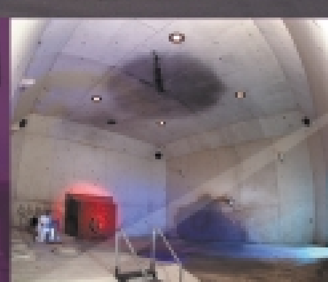
The Contained Firing Facility

at Site 300



Lawrence Livermore National Laboratory

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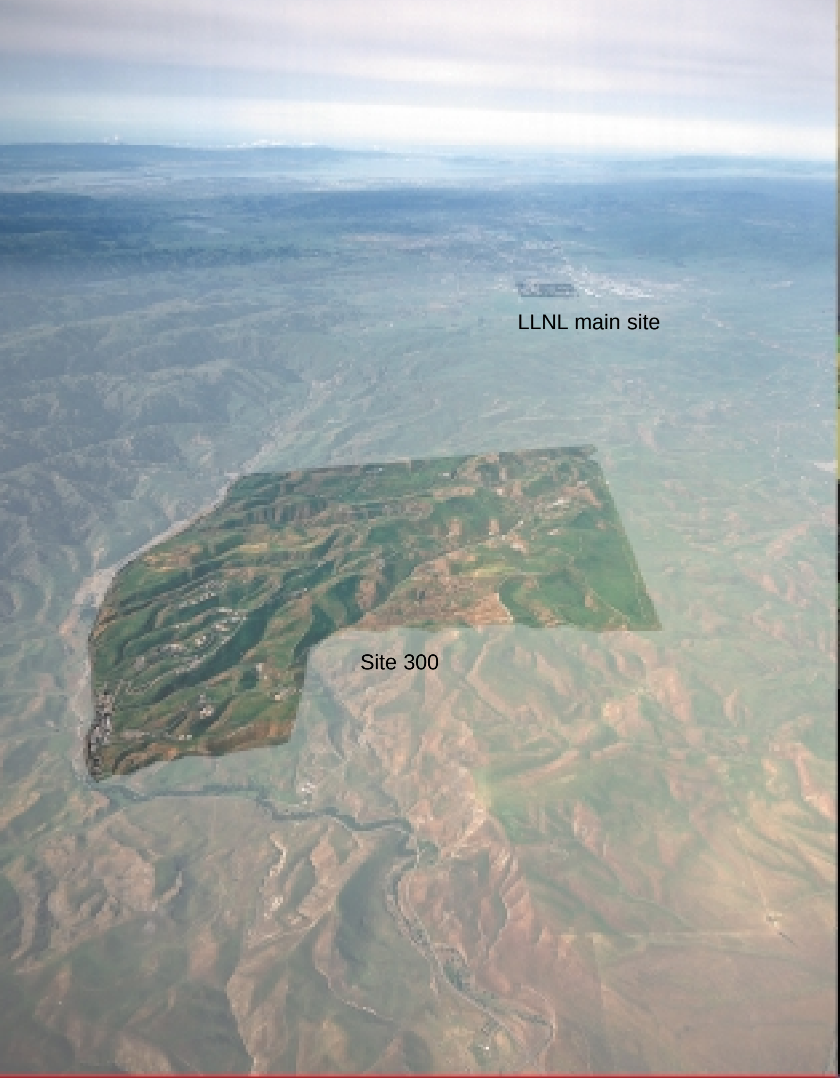


The Contained Firing Facility is located 15 miles east of the Lawrence Livermore National Laboratory main site, set to the north in the Experimental Test Site known as Site 300.

Experimental data gathered at the Contained Firing Facility will help validate the best computer codes in our assessment of weapon operation.

Our MISSION & *Challenges*

Stewardship of the U. S. nuclear stockpile is the foremost responsibility of the Lawrence Livermore National Laboratory. In the past, to ensure that a nuclear warhead would function according to its design intent, Livermore scientists could always rely on underground tests of complete nuclear weapons. In the absence of nuclear testing, we must now rely on interrelated calculations, validated by non-nuclear experimental results and benchmarked against past nuclear test data, for the continued certification of the stockpile.

With no new designs of nuclear weapons, many nuclear warheads in the U.S. stockpile must continue to function far past their original expected lifetimes. As components and materials age, problems will arise. Stockpile Life Extension Programs can extend system lifetimes but can also introduce performance uncertainties. Major warhead refurbishment will require robust non-nuclear experiments and enhanced simulations that together must compensate for the loss of nuclear testing.

The success and effectiveness of the nation’s nuclear deterrence policy depend on our ability to maintain confidence in the stockpile. Livermore scientists are making breakthrough advances in developing computational and experimental tools to help ensure the success of our mission. These tools will allow us to characterize individual phenomena and quantitatively predict integrated performance.

The Contained Firing Facility (CFF) is a premier experimental facility for gathering implosion data to support our core mission. Its multiple, large-scale diagnostics contribute significantly to the fundamental understanding of nuclear weapons and assessment of integrated performance. While the CFF is a key element of LLNL’s comprehensive hydrodynamic testing capabilities, its unique containment design also represents our strong commitment to the protection of the environment and to personnel health and safety.

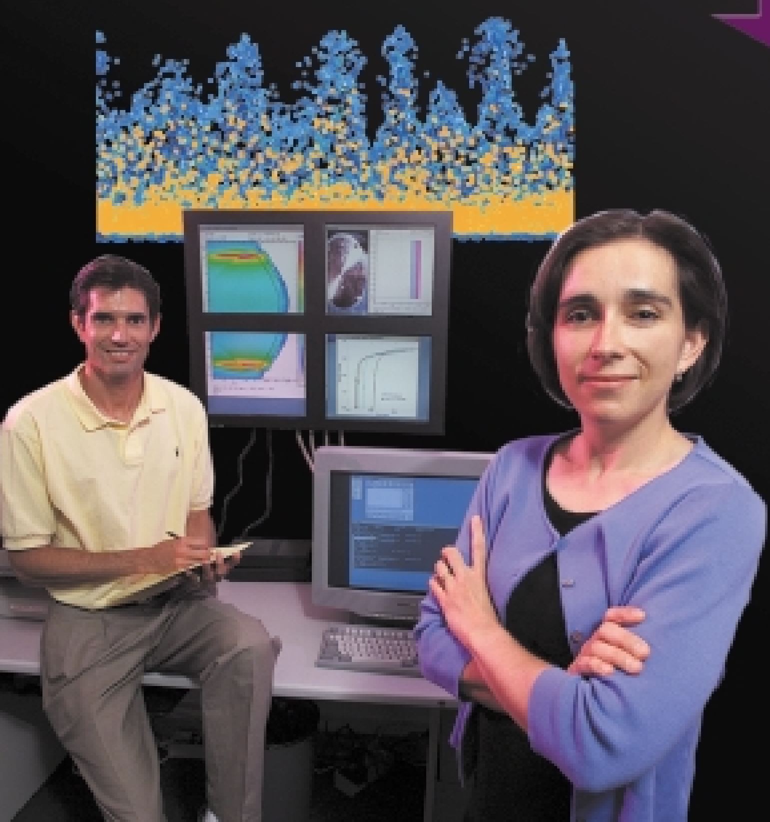
Stewardship Triad

Integrating Expert Judgment, Simulations, and Experiments

With nuclear testing and new weapon development no longer options, stockpile stewardship must rely on an improved understanding of current nuclear weapons based on greatly enhanced experimental facilities and computational models. However, the process of integrating experimental data and simulations cannot be credible without the expert judgment of skilled scientists and engineers with the technical insight that inspires confidence in the status of the stockpile. The confluence of experiments, simulations, and people constitutes the triad approach in implementing the Stockpile Stewardship Program.

Expert Judgment

To tackle the challenges in stockpile stewardship, Livermore scientists routinely combine breakthrough computer simulations, state-of-the-art experimental diagnostics, and a culture in which weapons engineers, scientists, and code developers work cooperatively along side each other. One critical element in all our activities is this multidisciplinary approach in which experts of various specialties decide the scope of experiments and identify the requirements for simulations.



Simulations

In the absence of nuclear tests, many complex phenomena in a nuclear detonation can only be simulated with the most powerful computers. Simulating a nuclear explosion in three dimensions and with high fidelity, once thought impossible, can be achieved through the capabilities offered by the Accelerated Strategic Computing Initiative.

