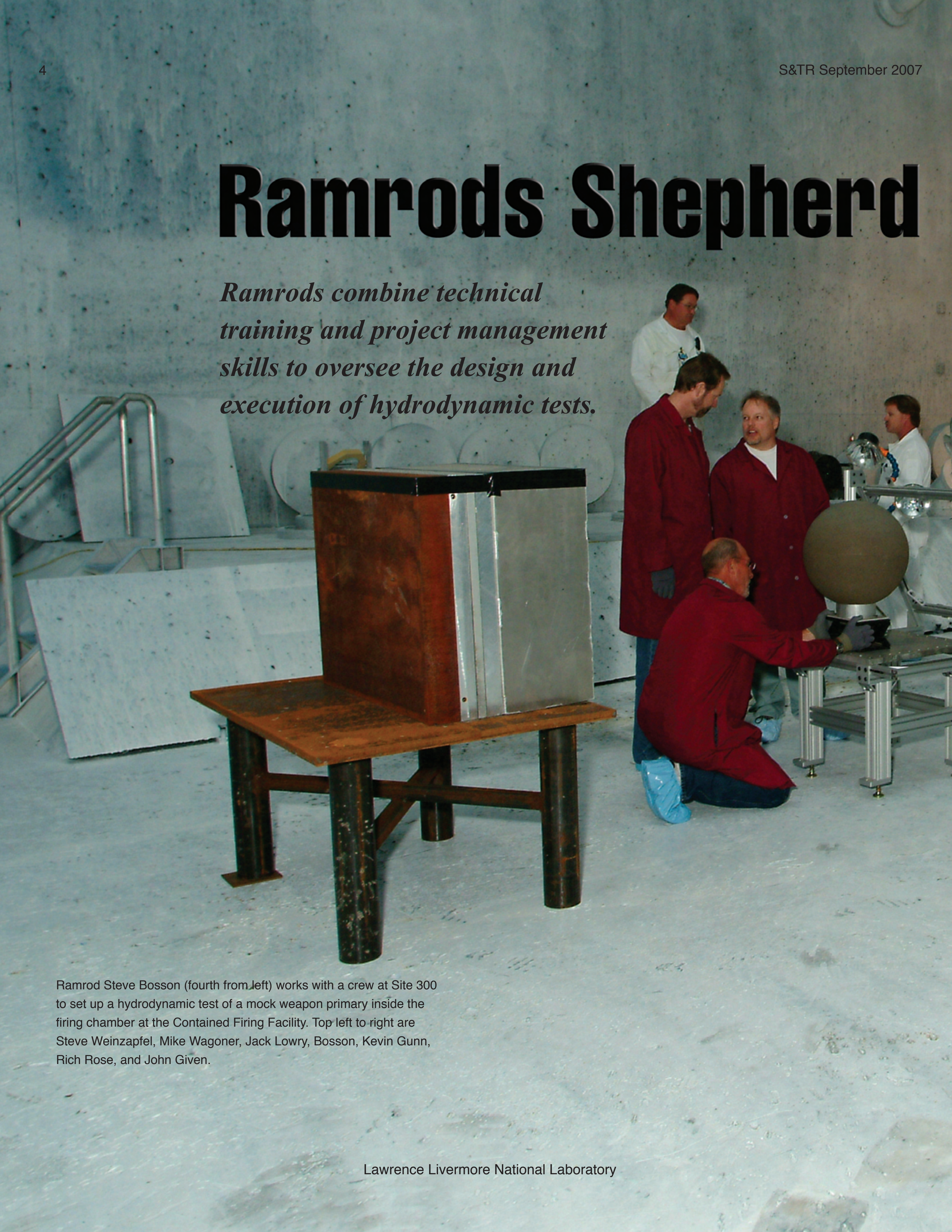
