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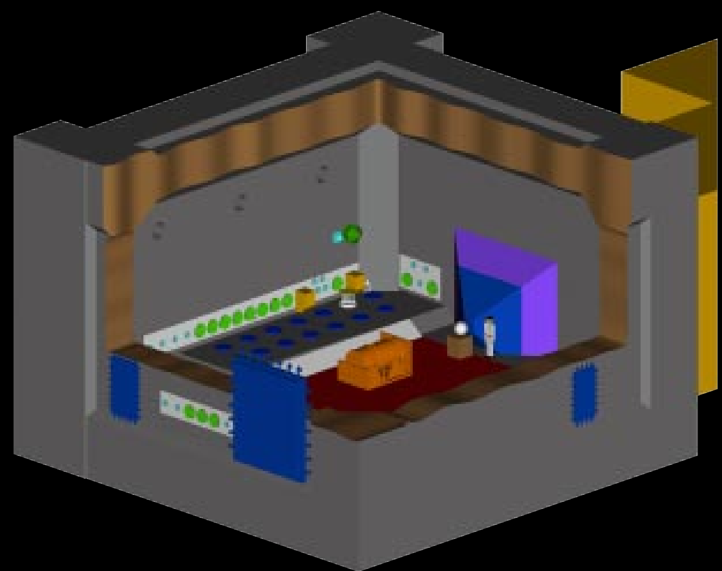

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Science & Technology REVIEW

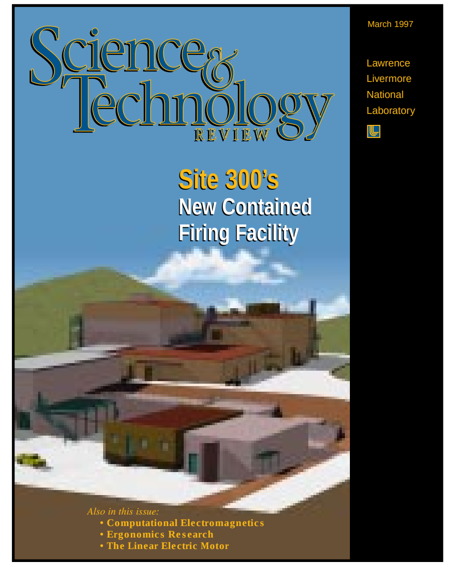
Lawrence
Livermore
National
Laboratory

Site 300's New Contained Firing Facility

Also in this issue:

About the Cover

The planned Contained Firing Facility at the Laboratory's Site 300 will enable explosives testing to continue indoors once the facility is complete. Construction is slated to begin in 1998. The article beginning on p. 4 describes the facility's capabilities and built-in environmental protections.



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Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published ten times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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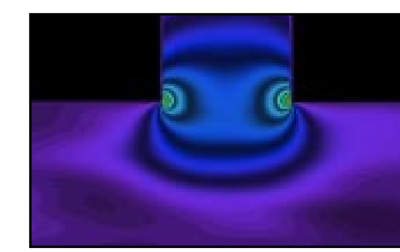

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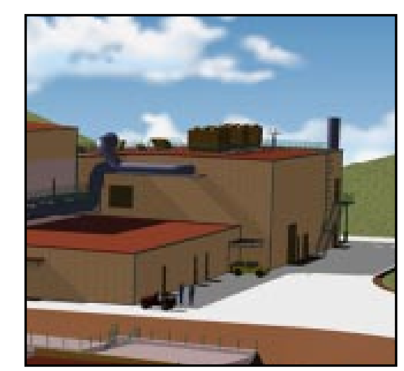

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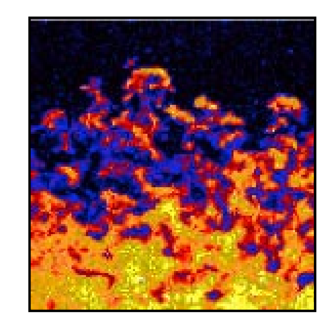

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DOE selects Livermore as site for $1.1 billion laser

Groundbreaking is expected soon at Lawrence Livermore for construction of the National Ignition Facility (NIF). The 192-beam, $1.1-billion laser will play a central role in the nation's science-based strategy for maintaining the safety and reliability of the country's stockpiled nuclear weapons.

The NIF is designed to achieve fusion ignition and push the boundaries of high-temperature and high-density physics while helping researchers validate advanced weapons codes, evaluate specific problems that may develop in warheads as they age, and maintain expertise about nuclear weapons. NIF will also support Laboratory missions in energy, basic science, and technology.

Livermore's selection as the site for NIF was announced by the Department of Energy last December in conjunction with the issuance of a formal decision on a comprehensive plan for managing the nation's nuclear weapons, including a makeover of the nuclear weapons complex. The Stockpile Stewardship and Management Program is DOE's blueprint for using scientific means to maintain the safety and reliability of the stockpile in the absence of nuclear testing.

Over 75% of NIF's cost will be spent in the construction and manufacturing industries. More than 6,000 jobs will be created during the 1996–2002 design and construction phase of the project; about 2,800 of those jobs will be in the San Francisco Bay Area.

Contact: Bill Hogan (510) 422-1344 (hogan5@llnl.gov).

Lab sensors help find possible lunar ice

Livermore researchers contributed to the discovery, announced last year, that a perpetually dark, frigid region at the Moon's South Pole could be a cold trap harboring ice crystals carried there by comets or asteroids.

Sensors developed at the Laboratory were used on Clementine I, the lunar mapping satellite that orbited the Moon in 1994, to determine the depth of a large area of craters and basins at the lunar South Pole.

Stewart Nozette, deputy program manager for Clementine I, proposed the novel idea of using Clementine's communications transmitter as a radar to test a theory that ice crystals might be trapped there. Nozette and fellow scientists succeeded in acquiring radar signatures that indicated the presence of "volatiles" in the polar region, probably in the form of water or methane ice.

The Clementine mission was sponsored by the Department of Defense and NASA as a way to test sensor technology to be used by the Ballistic Missile Defense Organization. The Lab created the package of six sensors used to map the Moon and gather various data.

Contact: Stewart Nozette (510) 424-4964.

Partnership aids in port-wine birthmark treatment

Doctors soon will be able to individually tailor treatments for removal of port-wine-stain birthmarks thanks to a research partnership between Lawrence Livermore and the University of California at Irvine's Beckman Laser Institute and Medical Clinic.

A birthmark that affects about 12,000 Americans born each year, port-wine stains result from an excessive number of oversized blood vessels near the skin's surface. In the past, doctors have had to treat the light pink to deep purple discolorations by simply estimating the laser energy and pulse length needed to remove them.

The medical community's newest tool is a computer code that helps doctors pinpoint the precise laser parameters needed to remove port-wine stains on an individual patient basis. Originally developed by Livermore electronics engineer Dennis Goodman to improve astronomical imaging, the code has been converted by Goodman and Beckman researchers into a diagnostic tool for birthmark removal.

Goodman started working with Beckman researchers in 1993 under a partnership arrangement and has continued to conduct research with the clinic's medical staff. Clinical trials using the three-dimensional diagnostic technique to treat patients have started and will continue for about a year.

Contact: Dennis Goodman (510) 423-7893 (goodman1@llnl.gov).

Livermore cosponsors environmental security workshop

A broad cross section of scientists, government leaders, and academics met in Monterey, California, last December to identify local, regional, and global environmental concerns relevant to U.S. national interests and to discuss the role of science in understanding and resolving them.

Entitled "Environmental Security and National Security: An International Challenge to Science and Technology," the workshop attracted over 100 representatives from the environmental, national security, and research communities. They were exposed to an array of environmental security issues by scholars in international law, policy analysis, industrial ecology, energy, global systems, and public health.

The event was cosponsored by the Laboratory, the University of California, Massachusetts Institute of Technology, Stanford University's Institute for International Studies, Columbia University, the Woodrow Wilson Center, and the U.S. Departments of Energy, Defense, and State.

Contact: T. J. Gilmartin (510) 422-9793 (gilmartin1@llnl.gov).

The Contained Firing Facility in a Changing Environment

THE article that follows on the new Contained Firing Facility (CFF) at Site 300 describes one of our activities to ensure that the U.S. retains the capability to support the nuclear stockpile while acknowledging and responding to environmental concerns (see p. 4). Building 801, where the facility is being constructed, is the site of advanced, high-speed optical and electronic diagnostic equipment as well as our recently upgraded flash x-ray machine, which will be discussed in an upcoming *Science & Technology Review* article. Upon the completion of the new CFF in 2000, we will possess a one-of-a-kind, indoor hydrodynamic testing capability.

Improved capabilities were not, however, the only driving force behind building the facility. We have been planning for some ten years for the facility, which will better protect the surrounding environment. This kind of change is necessarily much more complex to build into the facility than an equipment upgrade alone.