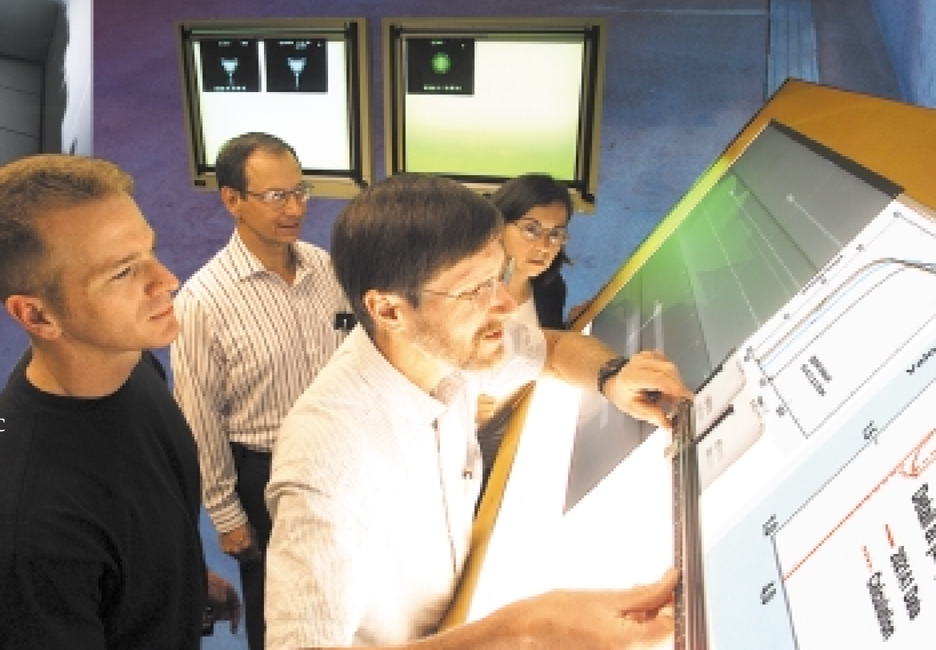
Computers also play a crucial role in predicting results and refining experimental configurations. The knowledge gained from experiments in turn is incorporated by code developers and weapon designers to further refine and validate computer models.

Scientists and engineers face the new challenge of interrelating and extrapolating data from different experiments and simulations to provide an overall evaluation of weapon safety and performance. Even the most advanced non-nuclear experiments can access only a small portion of the physics regimes or material dynamics relevant to nuclear weapons. The unprecedented computational capabilities can accurately predict weapon performance only if the models in the codes are carefully validated by experimental data. Furthermore, experimental data and simulations must be compared with past nuclear test data in order to establish credibility and trends in our assessment of weapon operation.

The iterative and dynamic process of the triad loop includes the indispensable feedback of expert judgment to improve experiments and simulations. The knowledge we gain from experiments and simulations will improve our underlying understanding in many areas, including remanufacturing options, weapon aging, the effect of weapon environment, and overall nuclear performance.

Experiments

Without underground tests of complete nuclear weapons, Livermore scientists now rely on non-nuclear experiments to study individual phenomena of a nuclear device at a more fundamental level. A premier experimental facility, the Contained Firing Facility represents a key capability in our triad approach for assessing primary performance. A suite of robust diagnostic devices will enable scientists to gather complex data across multiple aspects of weapon operation for comparison with computational predictions.



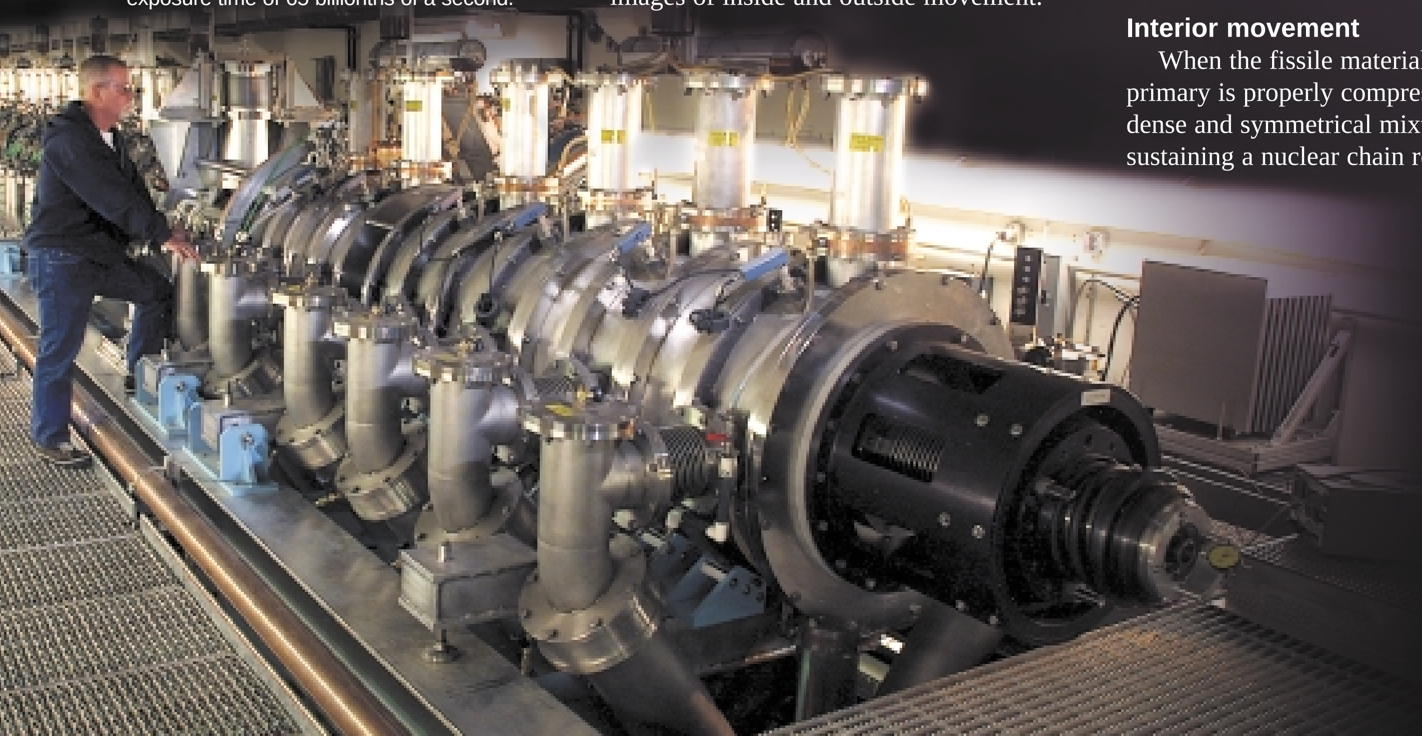
Hydrodynamic Experiments

Probing the Behavior of Compressed Materials

In a hydrodynamic experiment, we study the behavior of solid materials (typically metals) by detonating high-power chemical explosives that surround the solids. Because the temperatures and pressures generated by the high explosive detonation can be very high, metals that are ordinarily considered hard may readily deform. That is, they may flow like a fluid (almost a gas) and compress into a denser form.

Hydrodynamic testing, or hydrotesting for short, is a key tool for scientists to gather crucial data necessary for assessing the operation of a nuclear weapon's primary stage. The data and knowledge we gain from hydrotests allow us to improve our computer models and our understanding of the implosion process (see box). However, scientists have only a fraction of a second after a detonation to gather data before everything is destroyed by the high explosives. Only with great precision and fine control can all events, including multiple diagnostic measurements and the high explosive burst, be synchronized to produce the data we need.

LLNL's Flash X-Ray (FXR) machine is a major part of the Contained Firing Facility. With x-ray radiographic technology pioneered by Livermore scientists, the FXR accelerator can penetrate even the thickest primary in the stockpile. Its x rays can freeze a dynamic motion at an exposure time of 65 billionths of a second.



Consolidation of Multidiagnostics

The Contained Firing Facility offers the most extensive and complete suite of diagnostic equipment in the nation for the study of explosive detonations and implosion in nuclear devices. Multiple diagnostic devices can be employed simultaneously to measure different phases of an experiment. Each diagnostic provides a unique look at the implosion process at different times—its initial velocity history, the progressive energy delivered, and images of inside and outside movement.