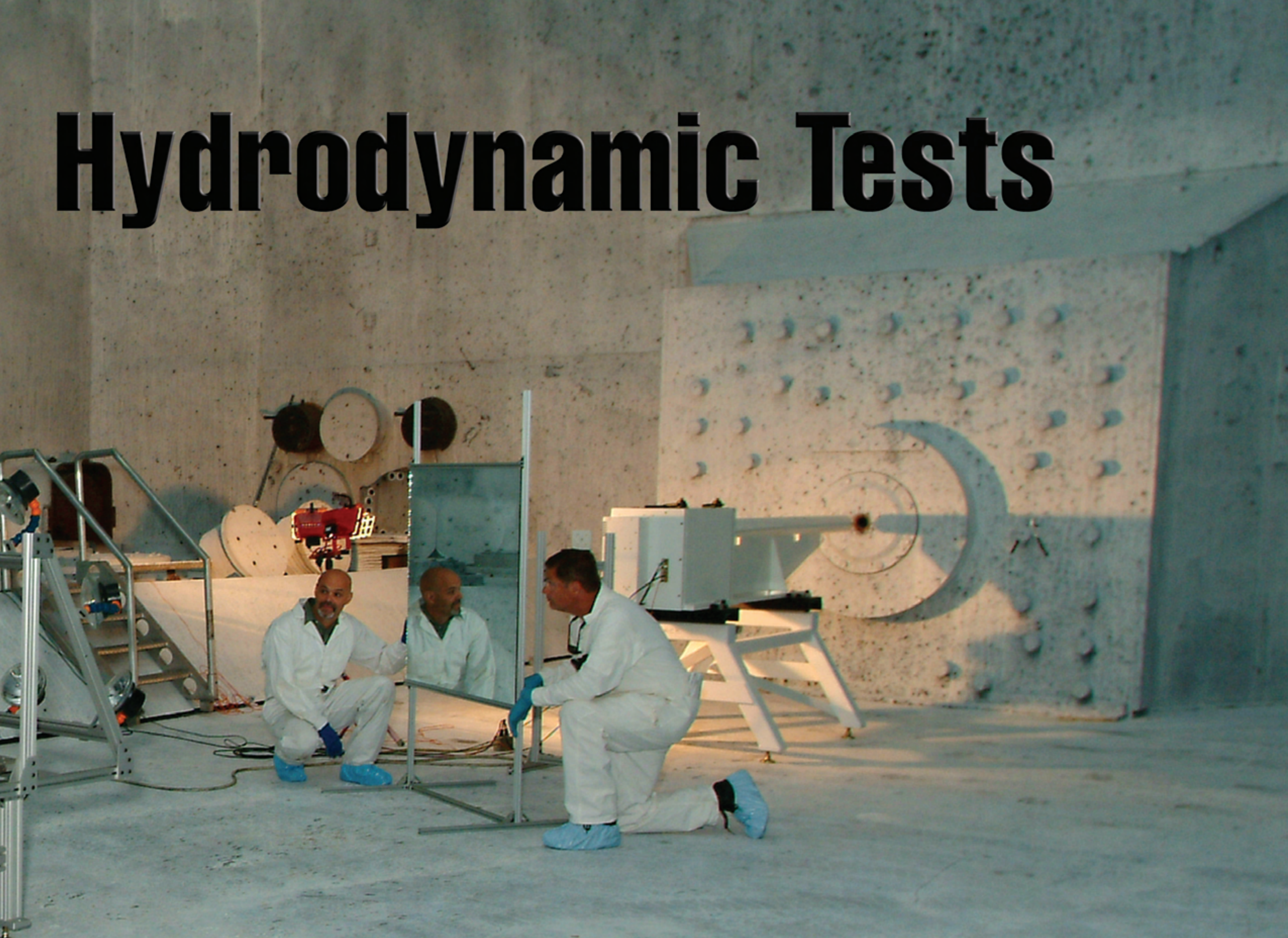
Ramrods Shepherd