On a different scale, the nuclear weapons community in the U.S. has experienced its own dramatic changes in the past seven years. The most visible of these changes is the cessation of nuclear testing. In addition, the U.S. has been reducing the number of weapons in the stockpile while not developing any new nuclear weapons. The capacity and capability of the nuclear weapons production facilities are also undergoing changes. To assure the President that the remaining weapons remain safe and reliable, the Defense Programs part of DOE has created a comprehensive Stockpile Stewardship and Management Plan that describes how DOE and its laboratories and plants will work together to accomplish this objective.

Lawrence Livermore has a significant role in this plan. Part of our responsibility is to ensure that the warheads that were originally designed by the Laboratory continue to perform as originally designed. We also act as peer reviewers for analyses that Los Alamos National Laboratory performs on the weapons it has designed. Even without the availability of nuclear testing, we continue to test many of the non-nuclear components. For instance, we use surrogate materials to replace the radioactive materials used in real nuclear weapons so we can test the integrated performance of the design. For many years at Site 300, we have performed this kind of hydrodynamic testing, now even more important in the absence of nuclear testing. The CFF will improve the Laboratory's ability to continue with such testing in support of its mission commitments to stockpile stewardship and management.

LLNL remains committed to supporting the President and the nation's nuclear weapons policy by identifying and addressing issues that will ensure that the nation's nuclear deterrent is available in a known and stable condition. The CFF aids Livermore's strides toward this goal.

■ Michael Anastasio is Associate Director for Defense and Nuclear Technologies.

Site 300's New Contained Firing Facility

Protecting the environment, worker health and safety, and our nation's nuclear arsenal—the CFF will be a building for the 21st century.

Figure 1. The Contained Firing Facility is in the design phase. Construction will begin in 1998.

SOMETIME in 2000, far fewer loud "BOOMS" will resonate from Site 300, the Laboratory's explosives test complex. Lawrence Livermore National Laboratory's new Contained Firing Facility (CFF) will begin operation that year to provide indoor testing of high explosives, and most open-air experiments at Site 300 will be discontinued.

The new Contained Firing Facility (Figure 1) will be an important adjunct to Livermore's science-based stockpile stewardship program.* Without the validation provided by underground nuclear tests, Livermore scientists must still assure the safety and reliability of our nation's nuclear stockpile as weapons age beyond their originally planned life. Computer modeling supplies a wealth of information about how the explosives and assemblies in nuclear weapons will behave, but improved hydrodynamic testing of certain components is necessary to validate the computations.

Situated in the hills between the cities of Livermore and Tracy, Site 300 has been used since 1955 to perform experiments that measure variables important to nuclear weapon safety, conventional ordnance designs, and possible accidents (such as fires) involving explosives. The CFF will drastically reduce emissions to the environment and minimize the generation of hazardous waste, noise, and blast pressures. Although emissions from open-air testing at Site 300 are well within current environmental standards, the CFF is an "insurance policy" that will allow continued high-explosives testing should environmental requirements change. Future residential development in an area less than a mile away will also benefit from the facility's environmental precautions.

The new $50-million facility is currently in the final design stage, under the leadership of Livermore's Charles F. (Joe) Baker, who is project manager for the CFF project. Holmes and Narver Inc. of Orange, California, completed the conceptual design,[1] and the Parsons Infrastructure and Technology Group of Pasadena, California, started the final design in February 1996.

Construction of the new containment facilities at Building 801, scheduled to begin in April 1998, will require complete shutdown of operations at the building. According to Baker, "Even on an accelerated schedule for construction, equipment installation, final testing, and activation, downtime is estimated to be 28 months. With careful planning and early integration of acceptance testing with construction, we are working to minimize downtime and get testing at Building 801 back on line as quickly as possible."

CFF Design

Upon completion, the CFF will be a permanent, state-of-the-art firing chamber constructed on the site of Building 801's present open-air firing table. About 2,500 square meters will be added to Building 801, also the site of LLNL's recently upgraded 18-megaelectron-volt flash x-ray (FXR) machine. Building 801 contains a variety of other advanced, high-speed optical and electronic diagnostic equipment that together constitute a unique capability to diagnose the behavior of high-explosives-driven assemblies.

The CFF additions consist of four components: a firing chamber, a support area, a diagnostic equipment area, and an office/conference module, as shown in Figure 2.

The heart of the CFF is the firing chamber. Slightly larger than half a small gymnasium (16 by 18 meters and 10 meters high), the firing chamber will contain the blast overpressure and debris from detonations of up to 60 kilograms (kg) of cased explosive charges. The inside surfaces of the chamber will be protected from shrapnel traveling as fast as 1.5 kilometers per second with 38-millimeter-thick mild steel plates. To permit repetitive firings, all main structural elements of the firing chamber are required to remain elastic when subjected to blast. Detonations will be

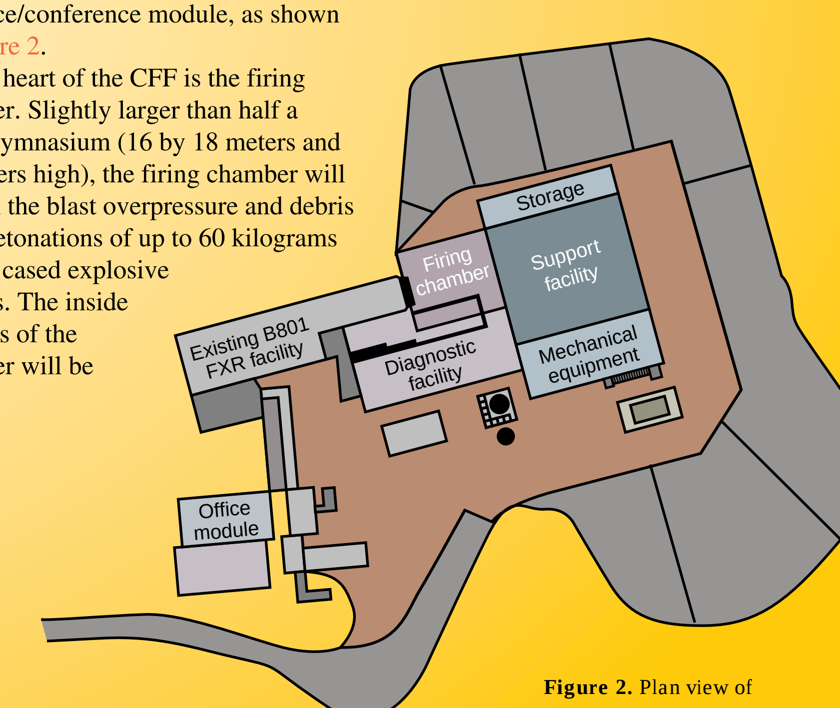


Figure 2. Plan view of new CFF facility.

* For more information on Livermore's stockpile stewardship program, see *Science & Technology Review,* August 1996, pp. 6–15.

conducted above a 150-millimeter-thick steel firing surface (the shot anvil) embedded in the floor.

All main structural elements of the firing chamber must be able to withstand repetitive firing as well as meet design safety standards. These criteria require the structure to withstand a 94-kg TNT blast, which is the equivalent to 60 kg of high explosives. During the testing phase of the project, “overtests” will be run using 75 kg of high explosives to assure that the building can withstand planned 60-kg detonations.

A key aspect of the new facility is that the rectangular concrete firing chamber will be made with low-cost, conventional reinforcement, as opposed to the labor-intensive, laced reinforcement commonly found in many blast-resistant structures. From a materials standpoint, a spherical chamber shape would be more blast efficient, but a slightly heavier, rectangular shape is cheaper to construct, provides easier and more desirable setup and working surfaces, and encompasses existing diagnostic systems. The thickness of the reinforced concrete walls, ceiling, and floor of the chamber will be 1.2, 1.4, and 1.8 m, respectively.

The support area, which measures about 1,500 meters^2, is for preparing the nonexplosive components of an experiment and also for equipment and materials storage, personnel locker rooms, rest rooms, and decontamination showers. It also houses filters, scrubbers, and a temporary waste-accumulation area for the waste products from testing.

The diagnostic equipment area (about 600 meters^2) will accommodate a multibeam Fabry-Perot velocimeter to measure velocity–time histories from as many as 20 points on an explosively driven metal surface.[2] The velocimeter optical equipment will take measurements through 12 horizontal optical lines of sight into the firing chamber. There are already 11 vertical optical lines of sight from the existing camera room, which is now beneath the open-air firing table and will soon be under the new contained firing chamber.

LLNL Blast-Effects Testing

After reviewing the conceptual design report, Baker and his engineering staff identified three design issues related to blast effects that would benefit from further investigation: shrapnel mitigation, close-in shock loading, and total structural response.[3] Staff from Livermore and Site 300 performed additional testing in these areas to verify the planned approach or to modify the design as required. Together these tests confirmed that with proper protection, a rectangular firing chamber constructed of low-cost, conventionally reinforced concrete will be acceptable.