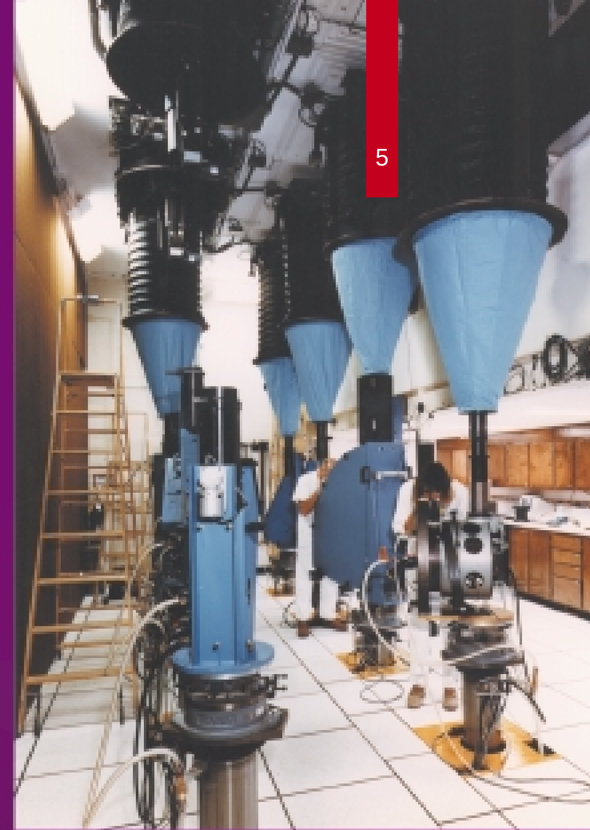
Implosion velocity

When a high explosive in a primary is detonated, its shock waves can travel up to 10 kilometers per second—20 times faster than a moving bullet—forcing the enclosed materials to compress. The velocity of such rapid detonation, in fact, is not constant and may yield valuable information about the design of the primary. Experimental records of the velocity history and energy flow during the course of the implosion are compared with computational data in order to assess the ultimate performance of the device.

Interior movement

When the fissile material in a nuclear primary is properly compressed, it forms a dense and symmetrical mixture capable of sustaining a nuclear chain reaction.

Four arrays of five-beam velocimeters, shown here with streak cameras, allow simultaneous velocity measurements of up to 20 spots in a single experiment.



High-speed optical equipment, such as rotating-mirror cameras and image-converter cameras, captures the exterior movement of a fast-moving exploding object during hydrotests.

Livermore scientists pioneered most of the x-ray radiographic technologies that we use to examine the interior of an imploding primary, measuring its size and density. Radiographic data can help identify factors that may affect the symmetry of the implosion.

Exterior movement

The exterior features of a rapidly exploding object can escape the naked eye or even conventional cameras. Many fine-scale features—including instabilities and the breakup of the material during the evolution of an explosion—can be captured by ultra-high-speed cameras. Images obtained by our special optical equipment provide insight into dynamic material response and afford the opportunity to validate our best computer models.

Benefits to Stockpile Stewardship

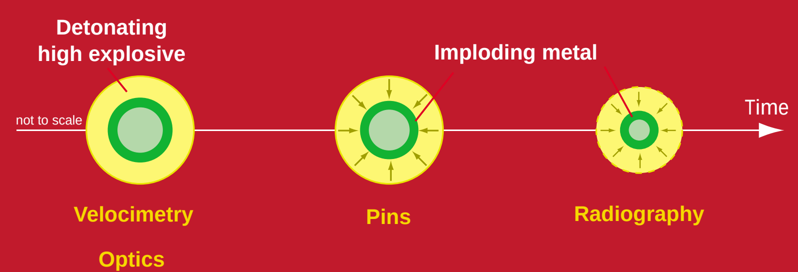
During a nuclear implosion, the extreme conditions generated by the high explosive detonation may cause metals to break apart (spall) or push a spray of metal particles (ejecta) from a free surface—both likely to affect the function of a nuclear device. Understanding the impact of spall and ejecta thus demands the most sophisticated diagnostic capabilities offered by the Contained Firing Facility. These capabilities, together with a strong focus on computer validation and expert judgment, will improve our understanding of how the implosion processes may affect weapon performance, enabling us to ensure continuing confidence in the safety and reliability of the U.S. stockpile.

What is Implosion?

Why are multiple diagnostics necessary to study implosion?

A modern nuclear weapon comprises a primary explosive device and a secondary, both enclosed within a radiation case to contain x rays from the primary explosion. In the primary device, a shell of fissile material (uranium or plutonium, or both) 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 and forces the enclosed fissile material to compress into a smaller and smaller space. The uniform compression process of the fissile material, known as an implosion, leads to a nuclear chain reaction, which generates tremendous energy. The energy released from the primary triggers the secondary to produce the overall nuclear yield of a device.

In typical hydrotests to study implosions, a velocimeter gathers initial velocity data at a resolution of less than a billionth of a second. Optical equipment, including ultra-high-speed cameras, captures progressive images of rapid exterior movement. Shorting pins measure interior surface arrival (when the surface of the experimental object moves inward and touches the pins). X-ray images of the interior reveal the density and symmetry of the compressed metals.



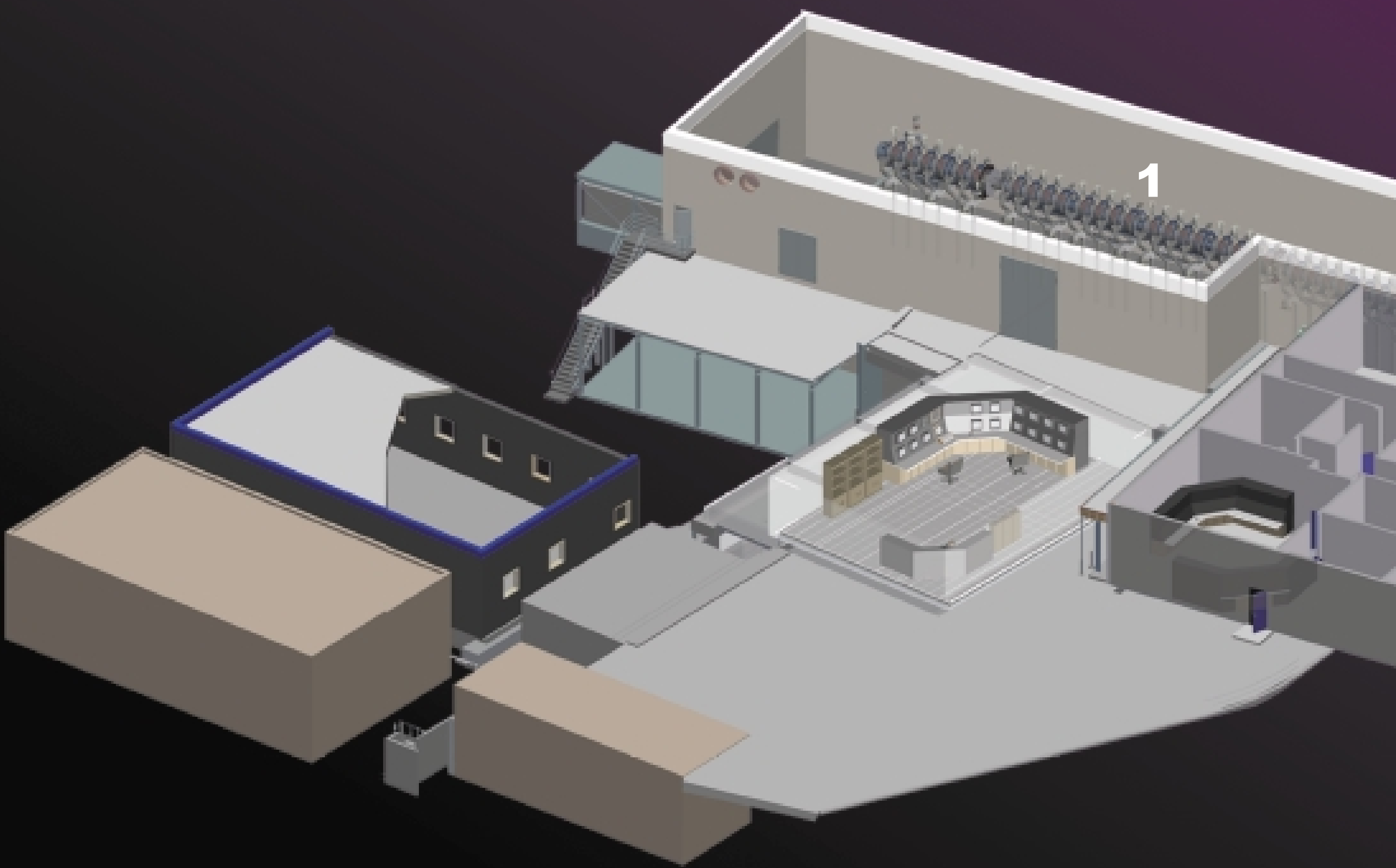
The Contained Firing Facility at Site 300