Ramrods combine technical training and project management skills to oversee the design and execution of hydrodynamic tests.



Ramrod Steve Bosson (fourth from left) works with a crew at Site 300 to set up a hydrodynamic test of a mock weapon primary inside the firing chamber at the Contained Firing Facility. Top left to right are Steve Weinzapfel, Mike Wagoner, Jack Lowry, Bosson, Kevin Gunn, Rich Rose, and John Given.

Hydrodynamic Tests



In the Wild West, ramrods oversaw cattle drives, keeping the herd moving over great distances and making sure it arrived at market on the scheduled date. For nearly a half-century, ramrods at Site 300, Livermore's Experimental Test Site, have kept crucial nonnuclear weapon tests moving on schedule. From the earliest experimental design discussion to the shot firing—at times a year or more later—ramrods are key to ensuring that hydrodynamic tests are completed on time and within budget and provide maximal data.

"Ramrods represent the design physicist in the field," says Steve Bosson, one of four Livermore ramrods. Two other ramrods, Bob Kuklo and Stan Ault, also work on hydrodynamic tests, while ramrod Robert Mailhot works on dynamic tests of plutonium conducted at the JASPER (Joint Actinide Shock Physics Experimental Research) Facility at the Department of Energy's Nevada Test Site.

During a hydrodynamic test, the detonation of high explosives sends a shock wave through the test material, causing it to flow like a liquid. Liquid behavior is described by hydrodynamic equations, so the experiments are called "hydros." For each experiment, Bosson works closely with engineers, technicians, design physicists, and crews at Site 300's firing facilities. He works primarily at Bunker 801, which is the site of the Contained Firing Facility. (See the box on p. 7.)

Bosson's responsibilities include helping weapon physicists design a test, creating a detailed experiment "preshot" (an exhaustive list of test specifications), supporting experiment design and readiness reviews, assisting and monitoring the experimental setup, and choosing diagnostic instruments and overseeing their emplacement. He also defines important environmental, safety, and health procedures for the experiment and documents these procedures for the team's use. Finally, Bosson is responsible for reducing test data, reviewing test results with design physicists, and ensuring that test data are archived.

"The job of ramrod requires technical training as well as project management experience," says Jim Janzen, who leads the hydrotest experiments group in the Defense and Nuclear Technologies (DNT) Directorate. When Livermore researchers first began hydrotesting in the 1950s, weapon design physicists were assigned on a rotating basis to ramrod the experiments. By the early 1990s, the ramrod role became highly specialized, and the hydrotest group was formed in DNT.

"The ramrod is the interface between the designer and the bunker world of Site 300," explains Janzen. "He must be able to quickly identify problems or risks when he looks at an experimental setup.

"A great deal of experience is needed to perform the job of ramrod well," says Janzen. "Ramrods need an enormous amount of training in many subjects such as electronics, pressure, fabrication, safety, and classification. If a ramrod makes a mistake, he can't fix it because the shot is over in less than a thousandth of a second. Months of work can be wasted."

Most Valuable Experimental Tool

Bosson works mainly on nonnuclear hydrodynamic tests for the National Nuclear Security Administration's (NNSA's) Stockpile Stewardship Program, although he also supports experiments on shaped charges and new munitions development for the Department of Defense. For stockpile stewardship, hydros are the most valuable experimental tool for diagnosing device performance of the primary stage in modern nuclear weapons. Primaries typically contain a sphere of plutonium called a pit. Hydrodynamic tests are conducted to study the behavior of surrogate primary-stage materials in response to extremely high temperatures and pressures. These tests are essential for the continued refining of computational models that simulate nuclear weapon performance. (See the box on p. 8.)

Design physicist Juliana Hsu says, "In the 1950s and 1960s, long before we had good computer codes, we did a hydro a week. We would fire one, change the design, build another, and fire it. As our codes got better, hydros got fewer in number." In the absence of underground nuclear testing, Livermore scientists today rely on computational models validated by previous nuclear data and nonnuclear experiments such as hydros to certify the stockpile.

Hydros allow scientists to characterize the energy delivered from a layer of high explosives surrounding a mock pit, the response of this pit to hydrodynamic shocks, and the resulting distribution of pit materials when they are highly compressed. In this way, the experiments reveal the behavior of a nuclear weapon design from high-explosive detonation

At Livermore's Site 300, Bunker 801 became the Contained Firing Facility when the bunker's open-air firing table was enclosed in 2000. The enclosure reduces emissions to the environment and minimizes the generation of hazardous waste, noise, and blast pressures. Construction of the firing chamber required 3,200 cubic meters of concrete and more than 2,000 metric tons of steel reinforcement. Equipment and diagnostic upgrades at the facility have greatly improved the quality of data gathered from hydrodynamic tests of mock weapon primaries.

to the beginning of the nuclear chain reaction. In most tests, scientists study a full-scale weapon mock-up, including the secondary, the other key section of a weapon, even though the experiments focus on the primary.