Shrapnel Mitigation

High-velocity fragments from cased explosives could do significant damage to the pressure liner in the firing chamber and thus compromise the containment and sealing of hazardous gases and particulates. Worst-case shrapnel-producing experiments at Site 300 were monitored and documented to evaluate various general-purpose shrapnel-protection schemes. (See Figure 3.) The resulting design is a replaceable, 5-centimeter-thick multilayer system of steel plates, to be installed on the inside concrete surfaces of the firing chamber walls and as “throw rugs” on the floor.

From this testing program, three important design modifications were identified:

- Still more local shielding will be required on an as-needed basis near those experiments that use materials such as shaped charges. Local shielding will permit the overall general-purpose shielding to be thinner, resulting in a cost saving.
- General-purpose shielding will be made from mild steel instead of armor plate to cut roughly half the shielding cost yet provide about 85% of the penetration resistance of armor plate.
- Multilayer technology—thinner shrapnel-mitigation plates separated by air spaces—will be used, permitting the total thickness of shielding to be reduced and facilitating replacement and repair.

Close-In Shock Loading

The highest shock loading that the Contained Firing Facility must withstand will occur on the floor just below the 60-kg shot anvil. Currently, because of the diagnostic requirements of the FXR and the desired optical lines of sight, the distance from the top of the shot anvil to the floor is 1.22 meters. (See Figure 4.) This short distance

Figure 3. Shrapnel damage to a steel plate after a test to determine how much shielding is necessary for the firing chamber.

results in high blast loading on the reinforced concrete floor of the chamber. Because floor damage has been a common problem for many blast chambers used by the Departments of Energy and Defense, close-in blast loading on the chamber floor was considered to be one of the most critical design issues.

To investigate this concern, a series of 19 experiments ranging from 25 to 200% of anticipated close-in blast loading were conducted on a one-quarter-scale section of the proposed floor design. Strain gages were embedded in the concrete and placed on the reinforcing bars, on the hold-down bolts, and under the anvil surface to measure blast-induced strains.

During these tests, measured strains on the reinforcement, the bolts, and the anvil were all within elastic limits for steel. But tensile strains in the concrete were 10 times those allowable and would be likely to cause severe concrete cracking and pulverizing over the long term. To reduce the measured strains in the concrete to acceptable elastic levels and to prevent pulverizing, a low-cost blast attenuation system placed between the high-explosive and the anvil was developed and tested. Interestingly, of the various blast attenuation systems studied, the least expensive one, a rubber doormat-type material, proved to be the only acceptable option (Figure 5).

Total Structural Response

Once shrapnel protection and shock loading criteria were determined, the engineering staff evaluated criteria for the entire structure of the new firing chamber. The primary design criterion was that the chamber exhibit a totally elastic response to detonations within it, meaning that the chamber must not incur any permanent changes to its size or shape over time. To evaluate the structure, Livermore staff engineered and constructed a one-quarter-scale model based on the conceptual design, and installed instruments such as strain gages, pressure transducers, and temperature gages. Sixteen scaled detonation tests were performed in the model (Figure 6), which exhibited a lightly damped vibrational response that placed the structure in alternating cycles of compression and tension. During compression, both the reinforcing steel and the concrete remained elastic. During tension, the reinforcing steel remained elastic, but the concrete elastic limit was exceeded in two areas, and the concrete cracked in both places.

Overall, the experiments demonstrated that a rectangular, conventionally reinforced, concrete structure can be used as a firing chamber. The final design will incorporate more steel reinforcing to reduce cracking.

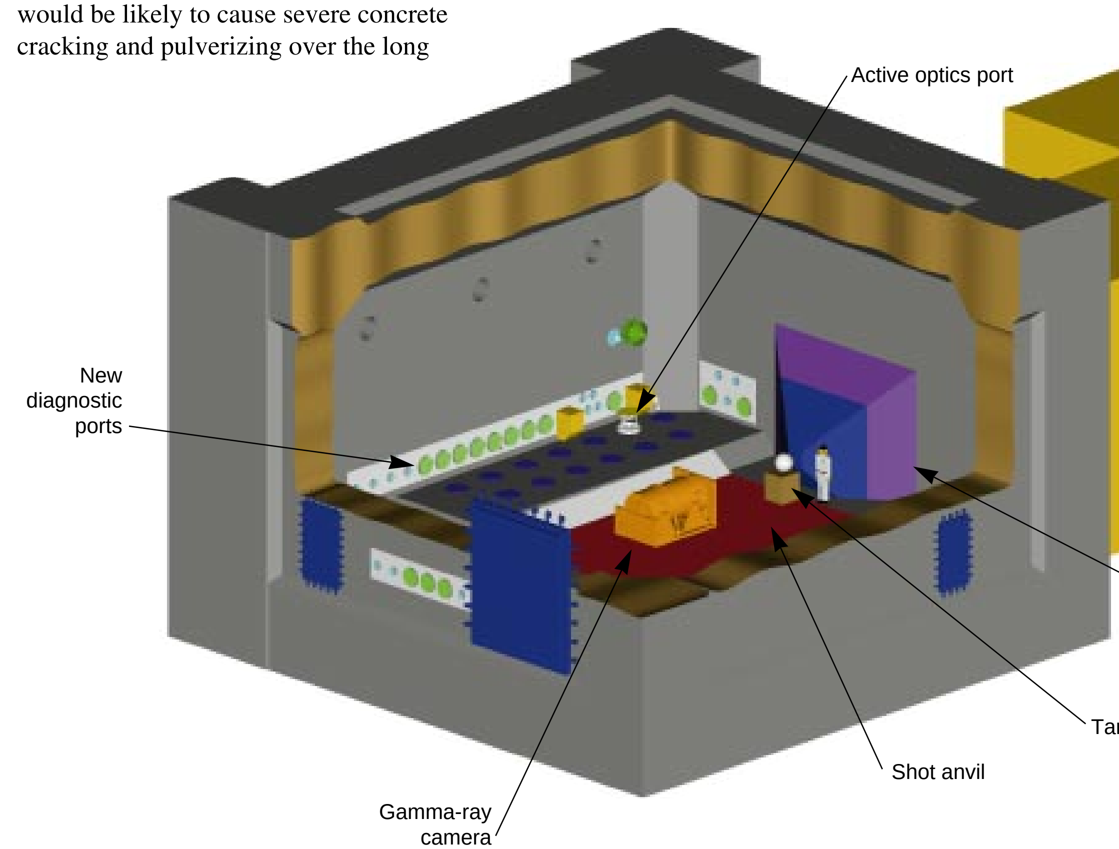


Figure 4. A design-generated drawing of the Contained Firing Facility’s firing chamber.

Built-in Protection

The design of the Contained Firing Facility incorporates numerous features to ensure the health and safety of those working inside the facility and to protect the outside environment.

Worker Protection

For workers in the facility, decontamination of the firing chamber after testing is very important. Some of the toxic and hazardous products from testing that will be monitored include ammonia, carbon monoxide, hydrogen chloride, hydrogen cyanide, hydrogen fluoride, nitrogen oxides, as well as aerosols of beryllium and other metals. Low-level radioactive aerosols are also expected from depleted uranium used in many tests.

Special mechanical systems will be installed for internal, closed water wash-down of the chamber interior after every test. The air and surfaces inside the chamber will be sampled for contamination, and cleanup will be repeated if necessary. Baker notes, “The goal is for employees to be able to return to the chamber to work after a test without having to wear protective clothing or breathing apparatus.” He adds, “Firing chambers tend to be dark and dingy. With the CFF, we are striving to achieve a bright, clean, laboratory-like atmosphere.”

Other features address the possibility that an otherwise well-planned experiment in the CFF for some reason might fail to detonate. Robotic systems for defusing and removing the explosive materials already exist and are being incorporated in the facility’s design.

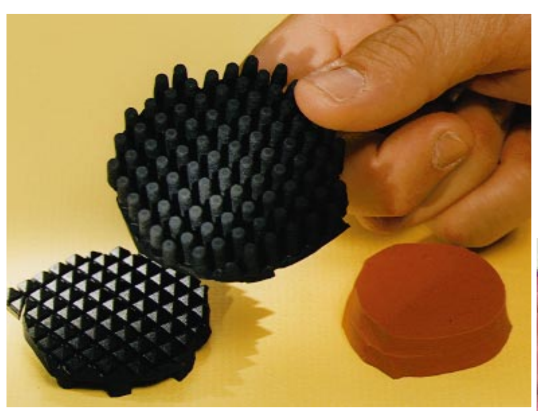
Near-Zero Discharge

“Contained firing” implies complete containment of all blast effects associated with the detonation of cased high-explosive materials, including noxious gases, aerosolized and chunky particulate matter, and impulse noise. The CFF project is based on a “near-zero discharge” policy. An occasional, inadvertent discharge would still be well within the limits of more stringent future regulations.