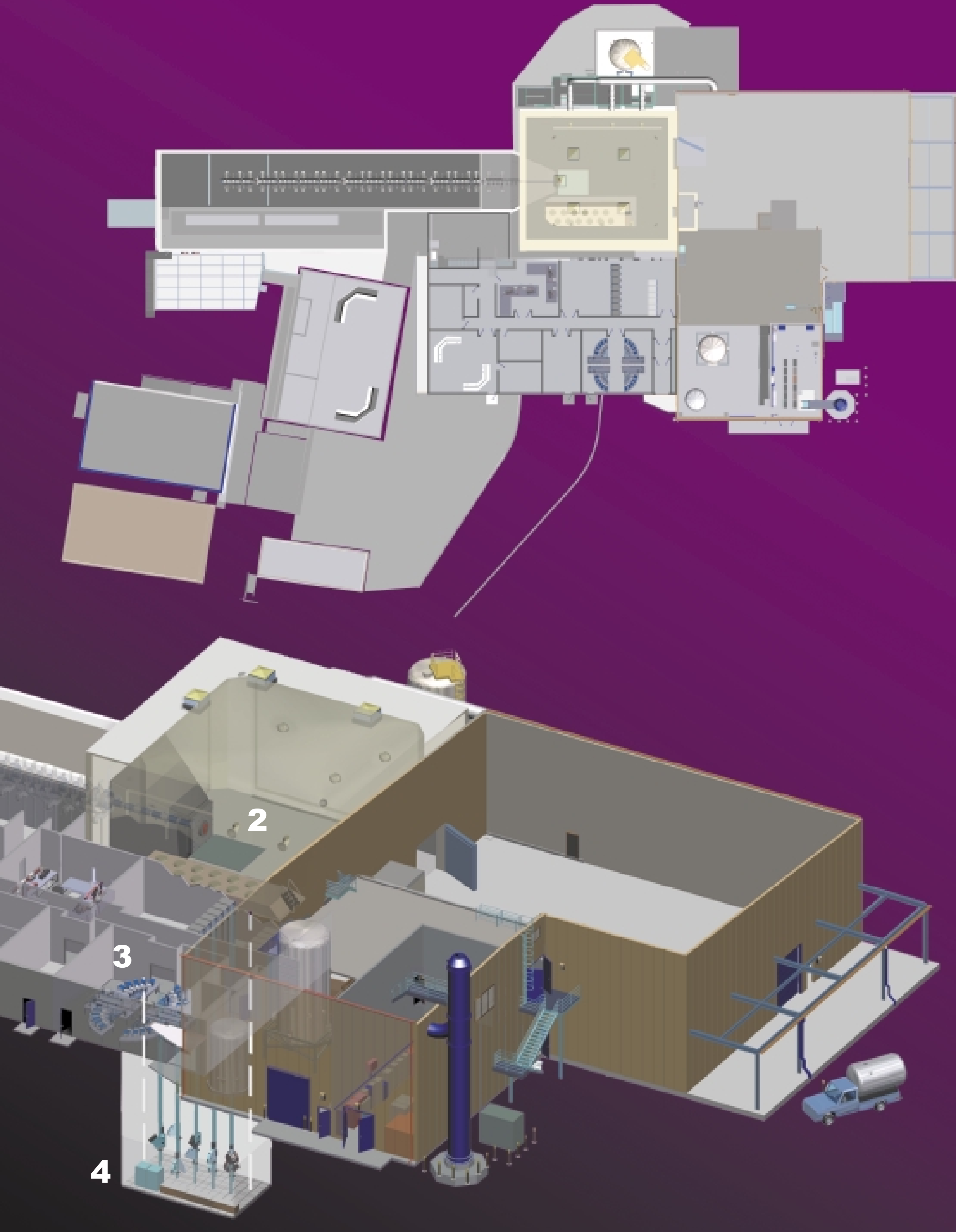
1. **FXR** The x rays from the FXR accelerator can freeze the dynamic motion of an imploding device down to 65 billionths of a second (65 nanoseconds) • It can penetrate even the thickest primary in the stockpile

2. **Containment Chamber** 3200 cubic meters of concrete and two thousand metric tons of steel were used to construct the frame of the firing chamber • Up to 60 kg of high explosives can be safely detonated in the firing chamber • Its inside surfaces are protected by 50-millimeter-thick steel plates from shrapnel traveling as fast as 1.5 kilometers per second

3. **Fabry-Perot Velocimeter** Four sets of five-beam velocimeters allow simultaneous measurements of up to 20 different spots in a single experiment

4. **High-Speed Cameras** A rotating-mirror camera has an equivalent frame rate of 2 million frames per second • An image-converter camera captures images at an exposure speed of two billionths of a second (2 nanoseconds)

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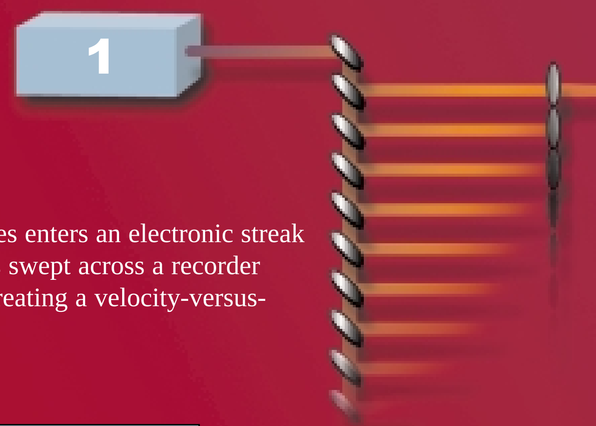
Multibeam Fabry-Perot Velocimetry

Measuring Shock Velocities



Stewardship Applications

During the initial phase of an implosion, high explosives expand rapidly after the detonation (at a speed of many kilometers per second) and cause the inner metals to compress. Livermore scientists have devised a multibeam Fabry-Perot velocimeter to gather accurate information about such high velocities and measure the complex behavior of metals. The Livermore velocimeter has three key features:

• It can provide direct, continuous data records of the surface velocity during the first 80 microseconds (millionths of a second) of the compression.

• Four sets of five-beam velocimeters allow simultaneous measurements of up to 20 different spots in a single experiment—important in identifying subtle variations within the same experiment.

• It can also distinguish multiple velocities at a given spot that may be caused by complex situations such as material spallation or surface ejecta.

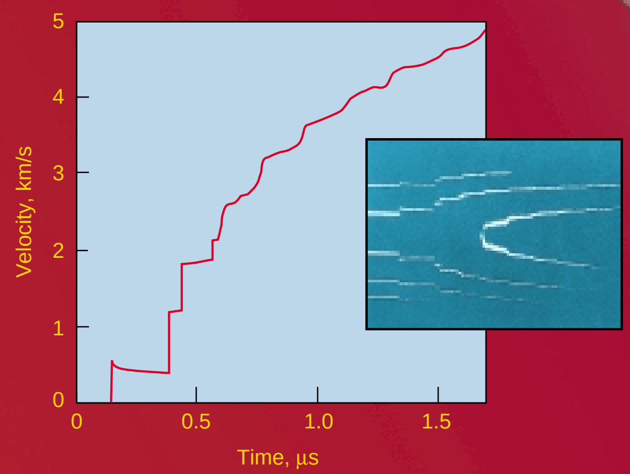
Multibeam Velocimeter in Action

1. A high-power Nd:YAG laser produces a very stable pulse of green light for 80 microseconds. This light source can be split into as many as 20 laser beams.

2. Optical fibers simultaneously relay the 20 laser beams to different spots of a surface. When the laser beams are reflected off the surface, the light's color (its frequency) is shifted as the surface area accelerates or decelerates.

3. A Fabry-Perot interferometer transforms changes in frequency into a moving array of bright dots, called interference fringes.

4. Each array of light fringes enters an electronic streak camera, where the image is swept across a recorder (film or digital detector), creating a velocity-versus-time record.



Data Collection

An image as recorded by a streak camera (inset) translates into the velocity-versus-time record shown on the graph. Livermore scientists compare velocity results such as these to calculations from hydrodynamic codes in order to validate parameters within the codes. Velocity data also give indications of materials behavior under extreme conditions, providing crucial information in improving our understanding of material properties.