The experiments involve first detonating chemical high explosives that surround a pit made of inert (nonfissile) material. The pit's surrogate metal has mechanical properties similar to those of plutonium, but it cannot produce nuclear reactions. "We test these surrogates to understand what the differences are so that the designers can confidently model the experiments for the surrogate metals," says Hsu.

Except for the nonfissile materials, experiments use the same parts and materials as stockpile devices, including the same high explosives. "We want the experimental device to be as close to the actual nuclear device as possible without using fissile material," says Matt Wraith of the Defense Technology Engineering Division in the Engineering Directorate.

Starts with Concept

Bosson works closely with three to five weapon design physicists a year. He monitors simultaneously three to four shots that are in various levels of readiness for testing. He and other ramrods are physically located near the design physicists in DNT to enhance coordination. "Steve and I have offices in the same building so it's easy for one of us to visit the other and stay on top of developments as a test date approaches," says Hsu.

Contained Firing Facility Protects the Environment

Most hydrodynamic tests, especially those that contain potentially hazardous materials, are conducted at the Contained Firing Facility (CFF). Constructed in 2000 at Bunker 801, this facility allows the Laboratory to conduct explosives tests indoors to minimize noise and reduce the emission of hazardous materials in the environment. While emissions from open-air testing at Site 300 meet current environmental standards, the CFF ensures that testing can continue as environmental regulations change.

A staging area and diagnostic equipment rooms with ports into the firing chamber are included in the facility, along with a support area, offices, and a control room from which the shot is fired.

At the heart of the facility is the firing chamber. Measuring 16 by 18 meters wide and 10 meters high, the chamber contains the blast overpressure and debris from detonations of up to 60 kilograms of high explosives. About 3,200 cubic meters of concrete and 2,000 metric tons of steel were used to construct the firing chamber, enough to build the frame of a 16- by 18-meter, 60-story office building. The firing chamber has 2-meter-thick floors and doors. Detonations are conducted above a 150-millimeter-thick steel surface (shot anvil) embedded in the floor. In addition, movable 50-millimeter-thick steel plates protect the chamber from shrapnel traveling as fast as 1.5 kilometers per second.

John Given adjusts gas flow that feeds into the firing chamber on the other side of the wall.

Rich Rose, Steve Bosson, and John Given monitor test preparations from the control room in the Contained Firing Facility.

Hydrodynamic experiments comprise several types of tests. Integrated weapon experiments (IWEs) re-create the exact specifications of a nuclear device except for the special nuclear material. IWEs can simultaneously address multiple performance-related questions. About six IWEs are conducted annually at Site 300's Bunker 801. Each one can cost more than $1.5 million.

IWEs are devoted to current stockpile stewardship issues or to refining supercomputer codes. The tests can evaluate new safety or security features or the aging of critical parts. Studying the effects of aging is important because many weapon systems are older than their intended design lifetimes. Over decades, materials can experience unanticipated changes from the intense radiation of nuclear devices.

IWEs include pin shots and core-punch tests as diagnostics. Pin shots evaluate the implosion of devices with a pin dome, a small sphere placed at the center of the implosion region. The sphere has hundreds of protruding radial pins of different lengths. (See the figure on p. 11.) The high explosive implodes the mock pit onto these timing pins. When the mock pit strikes each pin, the signals created track the implosion of material as it moves toward the center, thereby providing data about the temporal and spatial uniformity of the implosion.

In a core-punch test, scientists combine high-energy radiography and ultrasensitive diagnostics to capture the detailed shape of the pit as it is highly compressed near so-called bang time, when an actual device would go nuclear. This deep-penetration radiography yields a small (40- to 45-centimeter) digital image that is compared to images generated by hydrodynamics simulation codes.