The firing chamber will be a sealed structure to contain not only very high-amplitude, short-duration impulse shock pressures but also the much lower-amplitude and longer-duration quasistatic gas pressures that are typical of explosives detonated in closed firing chambers. Anchored to the inside of the concrete chamber surfaces will be a thin, continuous, mild-steel pressure liner that will seal the chamber and prevent detonation gases from passing through the concrete walls, ceiling, and floor, all of which may develop structurally acceptable hairline cracks as the facility ages. All doors, optical lines of sight, and other intrusions into the firing chamber will have seals that allow the firing chamber to function as a pressure vessel to contain the blast and quasistatic pressure. After the gases cool, blast dampers will open, and ventilation fans will fill the chamber with fresh air. The exhaust gases will be processed through high-efficiency particulate air (HEPA) filters and scrubbers before being released to the environment. Slight negative atmospheric pressures will be maintained afterward in the firing chamber and the support area to reduce the escape of unprocessed airborne hazardous particulates and gases to the environment.

Waste Disposal

Solid wastes and shot debris will be disposed of primarily as low-level radioactive waste, with virtually no mixed (toxic and radioactive) waste anticipated. The wash-down decontamination system will recirculate water spray within the chamber and filter out dust and particulates in the form of sludge, which will be handled appropriately. The elimination of most open-air testing at Site 300 will significantly reduce the amount of contaminated firing-table gravel waste. Livermore estimates that the CFF will reduce total solid waste to about one-tenth the amount generated in comparable shots today.



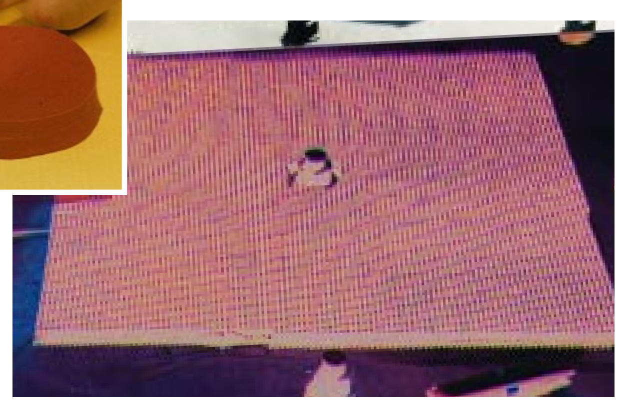


Figure 5. Tests determined that the blast attenuation system in the firing chamber should use a rubber doormat material between the test material and the anvil.

A New Flexibility

Given the growing importance of LLNL’s science-based stockpile stewardship program, the new CFF will give Lawrence Livermore the capability to continue high-explosives testing if environmental standards make open-air testing more difficult. According to Milt Grissom, Site 300 manager, “By the time the Contained Firing Facility is complete in 2000, it will indeed be a building for the 21st century—protecting the environment, worker health and safety, and our nation’s nuclear arsenal.”

—*Katie Walter*

Figure 6. Detonations inside a quarter-scale model were used to determine the facility's total structural response to future tests.

Key Words: environment, health and safety; flash x-ray (FXR) machine; high-explosives testing; stockpile stewardship.

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3. Documentation includes three informal reports by J. W. Pastrnak, C. F. Baker, and L. F. Simmons: shrapnel protection, UCRL-ID-110732; close-in blast loading, UCRL-JC-116822; and design validation, UCRL-ID-119432; LLNL–Livermore, CA (1992–1995).

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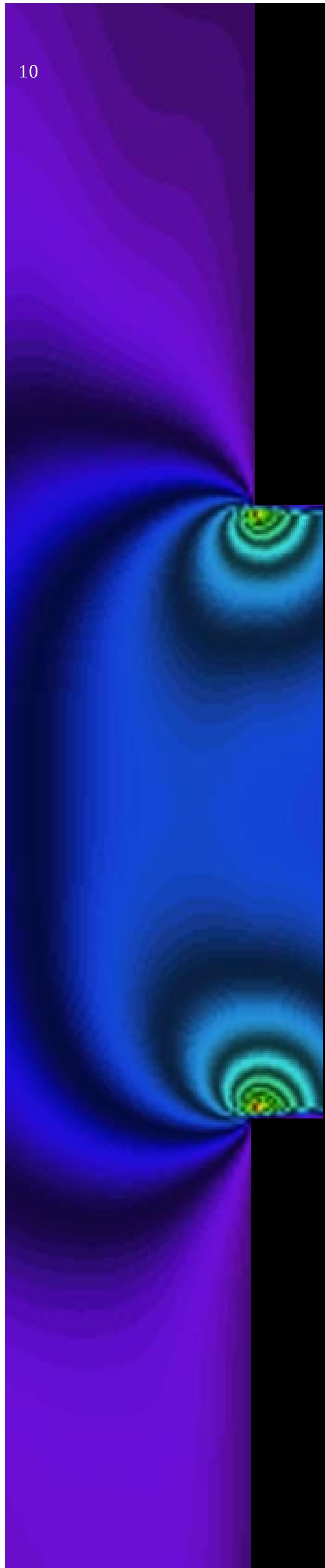
About the Engineer

CHARLES F. “JOE” BAKER received his B.S. in Civil Engineering in 1964 from the Georgia Institute of Technology. He worked for the State of California as a bridge engineer for six years before joining the Laboratory in 1970. Since then he has held a variety of positions in engineering, facilities design, construction management, and program management. Currently, he is Program Manager for the Advanced Hydrotest Facility, the Contained Firing Facility, and the Site 300 Facilities Revitalization Projects. Baker is an expert in designing buildings and structures to resist the effects of high-explosive blasts and is particularly knowledgeable about safety analyses for new facilities, investigations of accidental explosive detonation, and energetic materials testing.



Computational Electromagnetics: Codes and Capabilities

Livermore's computational electronics and electromagnetics engineers have a very direct mission: Give researchers the best electromagnetic modeling tools to solve real analysis and production problems.

LAWRENCE Livermore has long been recognized as a leader in the world of scientific computer simulations—creating multidimensional models of the dynamic and complex forces unleashed by nuclear explosives, visualizing the processes at work in the birth and death of stars, and studying the effects of greenhouse gases on global climate and of pollutants in our environment. It is not surprising, then, that the Laboratory is also a leading developer of computer codes that simulate propagation and interaction of electromagnetic (EM) fields.

Livermore's EM field experts study and model wave phenomena covering almost the entire electromagnetic spectrum (Figure 1). Applications are as varied as the wavelengths of interest: particle accelerator components, material science and pulsed power subsystems, photonic and optoelectronic devices, aerospace and radar systems, and microwave and microelectronics devices.

Building from its seminal work on time-domain algorithms[1] in the 1960s, the Laboratory has fashioned top-notch resources in electromagnetics and electronics modeling and characterization. Using Laboratory-developed two-dimensional and three-dimensional EM field and propagation modeling codes and EM measurement facilities, Livermore personnel can evaluate, design, fabricate, and test a wide range of accelerator systems and both impulse and continuous-wave RF (radio-frequency) microwave systems.

Center of Developing Technology

The Laboratory's unique connectivity has kindled progress in many key areas of accelerator design and photonic, opto-electronic, and RF systems. The focal point for these activities is the computational electronics and electromagnetics thrust area, which provides technical support for existing and developing programs. "We are a resource that crosses technical boundaries, yet we are integral to Livermore's major program areas," says thrust area leader Cliff Shang.

Administratively a part of Electronic Engineering's Defense Sciences Engineering Division, the thrust area operates like a technology development center. "With the EM Laboratory and EE personnel, the thrust area champions development of the best electromagnetic modeling capability available," says Richard Twogood, Deputy Associate Director for Electronics Engineering.

The thrust area has created a variety of production computer codes. (See the box on p. 13 for a summary of Livermore codes.) For example, Figure 2 shows how the NEC code is used in the development of an antenna for micropower impulse radar (MIR). Other codes are also in development.

With the codes, the EM Laboratory personnel fabricate the resulting systems and components and then analyze the prototypes against the codes.

Specialized Models for Analysis and Design

Creating new codes and refining production codes are the thrust area's primary activities, but the work does not occur in a vacuum. "We are not out just to design and develop EM codes," Shang says. "We develop modeling technology that can be directly applied to design problems, and we are adding new EM capabilities to anticipate future requirements of Laboratory programs. To accomplish these tasks effectively, our specialists work closely with program personnel."

Shang points out that "pairing experts from different disciplines—characteristic of the way the Laboratory does business—is essential for code development. This is the case in accelerator physics as well as in photonics and opto-electronics. The communities overlap. When you take the relevant knowledge and best codes from each to solve problems, you can end up with a new and very interesting set of codes."

Such codes are important because photonic devices are central to the growth of high-speed communications and computation. Signals in photonic networks can travel long distances at the speed of light, with very little power loss. These optoelectronic networks are made up of fibers, waveguides, sources, receivers, converters, and a host of other devices—all of which must be carefully designed if they are to work well together. Simulating a device before fabrication saves money and effort.