High-Speed Optics

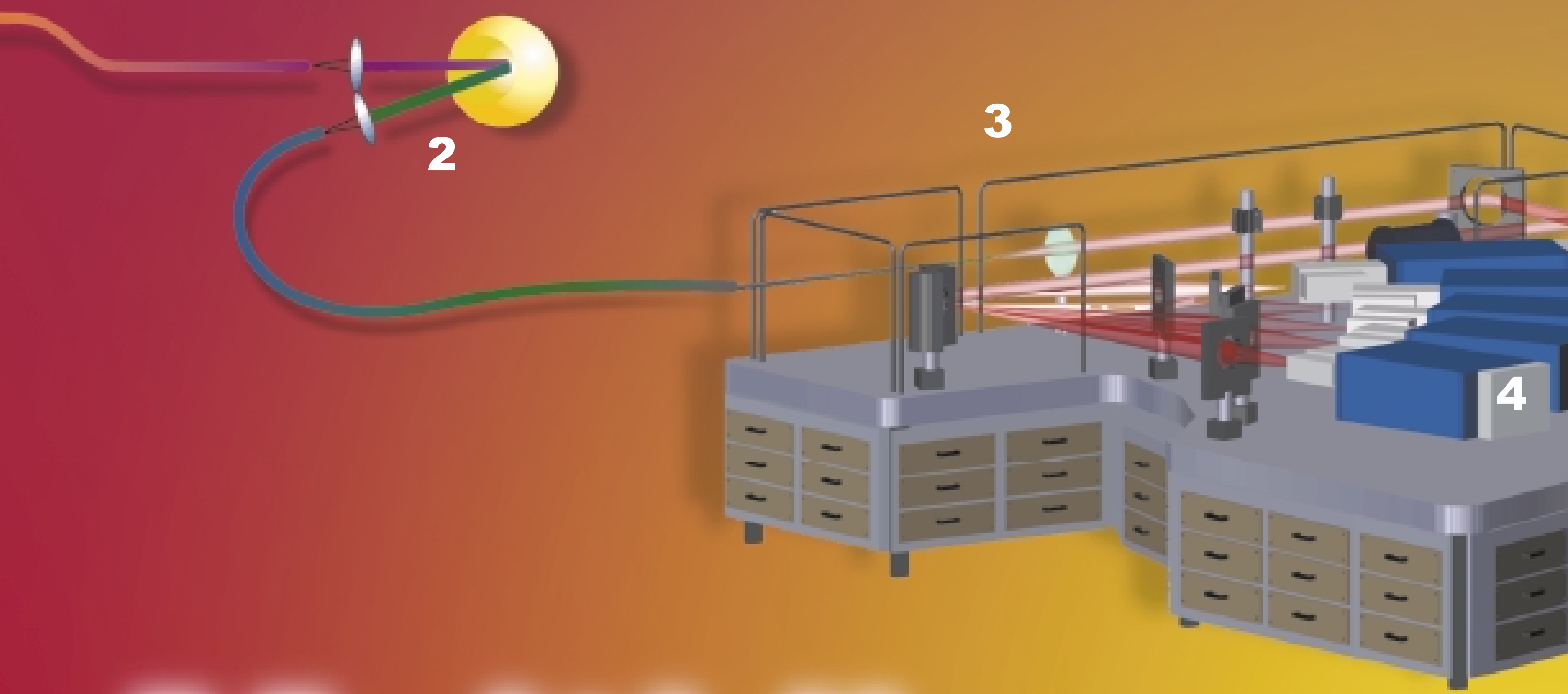
Capturing Exterior Dynamic Motions

Stewardship Applications

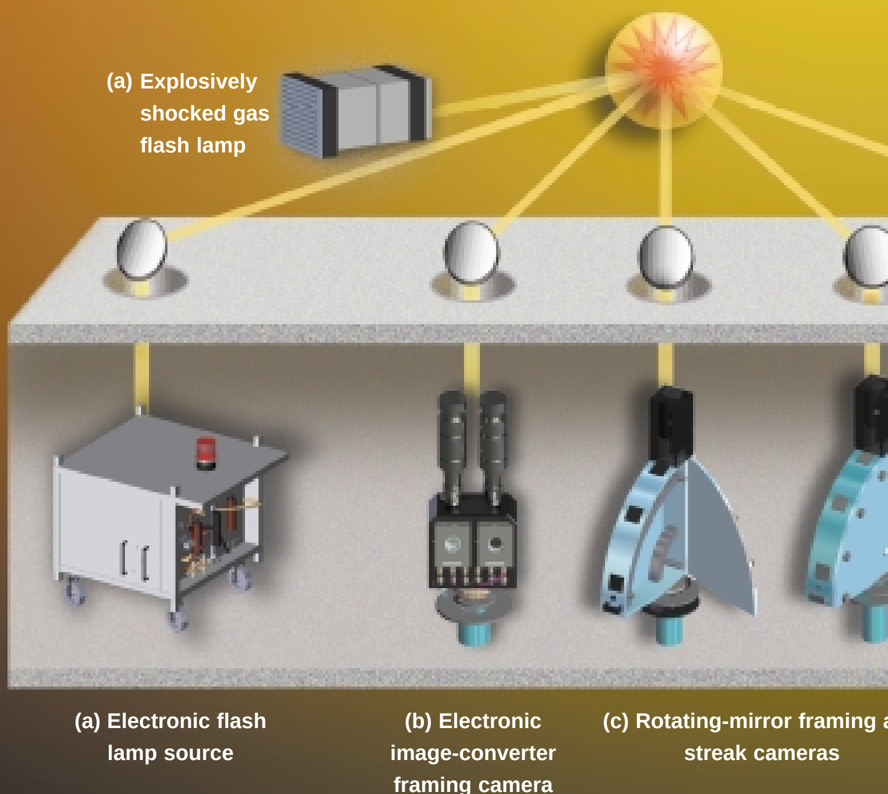
At a speed of more than 2,500 kilometers per second, the dynamic movement of an exploding primary can be recorded frame-by-frame through ultra-high-speed cameras. To achieve optimal data return, the placement of each component is carefully orchestrated with special attention to timing and illumination.

(a) Flash lamps, using either electronic discharge or explosively-shocked gas, are employed to produce a brief, intense ambient light flash.

(b) An image-converter (IC) camera transforms visible light (photons) to electrons so images of the finest features are captured electronically. Multiple



Multidiagnos



cameras can be clustered to provide stereo, three-dimensional images with exquisite detail.

(c) A rotating-mirror camera registers images by relaying light through a spinning mirror to a stationary arc of conventional film. It can capture up to 160 consecutive frames of images at an equivalent of 3 million frames per second, forming a movie-like record.

(d) Up to 8 pulses of ruby laser, each carefully timed and steered to see through ionized gas, provide the illumination source for the IC camera. The laser's ultra-short pulse (two billionths of a second, or 2 nanoseconds) allows an ultra-fast exposure time for the camera, virtually eliminating all motion blur.

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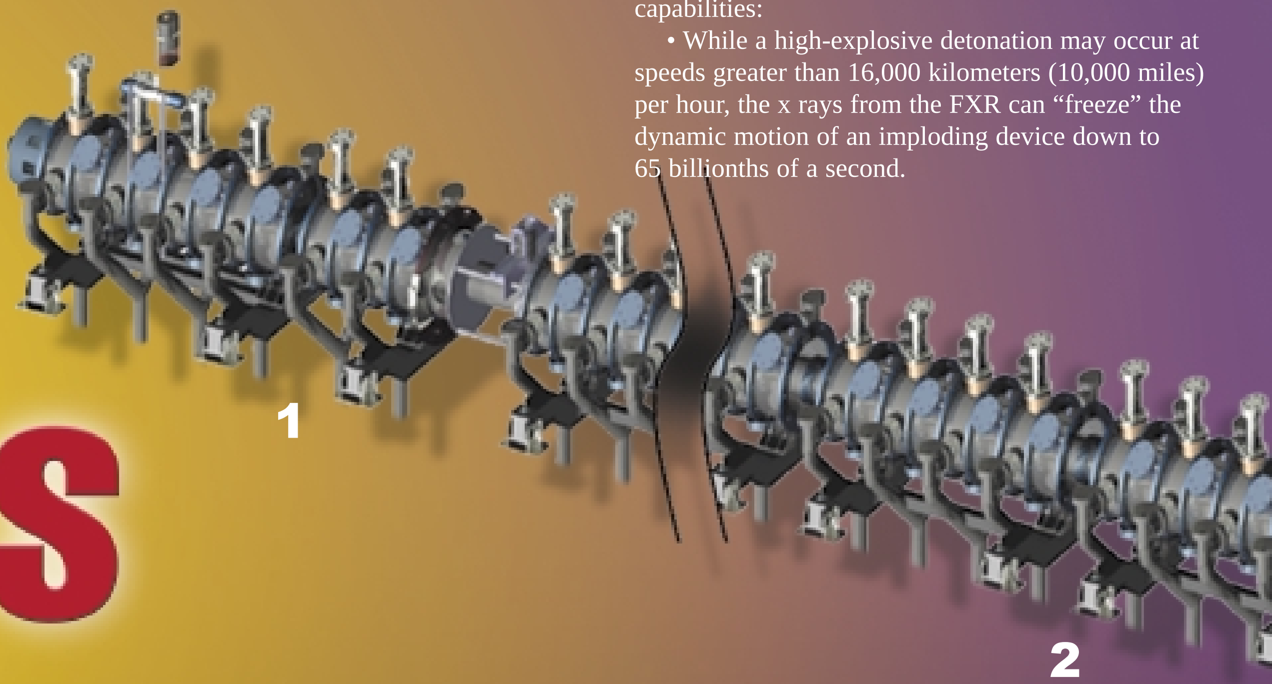
X-Ray Radiography