Bosson also works on focused hydrodynamic experiments that address a particular component or material associated with the primary. Focused experiments typically occur in a series. They may be studies of a certain material or a certain shape such as a cylinder. About 10 to 20 focused experiments per year are conducted at Site 300. Although focused tests cost less because of their engineered simplicity, they often require as many diagnostics as IWEs and thus are just as challenging to field.

Chronology of a Hydrotest

Once the decision has been made to conduct a particular test in support of stockpile stewardship, a design physicist develops a conceptual plan to field the experiment. At a conceptual review meeting, the design physicist, ramrod, device engineer, and design drafter discuss the proposed test. "We discuss whether the proposed plan makes sense," says Wraith. "Is there a better way to obtain the desired information?"

If a decision is made to proceed, discussions then focus on the required shock pressure, how much high explosive will be needed to create that pressure, the thickness of key parts, the materials involved, and the diagnostic instruments needed. "I depend on Steve to tell me what the appropriate diagnostics are for the experiment I'm proposing," says Hsu. (See the box on p. 10.)

After the conceptual review, mechanical designers from the Engineering Directorate begin drafting the required parts. The design physicist refines computer simulations to ensure that the experiment will have a reasonable probability of returning the desired information. Bosson focuses on the diagnostic requirements, such as ensuring clear lines of sight for the optical cameras. In this early stage, he creates the first of several three-dimensional computer-aided design (CAD) layouts that give a detailed mock-up of the experimental setup. The CAD layout includes the strategic placement of the

Nuclear Device Primary: Where It All Begins

In the past, to ensure that a nuclear warhead would function according to its design, Livermore scientists tested it underground at the Nevada Test Site. In the absence of nuclear testing, scientists must rely on advanced supercomputer codes, validated by nonnuclear experimental results and benchmarked against past nuclear test data, for the continued certification of the stockpile.

A modern nuclear weapon comprises a primary explosive device and a secondary. In the primary device, a pit of fissile material is surrounded by chemical high explosives. A nuclear explosion starts with the detonation of the high explosive, which generates a high-pressure, high-temperature environment. The high-explosive shock waves can travel up to 10 kilometers per second, forcing the enclosed fissile material to compress into an increasingly smaller space. The pit responds in a complex manner as it implodes to an extremely compact shape. In the process, materials deform, become extremely dense, and can even melt.

The uniform compression process of the fissile material leads to a nuclear fission chain reaction, which generates tremendous energy. The energy released from the primary triggers the secondary to produce the overall nuclear yield of a device.

Because the implosion geometry is crucial, implosion tests called hydrodynamic experiments are needed to ensure that the weapons in the nation's nuclear stockpile will perform as expected. Hydrodynamic experiments reveal the behavior of a nuclear weapon from the ignition of the high explosives to the beginning of the nuclear chain reaction. Data concerning the velocity of the imploding material and energy flow during the implosion help weapon scientists assess the ultimate performance of the device, better understand the implosion process, and refine computer models.

device, mirrors that reflect images to the optical cameras, and other diagnostic equipment. It also includes detailed drawings for various support structures, which are constructed from extruded aluminum.

Two to three months after the first conceptual review meeting, a design review is held. Participants review drawings for the required parts and decide if any modifications are needed. Bosson checks the orientations of the experimental package and its parts, such as the baseplate, to determine if equipment must be moved to ensure clean lines of sight for all diagnostics. "We don't want any parts to interfere with camera views," he explains.

Most of the parts are classified and must be manufactured by machinists in Livermore's onsite shops or obtained from other NNSA sites. Some parts, because of their materials or complicated designs, have a long manufacturing lead time. A few unclassified parts are manufactured by commercial shops.

"Steve is the integrator," says Hsu. "He is always in touch with people at Site 300, the participating engineers, and the Laboratory shops."