Many of the specialized codes created at Livermore have been made available to other government laboratories, universities, and industry. "The original NEC code is one of our most well-known codes," says Shang, "from the Department of Defense radar community to ham radio operators who design their own antennas."

In addition to their work in photonics and opto-electronics, EM thrust area personnel support a wide variety of Livermore R&D programs. Major emphases are stockpile stewardship and non-nuclear defense. For example, they are using their expertise and codes to support development of an advanced accelerator, which will help assure the safety and reliability of the nation's stockpiled nuclear weapons. They also support the Department of Defense (DoD) in assessing EM susceptibilities in conventional military systems.

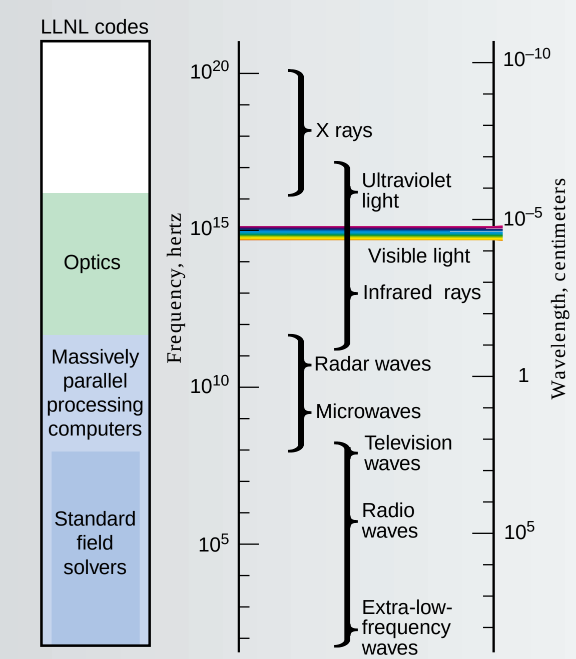


Figure 1. Laboratory expertise in computational electromagnetics is applied to problems across a wide area of the electromagnetic spectrum.

Focusing on Stockpile Stewardship

The Laboratory's capability to simulate, design, fabricate, and characterize accelerator technologies is being brought to bear in support of the nation's nuclear stockpile. As Livermore researchers design an advanced multibeamline accelerator for a proposed DOE program, a critical question is whether beam quality can be maintained when a single long-pulse (200-nanosecond to 2-microsecond) electron beam is split and channeled a number of times down subsidiary beam lines.

"It is a most difficult and complex problem, a true Grand Challenge," says Shang of the EM work on the design for what the DOE calls the Advanced Hydrotest Facility (AHF). Lawrence Livermore, Sandia, and Los Alamos national laboratories are coordinating separate technological approaches for the AHF. A DOE decision on which technology to adopt is expected in the year 2000, with the multimillion-dollar AHF operational in 2007. (See also the Contained Firing Facility article, beginning on p. 4.)

A 21st century diagnostic tool, AHF will provide multiple-angle, high-resolution x-ray images of materials in motion, such as an imploding device, to assure nuclear weapon reliability and safety. With the AHF, scientists will be able to assess the effect of high explosives on the weapon case. Livermore's role is to explore a linear induction accelerator that would generate a high-current (5-kiloamp), high-energy (20-megaelectron-volt) electron beam to produce x rays for radiography applications.

The Laboratory's experience in designing, building, and refining linear induction accelerators spans four decades. The current workhorse, the Flash X-Ray (FXR) radiography machine, has a single-pulse design (Figure 3). It is currently going through a second upgrade, this time to become a double-pulse system. Thrust area support includes modeling the injector performance and upgrading beam dynamics codes used to model high-current electron-beam transport.

Like the proposed AHF, the FXR allows scientists to assess issues related to safety, reliability, and performance of

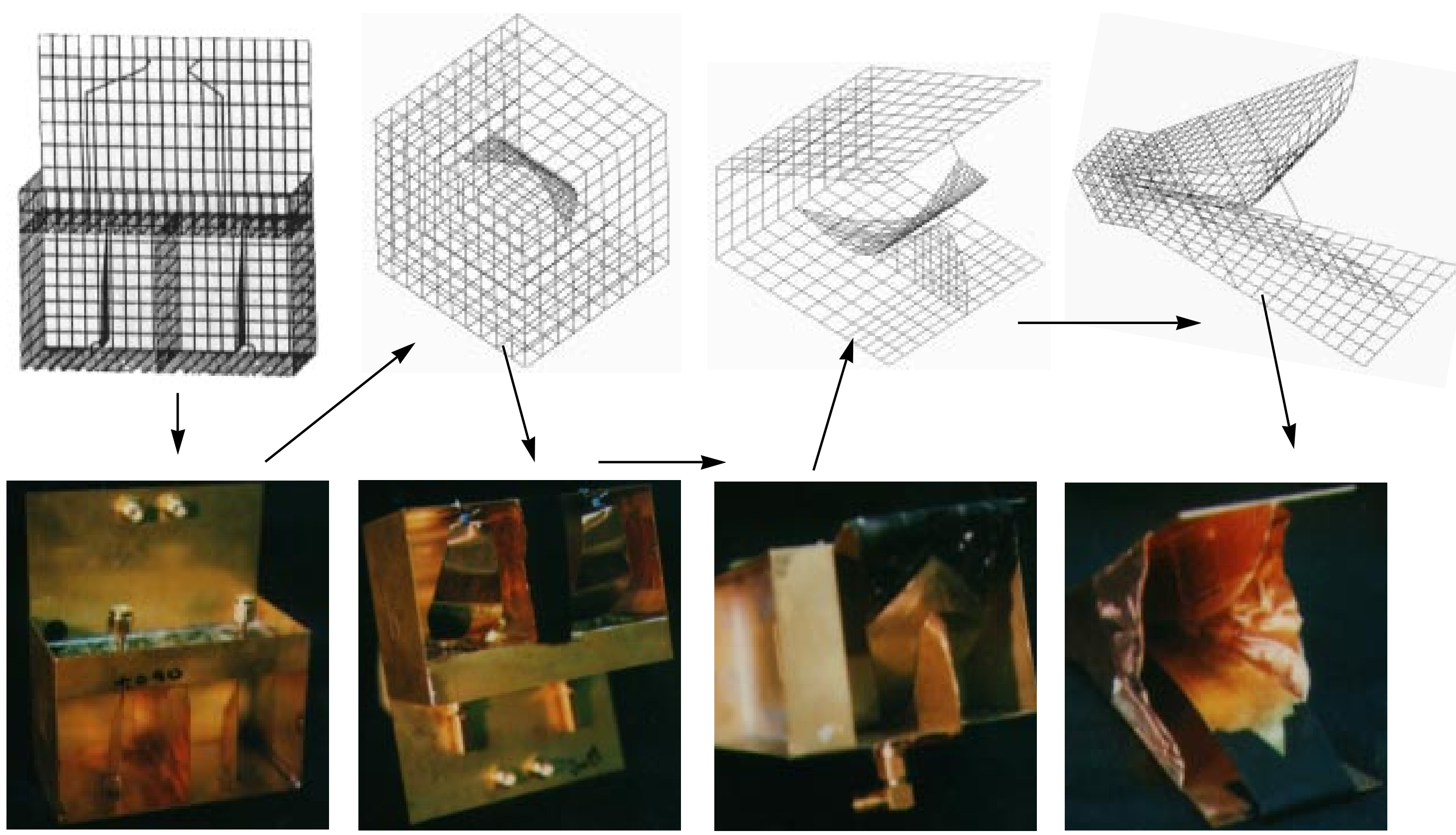


Figure 2. The Laboratory's specialists in EM used the NEC code in an iterative process to create a pulsed antenna to meet bandwidth and gain specifications. The project was a bridge deck inspection system using the Laboratory's micropower impulse radar (MIR) system (see the *S&TR* article on MIR, January/February 1996, p. 16–29.)

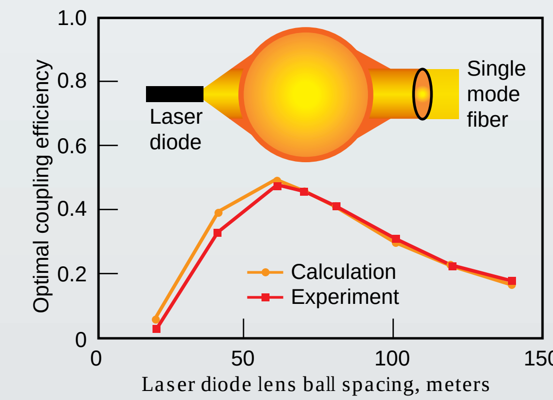
Livermore Codes

Rick Ratowsky calls it a Virtual Optical Bench, a user-friendly graphics interface for designers of photonic circuits, the optical world's equivalent of electronic circuits. "It is a photonics design tool with broad applicability," says Ratowsky, an electrical engineer.

Some photonics components have very small features, at a single wavelength scale; some features are very large, say thousands of wavelengths. Such devices have been very difficult to design because there is no easy way to put these differently scaled parts together.