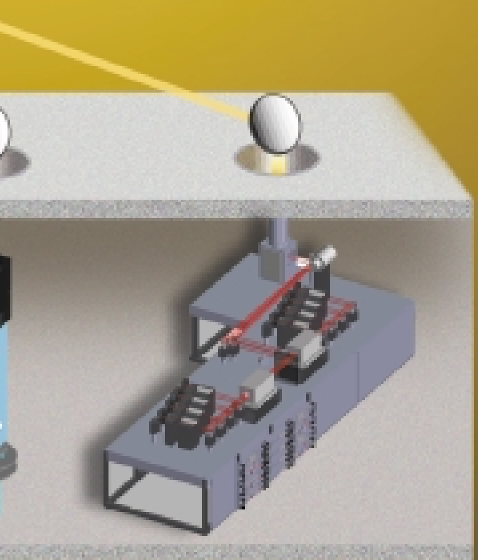
Peering into Implosion

Stewardship Applications

Livermore scientists use a high-dose x-ray machine known as the Flash X Ray, or FXR, to take interior images of a rapidly imploding primary. Together with a gamma-ray camera, the FXR offers three unique capabilities:

• While a high-explosive detonation may occur at speeds greater than 16,000 kilometers (10,000 miles) per hour, the x rays from the FXR can "freeze" the dynamic motion of an imploding device down to 65 billionths of a second.





(d) Ruby laser illumination source

Timing PINS

Relaying Implosion Uniformity

Stewardship Applications

An array of electronic shorting pins, known as a pin dome, can be placed within a test device to measure the elapsed time from initial detonation until the shell of an imploding explosive touches each pin. Because the pins have pre-set lengths and precise locations, they provide data about the temporal and spatial uniformity of the implosion.

• The density of an imploding primary increases significantly as a result of compression. However, the x rays from the FXR can penetrate even the thickest primary in the stockpile.

• FXR can produce high-resolution radiographs showing features as small as one thousandth of a meter (1 mm) in size. The ultra sharpness and clarity offered by a small "spot size" minimize possible blurring of the image.

The FXR in Action

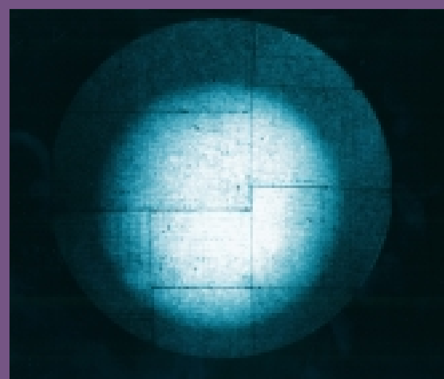
1. An injector introduces a high-current (3000-ampere) electron beam into the FXR accelerator.

2. After passing through 44 accelerator cells, the electrons are energized to 16 million volts, enough to light up 50 million homes (but for only 65 billionths of a second).

3. X-ray radiation is emitted when the electrons smash into a tantalum strip at the end of the accelerator. The high-energy x rays have a dose of 500 rad (radiation absorbed dose), or an equivalent of 30,000 medical x rays.

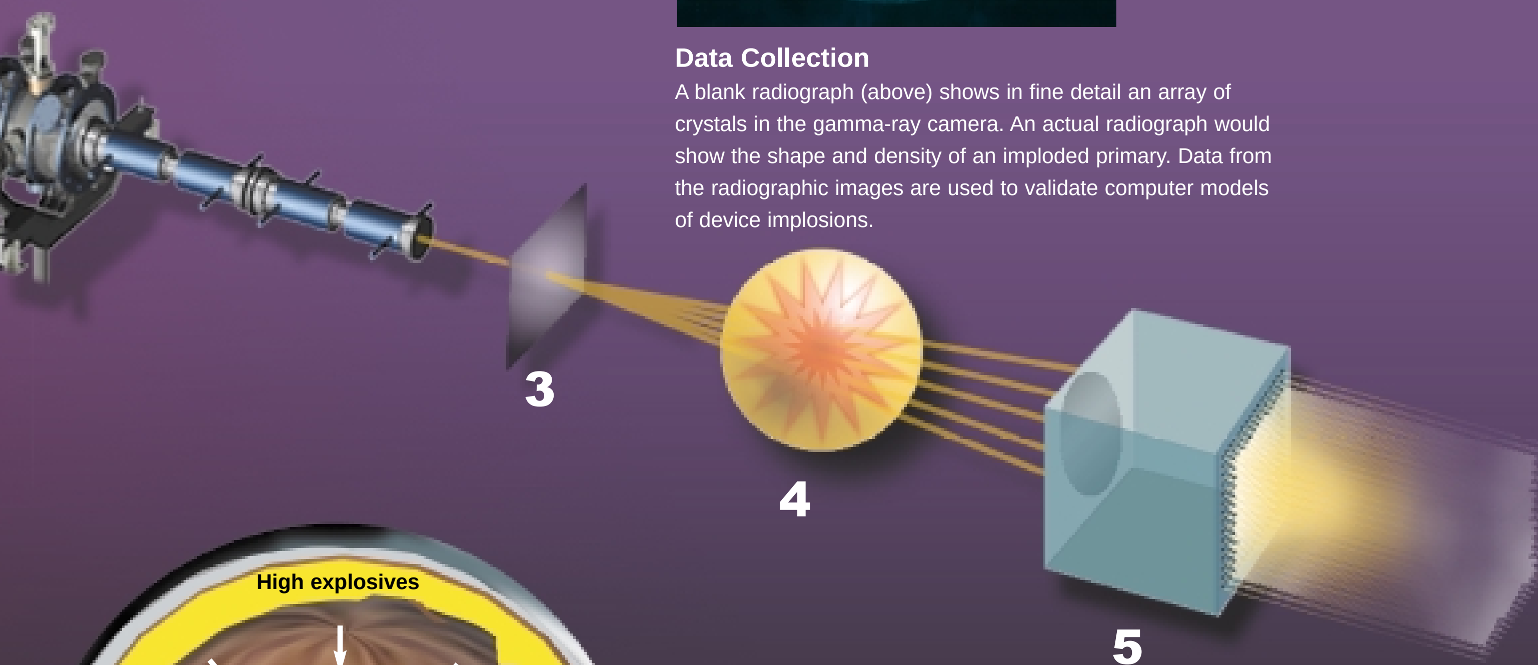
4. As the brief flash of x rays penetrates a highly compressed object, fewer x rays pass through dense areas, resulting in darker regions of an image.

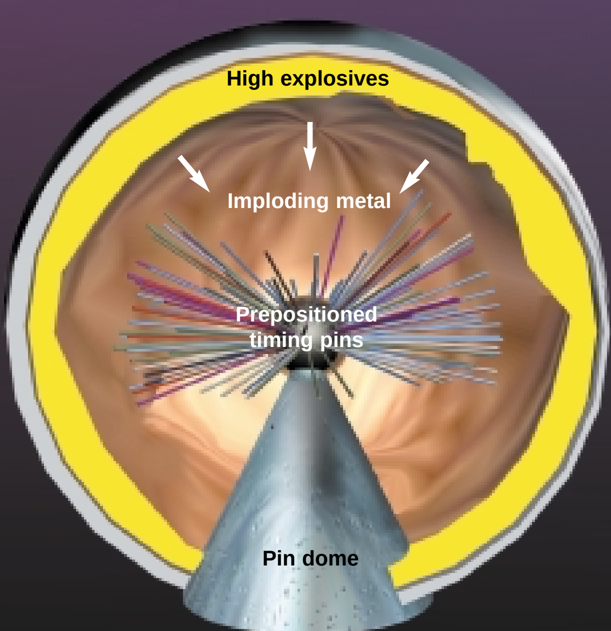
5. A highly sensitive detector system, called a gamma-ray camera, captures any radiation that passes through the device and converts it to visible light. This detector system is 100 times more sensitive than traditional x-ray film.



