HYDRODYNAMIC EXPERIMENTS SUPPORT Stockpile Stewardship

INSIDE a heavily shielded chamber with 1.8-meter-thick concrete walls, high explosives detonate around a mass of inert test material. Subjected to an intense shock wave, the material briefly acts like a liquid. Advanced diagnostic equipment installed throughout the chamber captures thousands of data points and x-ray images from almost every angle in a split second. The hydrodynamic test—so named for the equations that explain how liquids in motion behave—which took months to plan and a 50-person team of skilled designers, engineers, and technicians to orchestrate and execute, lasted just 100 microseconds. Now, the copious data gathered from that brief test will inform critical weapons design decisions in the service of keeping the nation's nuclear deterrent safe, secure, and effective.

Lawrence Livermore has carried out hundreds of hydrodynamic tests over the last six decades in support of the Stockpile Stewardship Program's goals in the absence of full-scale nuclear testing, which came to an end in 1992. With the advent of the National Nuclear Security Administration's life-extension programs (LEPs) and modification programs (see *S&TR,* October/November 2018, pp. 4–11), the need for and pace of hydrodynamic tests at the Laboratory's Site 300 have increased.

In 2007, Livermore's hydrodynamic testing program was addressing a variety of scientific queries, but the main objective was enabling the design and stewardship of the nation's nuclear stockpile by verifying the performance and safety of the nuclear explosives package—work typically accomplished through empirical testing in conjunction with physics model development and high-performance computing simulations (see *S&TR*, September 2007, pp.4–11). Integrated weapons experiments (IWEs), a key focus of the hydrodynamic tests at Site 300, study weapon systems, including the components that comprise a nuclear device. "IWEs are complex experiments that involve different physics and different measurement scales," says experimental physicist Reed Patterson. "In a hydrodynamic test, many things occur—physical and chemical reactions, debris dispersal,

Principal investigator Clif Mortensen (left) stands behind a tank filled with foam and water that will slow but not deform fragments produced in an experimental explosion while high-voltage, high-intensity flash lamps (above) illuminate the experiment for high-speed cameras that will record the breakup of the device.

interactions of different components. We examine the entire integrated system and compare the results of the hydrodynamic tests with simulations to provide more accurate assessments of the conditions that trigger a nuclear device's primary—the mass of plutonium that initiates full detonation."

Teaming Up for Success

"Every IWE starts with questions a weapons designer wants to answer. 'How will this react?' 'How will this material impact a device?' 'What happens when we alter this mechanism?' The members of the Laboratory's hydrodynamic test program do everything they can to help the weapons designers answer those questions with as much detailed data as possible," says Patterson. To do so, several multidisciplinary teams—ramrods, engineers, and diagnosticians—collaborate and devise the hydrodynamic experiments that produce data to yield those much-needed answers. During the engineering phase of a hydrodynamic experiment, the Laboratory's ramrods—named after the cattle hands responsible for ensuring herds arrived on time—evaluate the design of the experiment, configure the components with the engineering and diagnostics teams, and liaise with principal investigators to address emerging challenges. "You don't get a second chance," says ramrod and program group lead for hydrodynamic testing, Steve Bosson. "The test must be a success."

The Diagnostics Development Group works with the experiment designers and ramrods to determine which diagnostics to use, develop customized instrumentation, and provide technical and field support for existing diagnostics and data analysis. "We develop novel diagnostics when the design team wants to measure something new. It's our job to push the boundaries of what's possible," says program group leader Kerry Krauter. "We also troubleshoot and upgrade diagnostics and assist with data analysis." These diagnostics gather sophisticated data describing the debris generated by a detonation including debris velocity and position, the shape of the device as it deforms, and the resulting temperature and density of the blast material. "The weapons designers need to know

Inside Livermore's Site 300 Contained Firing Facility (CFF), Clif Mortensen (right) aligns a mirror that will reflect the experiment toward cameras as they capture the experiment while former Livermore technicians, Brian Pepmeirer (left) and Ashley Swan (center) inspect camera ports and ensure that debris will not interfere with data collection. Mortensen (far right) examines a unit that allows researchers to control the temperature of a hydrodynamic test.

more than the position, velocity, and shape of the debris. They want to know how the temperature changed during the blast, as well as how the density of the device changed. These data are challenging to measure directly during the microsecond duration of the test, so we make inferences and compare them with the Laboratory's simulations to fine-tune our findings and improve their fidelity," says Krauter.

Over the years, the Laboratory's hydrodynamic test diagnostics have yielded technologies specially developed by the Laboratory. Photonic doppler velocimetry measures the velocity of the device's destruction by recording the slight shift in the frequency of light reflected from it, also known as the Doppler effect. The surfaces of the device are tracked using broadband laser ranging (BLR), a technique also developed by researchers from several national laboratories including Livermore. BLR works by training a laser pulse on the device's surface that reflects back to an interferometer, which merges two or more light sources to create an interference pattern indicating the movement of fragments during the detonation. The hydrotest diagnostics also include x rays. Until recently, these x rays were captured on film, but researchers are now transitioning to digital media. "These improvements have increased spatial resolution," says Krauter. "Now, we can achieve incredibly precise, accurate measurements." With 160 data channels for determining position and velocity, new flash x-ray capabilities (see *S&TR,* July/August 2018, pp.12–15), and improvements in the coordination and execution of hydrodynamic tests, the Laboratory's ever-evolving diagnostic capabilities represent a substantial improvement over the last 15 years and have contributed to a quickening pace to meet the expanded demand for tests in support of the W80-4 LEP and the W87-1 Modification Program.

Subcritical Program Support

The hydrodynamic test program also now supports preparations for subcritical tests, which are similar to hydrodynamic tests except instead of inert material, they utilize plutonium, the fissile material in a nuclear device. A limited number of neutrons are released during a subcritical test to prevent a self-sustaining chain reaction. "Since

2007, we've doubled the number of ramrods to eight. Our heavy involvement in subcritical testing presents a big shift for the teams. Hydrodynamic testing ensures the subcritical program's success," says Patterson.

Use of hydrodynamics experiments and simulations provide a high degree of fidelity for comparison with subcritical tests even though plutonium behaves differently than the inert materials in the preparatory tests. A single subcritical experiment costs tens of millions of dollars, requires three to five years to plan, and involves hundreds of people with a broad range of expertise in physics, engineering, explosives, safety, chemistry, and materials science, as well as support staff to coordinate and execute the administration, classification, procurement, shipping, transportation, materials management, and information technology required to support an experiment. To assure that a subcritical test will succeed, Livermore's hydrodynamic test group will perform as many as half a dozen experiments to verify that the experimental setup planned for the subcritical tests will successfully record the data needed. Three major series of subcritical tests are in planning stages, the first of which, Nimble, is scheduled for 2022 and will take place at the U1a Complex at the Nevada National Security Site.

"To give the subcritical teams better confidence, we do a series of hydrodynamic experiments," says Jeff Florando, the associate program director for hydrodynamic and subcritical experiments. "One experiment might test the fragment mitigation strategy within its confinement vessel. You need to know what fragments will result after detonation, what kind of damage they cause, and how to decrease damage to the vessel and diagnostic equipment from a particular configuration." Other hydrodynamic tests ensure the timing of diagnostics measurements will be perfect. Getting the timing right is crucial because the tests and the opportunity to collect data lasts just nanoseconds. Patterson says, "Our mission demands that we work with a variety of hazards, including toxic and radioactive materials and high explosives. We do so in a safe and secure manner, making sure that we deliver the highest quality product to our customers, and that the test data we produce provides the answers they seek."

—Allan Chen

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