A modeling code known as MELD (Multi-Scale Electrodynamics) will allow different length scales to be used concurrently—saving optoelectronics researchers much time and effort. (See figure to right.) The MELD code draws on techniques of both the electromagnetics and optics communities and integrates them in a way never used before.

"I can't say that all the techniques themselves are unique to Livermore," observes Ratowsky, "but their implementation and integration are." MELD joins a long list of EM codes developed at Livermore. Following is a brief summary of key modeling codes. All are used to solve equations arising from the fundamental classical electromagnetic field equations enunciated by James Clerk Maxwell in 1873.



Because devices such as laser diodes and fiber optic cables have different spot sizes, intercomponent coupling of optical power is a major limitation of integrated opto-electronic systems. The solution to the problem may be a ball lens optical mode converter (above) developed jointly by Lawrence Livermore and Hewlett–Packard to match optical fields. Laboratory photonic codes were used to design the optimal match.

Code	Recent application	Function
AMOS	Analysis of FXR accelerator structure (also ATA, ETA-II, and DARHT)	Solves 2.5-D axisymmetric and planar extrusion problems
NEC	Simulation of LLNL's MIR antenna	Models wire and patch antennas in the frequency domain (3-D)
TSAR	Simulation of RAH-66 Comanche helicopter	Models field behavior
MELD[a]	Laser diode optimization	Integrates hybrid full-wave electromagnetic and optical algorithms
TIGER	Aceleration kicker and RF structures	Performs 3-D time-domain calculations on unstructured grids in a massively parallel processing environment
BEEMER	Optical directional couplers, lenses, and curved fibers	Designs and simulates 2-D integrated optical systems using the beam-propagation method
EIGER	Broadband, ridged-waveguide, horn antenna	Calculates 3-D steady-state EM fields in the presence of interesting materials

[a]MELD includes SPHERE2 and TSARLITE.

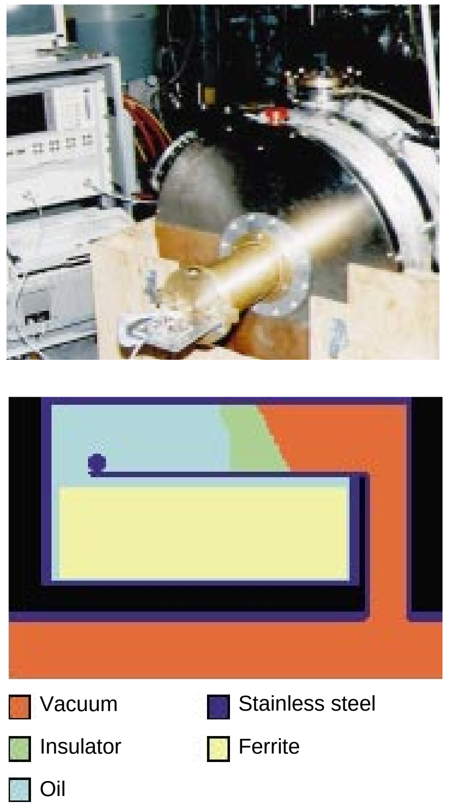


Figure 3. One accelerator cell of the Livermore Flash X Ray (FXR) (top) and its computational model (bottom), which will be used to design improvements to the machine.

a nuclear weapon's "primary," its fission trigger. In FXR hydrodynamic experiments, high explosives are detonated to produce pressures so high that solid materials, even when not melted, flow like fluids. X rays are created when charged particles generated by the FXR slam into a target made of a dense metal such as tantalum and provide images that are later analyzed. The FXR, however, offers only a single line-of-sight x-ray record. Stockpile weapons analysis requires simultaneous x-ray images from multiple angles, which the AHF will provide.

Ringing the high-explosive chamber with several linear accelerators to produce x rays for multiple imaging is very expensive. A Lawrence Livermore option proposes using a single linear induction accelerator that exploits a new and novel beamline component called the "kicker." The kicker (Figure 4) would displace a single electron beam pulse, effectively creating multiple pulses. Each pulse would travel down separate curved beamlines to encounter additional kickers for further splitting. Splitting would occur as many times as necessary to produce a specified number of beamlines for AHF diagnostics. An advanced kicker is also being developed by Livermore that could steer the beam horizontally as well as vertically, thus providing four or more different output beamlines from a single device. The challenge is to maintain beam quality in each subsidiary line. Proof-of-concept experiments for the AHF will be performed this year when Livermore's Experimental Test Accelerator-II (ETA-II) is refurbished and fitted with a kicker unit.

As part of the Laboratory's AHF design team, the EM experts are doing electromagnetic modeling of the beam-line components. Of particular interest are electromagnetic wakefields that could have an adverse impact on beam quality (see box and illustrations this page and p. 15).

"Our approach is to design an accelerator beamline component and simulate the design with our model. This iterative process refines the design before machinists begin fabricating accelerator components," explains electrical engineer Brian Poole. "We use those scattered wakefields to calculate the forces on charged particles that are injected into the beamline at subsequent times and to see how the beam quality is maintained."

Understanding AHF electromagnetic dynamics requires the utmost in computer resources. Solutions to some wakefield problems take a month or more of continuous supercomputer time, so some models are run on a smaller scale because of computer resources. For really large models that simulate the accelerator system being designed, the DOE's ASCI (Accelerated Strategic Computing Initiative) platform will be used. ASCI will allow more than a thousandfold increase in computational speed and data storage. Shang noted that thrust area personnel are developing three-dimensional, massively parallel, time-domain EM production codes that will exploit the new high-performance computing capabilities when they become available.

In addition to their work on radiographic systems such as FXR and AHF, thrust area personnel are involved in several other stockpile stewardship initiatives. They include:

- Designing the linear induction accelerator second-axis option of the Dual Axis Radiographic Hydrodynamic Test (DARHT) facility proposed for Los Alamos. DARHT would produce radiographic images with significantly higher spatial resolution and illumination intensity than are possible with present facilities.
- Developing integrated computer programs that will be used to design photonic circuits in the high-speed diagnostics of the National Ignition Facility (NIF). Analyzing high-power performance of optical components is another assignment performed for NIF, the 192-arm laser system that will simulate conditions of pressure, temperature, and density close to those that occur during the detonation of a nuclear weapon. (For more information on NIF, see *Energy & Technology Review*, November/December 1994.)
- Designing high-power microwave components and systems for the proposed Accelerator-Produced Tritium facility, an option being considered by the DOE as the primary source of tritium in the 21st century to replace the aging tritium in stockpiled nuclear weapons.
- Modeling and measuring the correct beam interaction physics in the

Understanding Wakefields

A charged particle beam traveling through an accelerator transport system, or beamline, has an associated electromagnetic (EM) field.

If the beamline is free of perturbations, the beam's EM field is not disturbed. However, a perturbation can modify the local electrodynamic properties of the structure.

Perturbations can consist of changes in cross section, apertures in the transport system wall, curved beamlines, or the introduction of different materials into the beam transport line.

As the charged particle beam streams past these perturbations in the structure, the beam's EM field is scattered from the structure. This EM field is called a wakefield (Figure 3) because the scattering occurs in the wake of the very-high-velocity particle.

This wakefield can interact with other particles traveling down the beamline behind the exciting particle, sometimes in an undesirable way, leading to the beam's degradation or, worse, breakup.

(a)

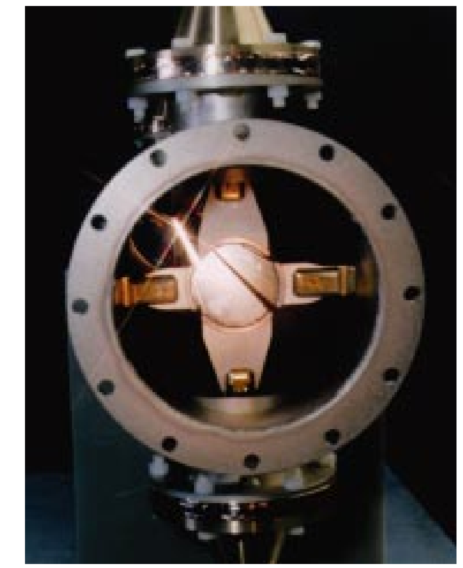
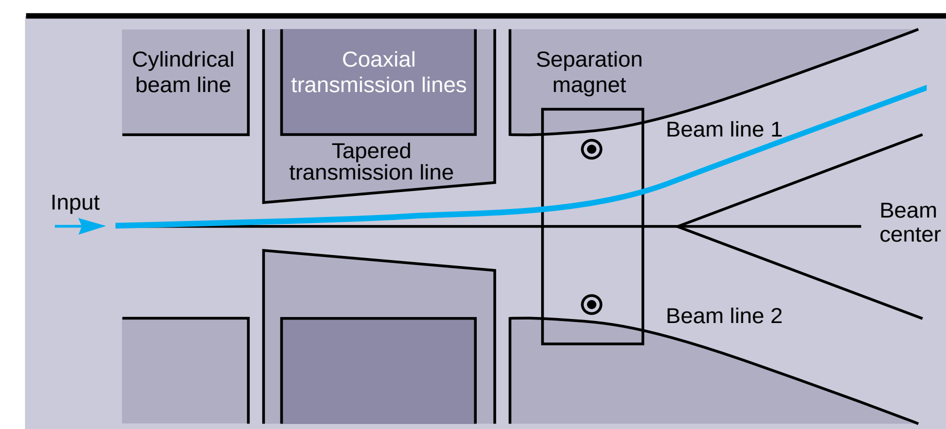