Data Collection

A blank radiograph (above) shows in fine detail an array of crystals in the gamma-ray camera. An actual radiograph would show the shape and density of an imploded primary. Data from the radiographic images are used to validate computer models of device implosions.





Firing Containment

Capping Decades of Hydrodynamic Testing Capabilities

Bringing large-scale hydrodynamic testing indoors—literally “putting a lid on it”—caps decades of hydrotesting experience at LLNL. In the past, all complex explosive-driven experiments at Site 300 that measure variables important to nuclear weapon operation were performed in the open air. Completed in 2001, the Contained Firing Facility represents our commitment to the protection of the environment, worker health and safety, and our nation’s nuclear stockpile. The centerpiece of the Contained Firing Facility, the containment chamber, is capable of containing the blast effects of detonations up to 60 kilograms (kg) of high explosive (see box). Furthermore, the facility consolidates our major hydrotesting diagnostics under one roof.

Pioneer in Containment Design

Containing a blast from 60 kg of high explosives requires tremendous amounts of strong materials—3200 cubic meters of concrete and two thousand metric tons of steel, to be exact. That’s enough concrete and steel to build the frame of a 16- by 18-meter, 60-story office building. Construction of the firing chamber—also 16 by 18 meters, but only 10 meters high—used those amounts for walls as much as two meters thick, floors, and doors of the firing chamber.

To ensure that the chamber will not incur any permanent changes to its size or shape over time, the inside surfaces of the firing chamber are protected by 50-millimeter-thick steel plates from shrapnel traveling as fast as 1.5 kilometers per second. Detonations will be conducted above a 150-millimeter-thick steel surface (the shot anvil) embedded in the floor.

To purge the air in the firing chamber after a hydrotest, the chamber is equipped with an air intake and exhaust system that can perform 10 air changes in half an hour. Exhaust air goes through a series of filters before being released into the atmosphere.

Personnel who then enter the firing chamber are fully suited up to protect them from any remaining hazardous materials. After removing the remains of the experiment, they turn on as necessary wash water system to remove any particulate matter from the walls and floor. A filtration system cleans the wash water.

The CFF can reduce total solid waste to about one-tenth the amount generated in comparable experiments elsewhere. Instead of plutonium, non-fissile surrogate materials are used in experiments at the CFF. Solid wastes and shot debris are disposed of primarily as low-level radioactive waste, with virtually no mixed (toxic and radioactive) waste.

State-of-the-Art Facility

The Contained Firing Facility dramatically reduces particle emissions to the environment and minimizes the generation of hazardous waste, noise, and blast pressures. While emissions from open-air testing at Site 300 have been within current environmental standards, use of the containment design ensures that testing can continue even as environmental requirements change. Future residential development not far from Site 300 will also benefit from these environmental precautions.

In addition to the state-of-art containment facility, the Contained Firing Facility houses one of the world’s most capable x-ray radiography machines and a complete suite of diagnostic equipment in its 4750 square meters of total space. The facility also includes a dedicated staging area for experimental preparation and several diagnostic equipment rooms with penetrations into the firing chamber.

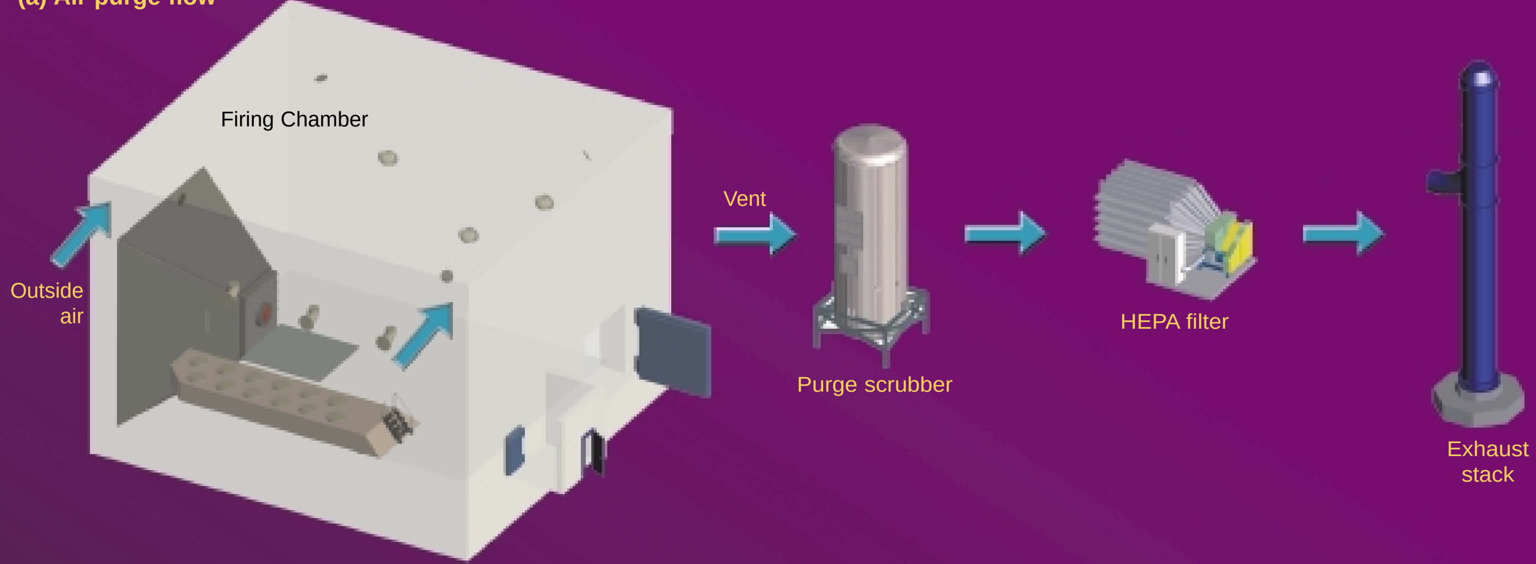
How much is 60 kilograms of high explosives?

Since the inception of hydrodynamic testing at LLNL, the concept of containment for detonations of 60 kg of high explosives was deemed impractical without an aggressive containment scheme. Such a containment structure must withstand repetitive firing of an equivalent 94-kg (206-lb) TNT explosion, or about 2000 times that of a hand grenade blast.

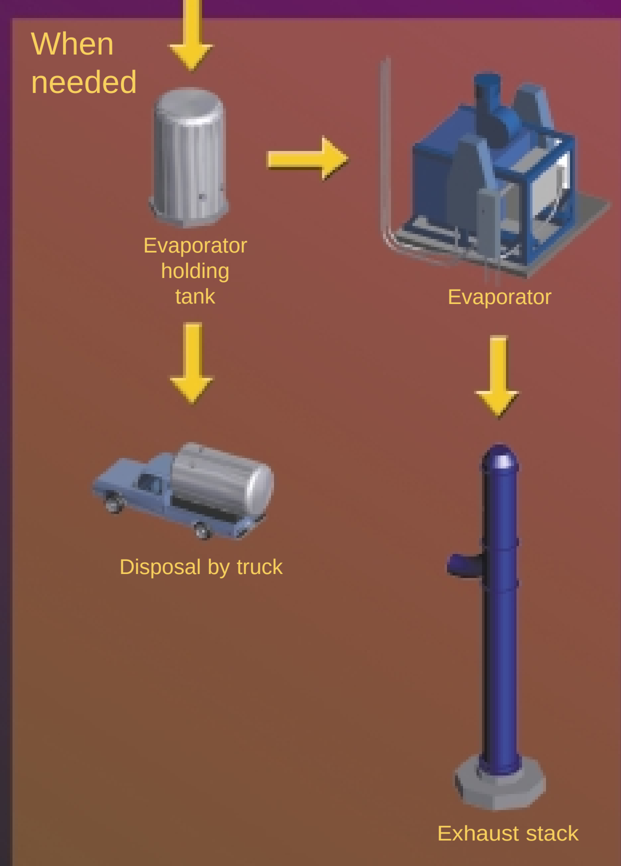
	Bullet	Grenade	Contained Firing Facility	Building Demolition
Mass of energetic materials	0.001 kg	0.03 kg	60 kg	≥100 kg

The containment limit of 60 kg of high explosives is designed to offer ample flexibility to conduct a complete spectrum of high explosive-driven experiments, including those with multiple test devices. The firing chamber can also accommodate the large explosive charges likely necessary in safety studies of nuclear systems.