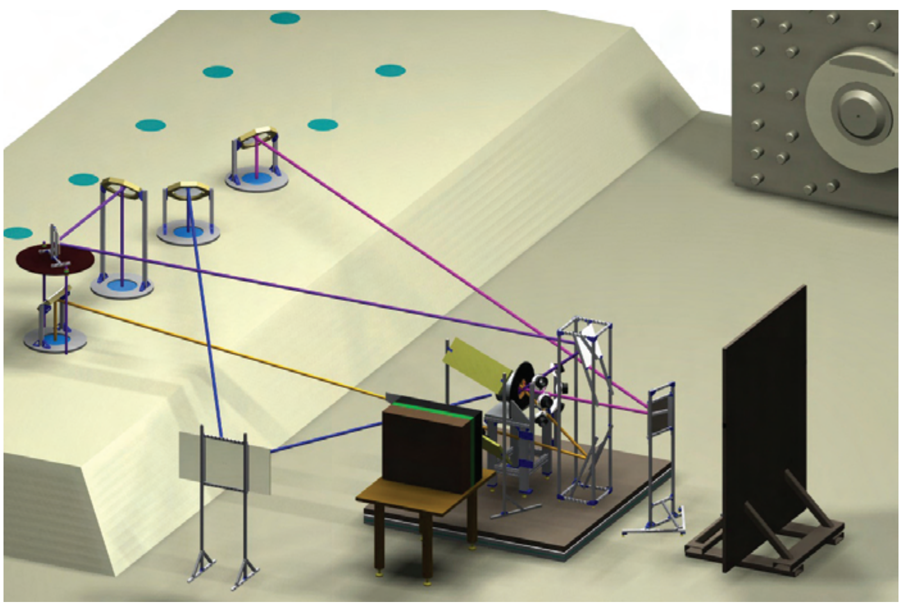
About one month before the scheduled firing date, Bosson completes an exhaustive preshot report. The report includes all timing specifications for the required diagnostics and lists the kind and amount of high explosives to be used. In addition, over the weeks leading up to the shot, Bosson briefs the bunker crew.

While the experiment is being assembled, Bosson serves as a representative for the design physicist. The bunker crew assembles various support structures based on Bosson's CAD layout. These stands and frameworks vary in shape and size to accommodate detectors and diagnostics such as mirrors for directing the optical views and lamps for illumination.

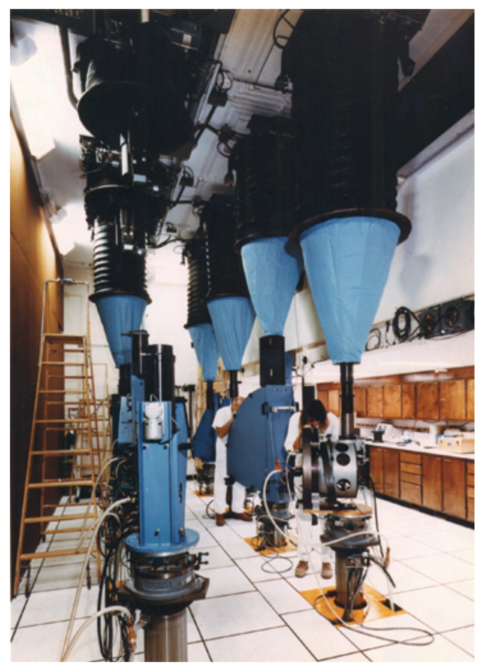
During the final hours of the countdown, Bosson stays in the control room with other bunker personnel and the design physicist. The team monitors the final preparations of the diagnostics and other systems. The firing, measured in tens of microseconds, culminates many months of design, preparation, manufacturing, and reviews.

After a Shot

Personnel who enter the firing chamber shortly after a test must don protective garb to protect themselves from any hazardous materials as they recover the radiographic film cassettes. After removing the remains of the experiment, they turn on a wash water system to remove any particulate matter



A computer-aided design layout shows placement of the experiment, which is surrounded by mirrors on stands, flashlamps, and a radiographic film cassette. Extremely energetic x rays emerge from the Flash X Ray machine through a port (upper right). Behind the experiment is the protective enclosure for radiographic film. Images from a series of mirrors are reflected to four optical cameras, providing different viewpoints. Each optical path is indicated by a different color. The cameras are located directly below the four ports on the left.



A room underneath the firing chamber houses high-speed optical cameras. Images from the hydrodynamic test are directed with mirrors in the firing chamber to ports at the tops of the black shrouds.