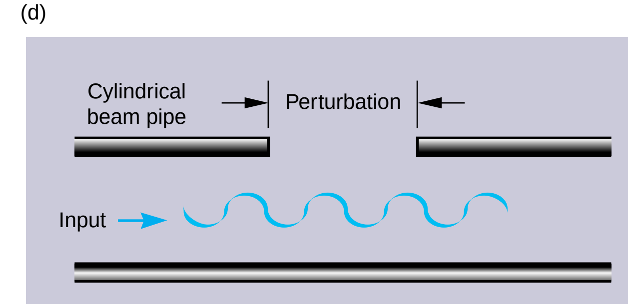
Figure 4. (a) The "kicker" structure developed for the proposed Advanced Hydrotest Facility consists of two pairs of nonlinearly tapered transmission lines enclosed in a cylindrical beamline. Each downstream beam may be split again into separate beams using additional kickers. (b) This schematic of the kicker shows the external coaxial transmission lines connecting the top and bottom strip lines. (c and d) Image and schematic of a wakefield calculation. The spectral characteristics of the longitudinal and transverse forces are determined on a test charge subjected to the wakefield.

(b)



(c)

(d)



accelerating structure for the Short-Pulse Spallation Source (a Los Alamos program).
- Analyzing and designing high-gradient insulation for development of compact accelerators.
- Analyzing heat dissipation in high-power optical components for NIF.
- Simulating beam controls for heavy-ion fusion.

Supporting Conventional Defense

Applying EM field theory to accelerator development is a multidisciplinary task that goes beyond traditional methods. However, these classical methods occupy a prime spot in the EM toolkit when researchers deal with problems that surface in today's commercially oriented, circuit-based microchip world. For example, aboard a commercial airliner, passengers are cautioned about when to use a cellular phone or laptop computer. The concern is that EM fields produced by the devices could interfere with the plane's electronic instruments and controls.

Indeed, susceptibility to signal and component damage and interference from EM signals are getting increased attention today from the DoD's Live Fire Test and Evaluation Office. The office routinely conducts tests to assess how DoD's conventional weapons systems—roughly 80 of them—stand up to ballistic and explosive assault. Because the Live Fire organization does not perform EM susceptibility tests on a regular basis, they contacted Livermore for assistance. The project is led by Livermore electrical engineer Scott D. Nelson of the Defense Sciences Engineering Division.

"Weapons systems are much more hardened to EM interference than systems on a conventional airliner," Nelson says, "but an EM weapon with enough power could cause problems in helicopters, airplanes, tanks, trucks, or missiles."

This spring, a Livermore team will return to the Naval Air Warfare Center at the China Lake Naval Weapons Center, California, for electromagnetic-effects experiments involving the Vietnam-era AH-1S Cobra helicopter. Understanding how external EM sources couple with the Cobra's communications, guidance, and weapons systems is helping designers of the newest Army helicopter, the RAH-66 Comanche, to pinpoint its potential EM susceptibilities.

The Laboratory's existing EM computer simulation models have been validated with numerous test objects, ranging from missiles and ships to planes and tanks. Because helicopters are fairly complex and have different parameters than other objects that have been tested, the team is now validating a simulation model for the Cobra, using data from tests they began at China Lake last summer. DoD's Live Fire Test and Evaluation Office made two flightworthy Cobras available for the initial EM experiments. For the studies, a Cobra was positioned atop a 10-meter tower made of unbeaded polyurethane foam. The foam, "invisible" to the microwaves, offered the illusion to instruments that the copter was hovering. The tower's base was a turntable that rotates 360 degrees to subject different parts of the helicopter to the microwave "fire." (See Figure 5.)

(a)

(b)

(c)

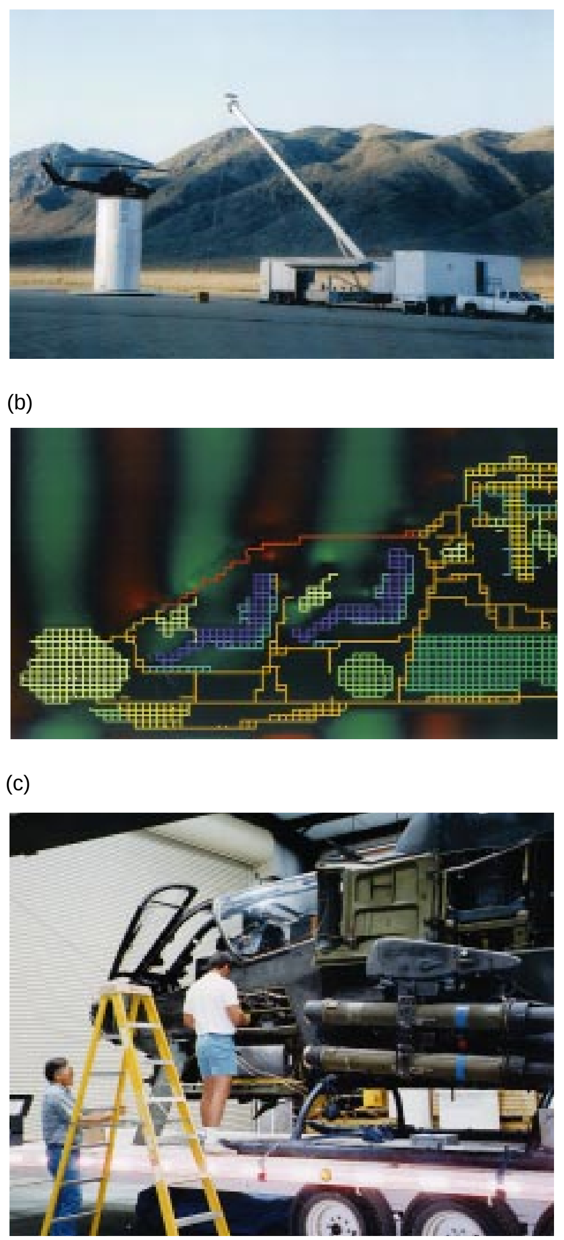


Figure 5. Low-power experiments at the Naval Air Warfare Center, China Lake, involve (a) positioning an AH-1S Cobra helicopter on a support tower. Livermore's portable time–frequency source and diagnostics trailer was used for monitoring the AH-1S testing points via fiber-optic connections. (b) Continuous-wave coupling measurements over a broad range represent a threat spectrum and include high-frequency-induced current measurements for monitoring the connecting signal lines and cavity coupling measurements. (c) Technicians place sensitive, nonobtrusive, RF sensors in the helicopter.

The Laboratory set up its portable microwave and RF test trailer at China Lake. The first tests measured the effects of low-power microwaves (200 watts) aimed at the helicopter from a boom-mounted external antenna. A fiber-optic system, running from inside the helicopter to the command trailer, carried information on the amount of power striking the target. Sensors placed on the copter registered the EM effect on the Cobra.

This summer, high-power tests (4 kilovolts per meter at a distance of 1,300 meters) will be performed by using a pulser supplied by Phillips Laboratory, an Air Force contractor, and the Naval Air Warfare Center's own 10-meter dish reflector to illuminate the target. Using the complete suite of Cobra EM modeling and comparing it with the field test data, Livermore will model Comanche EM susceptibilities.

The Laboratory EM team also will participate in a separate series of DoD high-power EM exercises at China Lake. Designed as a "shake-out" study of EM testing methodology, the exercises eventually could be used for full assessments of DoD weapons delivery systems.

Of the Livermore team's role in the shake-out tests, Nelson said, "We will serve the DoD as an unbiased participant, verifying that the contractor's equipment works as expected, that the RF source delivers the expected fluence on target, that characterization and measurements of the test object use known and trusted test methodologies, and that EM assessments represent realistic or anticipated threats. It is a role we know well."

—Dale Sprouse

Key Words: electromagnetic field, electromagnetic susceptibility, kicker, modeling, opto-electronics, photonics, wakefield.

Reference

1. K. S. Yee, "Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotopic Media," *IEEE Transactions on Antennas and Propagation* **AP-14**, 302–307 (May 1966).