(a) Air purge flow



(b) Water recycle and purge flow



As part of the “near-zero discharge” criterion, the CFF firing chamber employs multiple purge processes to achieve complete containment of all blast effects. After each test, ventilation fans (a) purge the chamber with fresh air. The exhaust gases are processed through high-efficiency particulate air (HEPA) filters and if necessary through a scrubber before being released to the environment. The wash-down decontamination system (b) recirculates water sprayed within the chamber and filters out dust and particulates in the form of sludge. The wash water can be recycled and used multiple times in the wash-down of the chamber. When the water is no longer usable, it can either be sent to LLNL’s main site for disposal or evaporated at the CFF.

Comprehensive Explosives Capability

From Synthesizing Molecules to Flowing Metals

While the Contained Firing Facility fulfills the need for a full-scale, multidiagnostic explosive-testing facility, LLNL's comprehensive explosives capability nonetheless begins at the molecular level—forming compounds that possess specific energy and density characteristics. From synthesis of new energetic materials to safety studies of explosives, from large-scale formulation to assembly of explosive devices, LLNL is a national resource with its complete spectrum of facilities and expertise in high explosives and high-explosive-driven experiments.

The High Explosives Applications Facility

A continuing demand for a fundamental understanding of the behavior of high explosives is driving Livermore's many advances in energetic materials, including breakthrough high-explosive materials and better theoretical models of their behavior. These advances would not be possible without the capabilities provided by the High Explosives Applications Facility (HEAF), located at the LLNL main site in Livermore.

To improve the safety and performance of our weapon systems, Livermore scientists continue to search for new and more efficient ways of synthesizing energetic molecules. Guided by advanced computer models and painstaking laboratory work, the synthesis process often produces only a few grams of a successful material to pass onto the formulation stage, where additional ingredients are incorporated for unique characteristics, such as insensitivity and flexibility. Up to 100 grams of high explosives can safely be formulated at the HEAF.

Why High Explosives?

Energetic chemistry is the most efficient non-nuclear means of storing energy for rapid release. For every cubic centimeter of material, a high-power chemical explosive can liberate its energy at an equivalent of nearly 10 billion watts. However, few people think of high explosives as precision instruments. The ideal high explosive must balance several precise requirements: It should be easy to form into parts of differing shape, yet resistant to deformation due to extreme conditions. It should detonate on demand but be difficult to explode accidentally. It should also be compatible with any surrounding materials while retaining its unique qualities indefinitely.

High-energy explosives play a role vital to proper weapon function. Only a precisely controlled high explosive detonation can lead to desired weapon performance. The extreme conditions created by an explosion include temperatures of nearly 5000°C and pressures so high that water can be squeezed to half of its starting volume.

Yet high explosives can be quite stable. Livermore scientists have pioneered the use of insensitive high explosives in weapon systems. These materials can be so safe and stable that bullets can penetrate through them without causing them to explode. It is the combination of high energy density, high power, and safety that makes high explosives both useful and unique materials.

Site 300 Explosive Processing Area

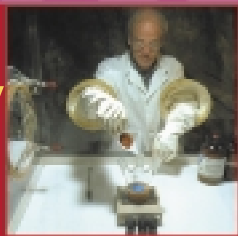
Large-quantity formulation of high explosives is performed 25 kilometers away at Lawrence Livermore's Experimental Test Site, known as Site 300. Home to the Contained Firing Facility and many other key explosvies facilities, Site 300 is set on 7,000 acres of rugged hills with diverse capabilities to support explosive and nondestructive testing.

Personnel at the explosive processing area at Site 300 routinely fabricate and machine high explosive mixtures into specified shapes. In addition, complex test devices are assembled and inspected with foremost precision at the processing area prior to testing. Despite the hazards of explosives, Site 300 has a stellar safety record with no injuries involving high explosives.

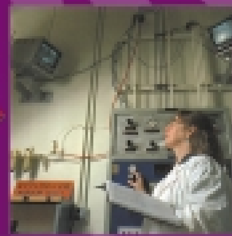
Explosives Testing at Both Sites

Depending on the size of the explosive charge, a high-explosive-driven experiment can be conducted either at the High Explosives Application Facility or at Site 300. Up to 10 kg of high explosives can be safely detonated in one of the seven containment tanks at the HEAF, whereas the firing chamber at the CFF can accommodate up to 60 kg of cased explosive charges and the use of depleted uranium and hazardous materials. Detonation experiments are supported by state-of-the-art diagnostic devices, including Fabry-Perot velocimeters, high-speed cameras, and x-ray radiographic equipment.

High Explosives Applications Facility
Livermore main site



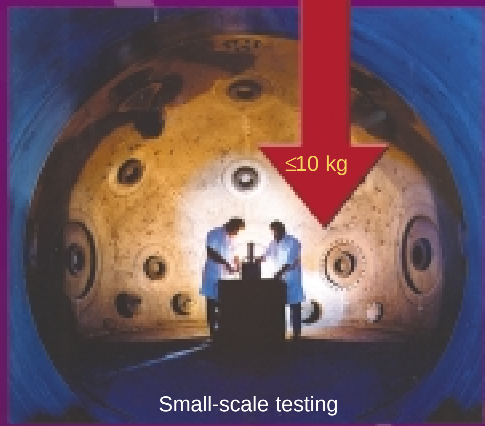
Synthesis of explosives molecules



Formulation of explosives

Safety and performance studies

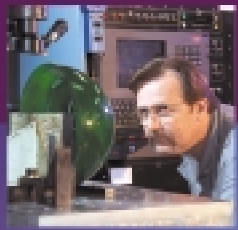
≤10 kg



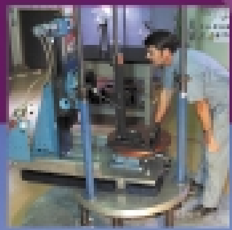
Small-scale testing

Site 300 HighExplosives Process Area

Large-scale formulation and processing



Machining



Assembly and inspection

≤60 kg

Site 300 Contained Firing Facility.
Large-scale testing

Beyond *Stewardship*

Supporting Other National Security Missions

The utility of the Contained Firing Facility extends beyond supporting stewardship of the U. S. nuclear stockpile. An important part of our national-security mission is the support of the Department of Defense in the development of advanced defense technologies.

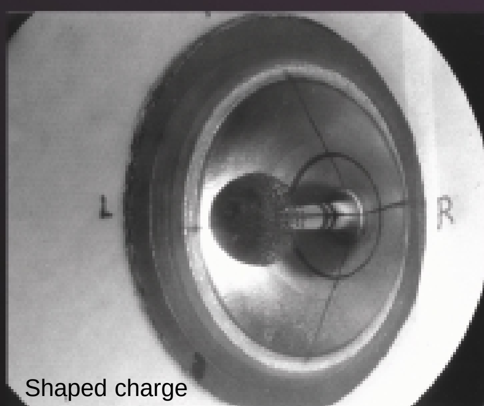
Experiments conducted at the CFF support long-term research and development of conventional weapons, such as shaped charges, which have been deployed by the Department of Defense in specialized armaments. These conventional weapons contain high explosives whose behavior and effects can be tested using the complete suite of diagnostic capabilities offered by the CFF.

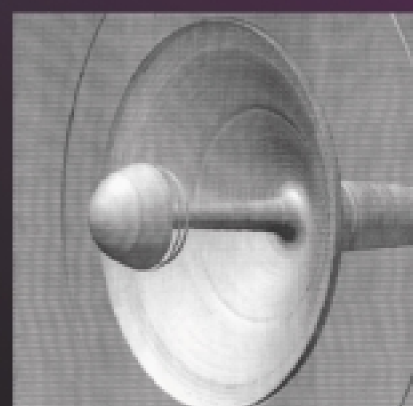
Detailed, quantitative study of shaped-charge dynamics also provides an ideal basis for testing the predictive capability of LLNL's best hydrodynamics codes. The leveraged resource enables us to contribute to technologies of interest to the DoD community while maintaining our nuclear weapons competencies.

Experimental results

Hydrocode calculations

An image-converter camera photograph of an elongating shaped-charge jet, taken at 19.3 microseconds after detonation, reveals fine details such as the grid lines on the jet stem.





Rotating-mirror camera photographs of a shaped-charge jet penetrating a steel target, taken at 40 microseconds after detonation, show good agreements with simulations.

The complete suite of diagnostic equipment at the Contained Firing Facility captures the fine features of a shaped-charge jet in unprecedented detail. Shown here are experimental data of a shaped-charge jet penetrating a steel target at a speed of 10 kilometers per second. The corresponding three-dimensional simulations of the jet show strong agreement to the experimental data, demonstrating the validity of the modeling code.

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