Diagnostics Track Events Microsecond by Microsecond

Scientists have only a fraction of a second after a detonation to gather data before the hydrodynamic test target and some of the diagnostic supports are destroyed. The Contained Firing Facility at Livermore's Site 300 has one of the most extensive suites of diagnostic equipment in the nation for studying explosive tests. Multiple diagnostic devices can be deployed simultaneously to measure different aspects of an experiment. Each diagnostic provides a different look at the implosion process, including its velocity and detailed images of inside and outside movement.

The most important diagnostic is the Flash X Ray (FXR), which was dedicated in April 1982 as the nation's most powerful linear-induction electron beam accelerator. FXR enables scientists to see into the heart of test objects at an exact moment after detonation, revealing data about implosion symmetry. The FXR source requires very high peak power available in a single pulse, and the timing and firing of the source in concert with the implosion of the device requires an extremely sophisticated system design. Because only one radiograph can be captured per experiment, timing is everything. Ramrod Steve Bosson says, "The x-ray pulse length is about 60 nanoseconds, and the test is over in 100 microseconds, so we need very precise timing to obtain the image at the right time."

The machine's x rays enter the firing chamber from a port in the chamber wall. The x rays penetrate more than 30 centimeters of steel in an intense flash of high energy and can freeze action in 65 nanoseconds. FXR's peak power is 500 rads (equivalent to 30,000 times a medical x ray), and its maximum resolving power is about 2 millimeters. Any x rays that pass through the event unattenuated are recorded on photographic film or, in the case of core-punch experiments, on the recording surface of a gamma-ray camera that is 70 times more sensitive than film. Fewer x rays pass through dense areas, resulting in darker regions of an image. Thick aluminum plates protect the film cases from shrapnel.

Radiographs taken with FXR can capture an entire target or concentrate on a small area. To focus on specific areas, as with core punches, scientists collimate the beam to make the image size less than 2 centimeters square.

Complementing the FXR images are those provided by optical cameras located below the firing chamber. Many fine-scale features, including instabilities and the breakup of material during the fast-moving explosion, are progressively captured by these ultrahigh-speed cameras. The images are directed to the underground cameras by a series of mirrors arrayed around the experimental package. To capture the fleeting reactions, each camera uses a spinning mirror with an equivalent frame rate of up to 2 million frames per second; the mirrors relay light to a stationary arc of conventional photographic film.

The hydrotest firing is dependent on the instant when all optical cameras' mirrors are perfectly in synch. At that moment, the high explosive is detonated to begin the implosion process. Mirrors must be sacrificed by small explosive charges, or the cameras will keep recording, thereby overwriting the film. Two types of cameras are used. The first projects 26 frames onto 70-millimeter film; the second projects 80 frames onto 35-millimeter film. Each frame is typically separated by a microsecond.

Most experiments also involve heterodyne measurements, which track and record the velocity of moving surfaces. In these measurements, laser light passes through a probe at the end of an optical fiber focused on a selected spot on a surface. The same probe picks up the reflected light signal, and the light's color (frequency) is shifted in proportion to the instantaneous velocity of the surface moving toward the probe. The technique can measure velocities of up to 5 millimeters per microsecond.

Mechanical technologist Keith Lewis works on the Flash X Ray (FXR) accelerator, an important diagnostic tool for hydrodynamic testing. The firing chamber is behind the wall at the far end of FXR.

John Given, Steve Bosson, and Jack Lowry adjust the quality of the FXR beam, which enters the firing chamber through the port behind them. FXR is on the other side of the wall to protect it from explosive debris.

from the walls and floor. A filtration system removes dust and particulates from the wastewater, which is recycled. At the same time, ventilation fans flood the chamber with fresh air and process exhaust gases through high-efficiency particulate air filters. (See *S&TR*, June 2004, pp. 21–24.)

Members of the hydrotest group scan the radiographic and photographic film to make digital images. The individual frames from the photographic film are combined to create a short movie. In addition, pin-shot test data are converted to a useful form for the design physicist. Physicists then study the experimental data for months, incorporating results into supercomputer codes.

As Bosson continues his work at Site 300, he is also supporting Livermore-designed hydrotests at Los Alamos National Laboratory's Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility. DARHT's first axis began producing single, two-dimensional images of the device implosion in the fall of 2000. The second axis, which is perpendicular to the first, will capture four images in succession over 2 microseconds. One of these images, taken at the same time as the image from the first axis, can be used to generate a three-dimensional view of the device at a given time. The other images from the second axis can be combined with the fourth to generate a short movie of the device implosion.

"Ramrods really tie the program together," says Hsu. In the end, the long record of successful hydrotests shepherded by ramrods ensures the continued confidence in the nation's aging nuclear weapons stockpile.

—Arnie Heller

Key Words: Contained Firing Facility (CFF), core-punch test, Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility, Flash X Ray (FXR), high explosive, hydrodynamic experiments, integrated weapon experiment (IWE), nuclear weapon, pin test, primary, ramrod, Site 300.

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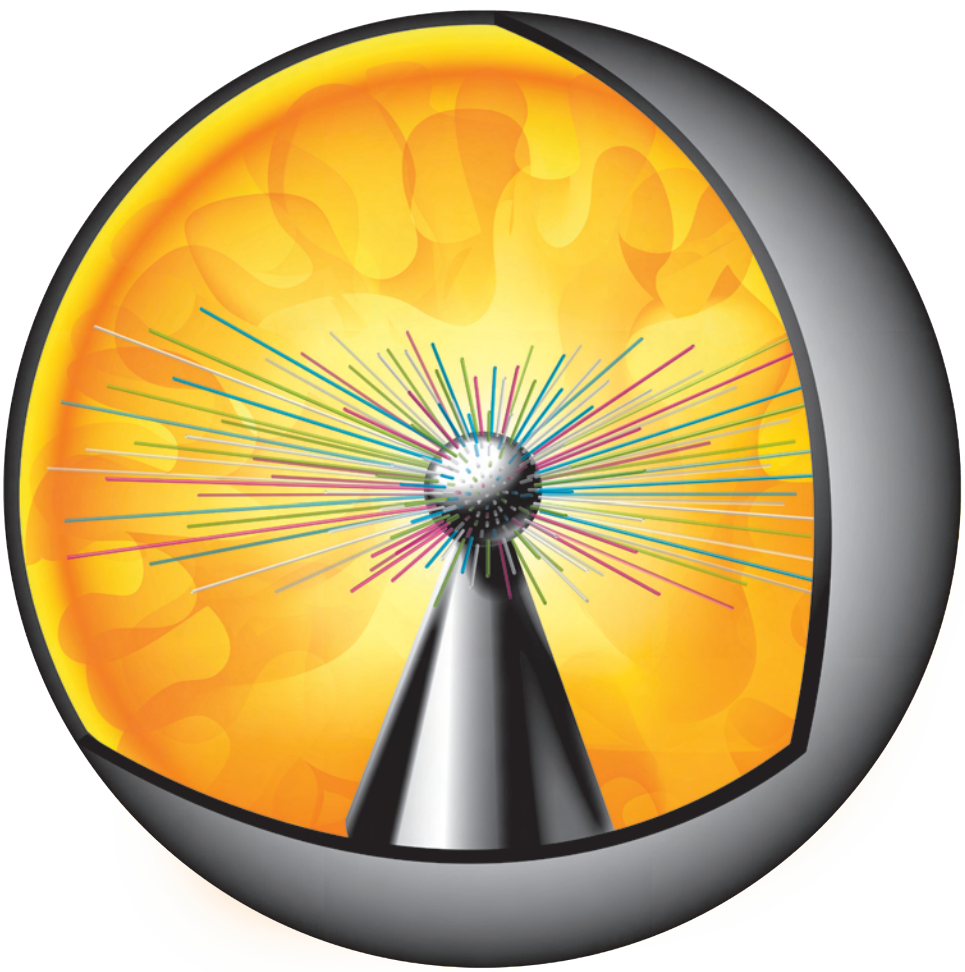

A cutaway of an experimental device shows a pin-dome diagnostic for evaluating the implosion of a device. As the sphere implodes, signals from the pins track the imploded material moving toward the center, thereby providing data about the temporal and spatial uniformity of the implosion.