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About the Engineers

Electrical engineers who collaborate in the Laboratory's computational electronics and electromagnetic thrust area include: (first row) DAVID STEICH, STEVE SAMPAYAN, JEFF KALLMAN, CLIFF SHANG, and BRIAN POOLE; (second row) RICK RATOWSKY, TOM ROSENBURY, and SCOTT D. NELSON. For more information about their work, visit their Internet home page on EM codes at http://www.llnl.gov/eng/ee/documents/ceeta.html and EM facilities at http://www-dsed.llnl.gov/documents/facilities.html. The group is pictured in front of the Experimental Test Accelerator-II (ETA-II). The ETA is a testbed for beam experiments n advanced hydrodynamics testing to characterize the accelerator and design key components such as the kicker described on p. 15. The accelerator ultimately will be a part of the Laboratory's Advanced Hydrotest Facility.

Ergonomics Research: Impact on Injuries

NO tool has characterized the modern workplace like the personal computer. An estimated 60 million PCs adorn desks in virtually every work environment today, achieving remarkable increases in productivity while virtually transforming entire industries. At the same time, however, an increasing number of employees are heavy computer users who suffer painful and sometimes debilitating (and occasionally career-ending) injuries called work-related musculoskeletal disorders (WRMSDs) involving their hands and arms.

According to Dr. Steve Burastero, director of Lawrence Livermore's Interdisciplinary Ergonomics Research Program and a physician in the Health Services Department, the mounting numbers of injuries should not come as a surprise. After all, someone typing 60 words per minute for 6 hours a day will keystroke a half-million keys every week, often in an awkward position or under stress.

Burastero says the number of cases of WRMSDs has increased dramatically to near-epidemic proportions in the U.S. workforce, from about 20% of occupational illnesses nationwide in 1981 to more than 60% of all occupational illnesses today, according to U.S. Bureau of Labor statistics. Within computer-intensive occupations, the incidence of injury has doubled every year for the past four years.

These disorders cost the nation over $40 billion per year in medical costs alone. When productivity losses and disability and retraining costs are included, the total bill may top $80 billion per year. A common injury is tendonitis—inflammation of tendons, which connect muscle to bone. Another well-publicized injury, carpal tunnel syndrome, involves damage to the median nerve that travels through a tight space in the wrist called the carpal tunnel.

Burastero notes that in the past, safety at most work sites, including Lawrence Livermore, traditionally focused on avoiding accidental injuries caused by hazardous materials or industrial equipment. As a result, procedures and instruments were developed that can detect, for example, toxic solvents at extremely low levels.

"We have technology that is very good for detecting the most minute amounts of hazardous materials," says Burastero.

Clinical tests are done with Livermore subjects. Ergonomist Pat Tittiranonda shows Nancy Johnson how a nerve conduction test would be performed to assess the symptoms of carpal-tunnel syndrome. Probes on the finger and wrist measure the nerve conduction velocity across the wrist joint.

"The technology for measuring musculoskeletal risk is very crude in comparison. At Lawrence Livermore, we rarely see people inhaling toxic materials, but, as at worksites everywhere, we see musculoskeletal injuries among computer users."

Experts say preventing WRMSDs begins with ergonomics, a relatively new field concerned with studying the interaction between individuals and their working environment to ensure that tasks are performed safely and efficiently. Burastero contends, however, that all too often, products labeled ergonomic are not backed by data gained from rigorous research or extensive field trials. As a result, there's a surprising lack of knowledge on how injuries can be prevented.

In response to the lack of scientific data, Lawrence Livermore's Interdisciplinary Ergonomics Research Program is addressing comprehensively the problem of WRMSDs plaguing U.S. industry. The program uses a multidisciplinary research team that taps LLNL's strengths in human factors design and engineering, computational modeling, biomechanical engineering, sensors, industrial hygiene, and occupational medicine.

These strengths make it appropriate for Lawrence Livermore to tackle a pressing national problem such as WRMSDs, says Burastero. The LLNL work is funded by Livermore's Laboratory Directed Research and Development, the Department of Energy, and the computer industry. The research projects have attracted collaborators from the University of California's San Francisco School of Medicine, UC Berkeley, the National Institute of Occupational Health in Sweden, and the University of Michigan.

The research is also closely aligned with the Laboratory's Center for Healthcare Technologies and an internal ergonomics program. The latter is an employee-oriented research program that aims to reduce the severity of ergonomic injuries and illnesses at the Laboratory and to reduce the lost and restricted time attributed to these injuries.

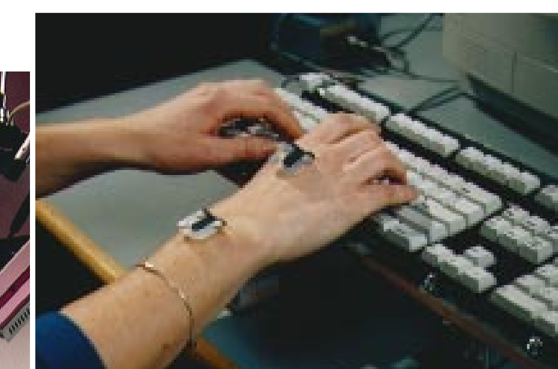
Unique Resources at LLNL

Livermore's ergonomics research program draws upon a combination of four resources, which together exist nowhere else in the national laboratory family. The first is an ergonomics laboratory (see photo below) that is outfitted with state-of-the-art three-dimensional motion-analysis equipment that is used to study dynamic wrist motion, a sensor-based hand tracking system, an image processing lab, and a variety of ergonomic assessment equipment. Much of the equipment can be transported to an employee's worksite for "real-world" analysis of how people interact with their computers.

The ergonomics lab works closely with computational modeling experts in LLNL's Institute for Scientific Computing Research. This modeling capability, the program's second significant resource, is being applied to the study of human–machine interactions. For example, ergonomics laboratory data help validate the work of LLNL bioengineer Karin Hollerbach, who is developing a dynamic computational model of the bones and joints that are often associated with these injuries. (See September 1996 *S&TR*, pp. 19–21.)

Biomedical engineer Robert Van Vorhis, who coordinates the ergonomics lab, also heads the technical aspects of a project to enhance a physician's visualization during endoscopic surgery for carpal tunnel syndrome. Improvements in endoscopic surgery could improve the cure rate of this minimally invasive surgical procedure such that, when it is successful, employees return to work in two weeks instead of six. This project is also leveraging Livermore's capabilities in optics and digital imaging with spinoff applications in advanced manufacturing.

The ergonomics research program's third major resource is Health Services' occupational health clinic (see photo on



Laboratory tests are conducted in setups like this one with hand-tracking devices (above) and digital cameras (left). Providing valuable data to the research program, graphic designer Kitty Tinsley tries out various keyboards to find a keyboard design that matches her needs.

previous page), which has expertise in the diagnosis, treatment, and rehabilitation of WRMSDs. Livermore physicians and nurse practitioners diagnose and manage problems while physical therapists administer on-site treatment.

Finally, LLNL's large, stable, and innovative workforce provides excellent subjects for testing new products in the workplace and for providing valuable feedback. "We are a mini-town, with every profession represented, including editors, administrators, accountants, computer scientists, physicists, technicians, and engineers," says Burastero. All use computers differently, and most, he adds, are not shy about voicing their ideas and problems concerning computer usage.

With these four resources—laboratory, computer modeling, clinic, and employees—Livermore is providing a better picture of how these injuries are initiated and prevented and the role that computer accessories play in prevention and cure. Burastero says combining data from laboratory studies, workplace observation, long-term subject feedback, and expert medical monitoring is much preferable to other methods that consist solely of testing people in a controlled setting for a few hours or lending them a product to try.

Much of the research program's focus has been studying recent alternatives to standard computer keyboards. Conventional keyboards have been suspected of causing or exacerbating WRMSDs because their design can encourage use with wrists bent into awkward postures. Burastero notes that keyboards really have not changed much during the past 30 years—witness the host of "vestigial keys" such as "scroll lock" that date from the PC's earliest days.

Pat Tittiranonda, an ergonomist with the program, recently completed the most comprehensive computer-keyboard study ever performed. The three-year study involved 80 participants representing a broad range of occupations at Livermore. All had suffered WRMSDs such as carpal-tunnel syndrome or tendonitis. The volunteers were given one of four alternate keyboards to use for six months. The keyboards had been developed and marketed by different companies with the goals of increasing user comfort and reducing the risks of awkward wrist postures.

Over a period of six months, the research team closely analyzed how the subjects used their keyboards, including how much force they exerted on the keys with their fingers. The team also did video and three-dimensional motion analysis of the volunteers working at their computers. The results showed for the first time that keyboards specifically designed to lessen pressure on wrists can relieve the symptoms of WRMSDs and promote recovery. What's more, many of the alternative keyboards did not impair productivity and were relatively easy to learn.

The test subjects also completed a questionnaire on supervisor and coworker support and conflict. The data affirmed preliminary findings that the effectiveness of ergonomic interventions can be reduced in a stressful working situation.

The study, says Burastero, should have a "significant impact" by changing the way keyboards are designed and providing safety and health professionals with a greater understanding of the role of keyboards in WRMSDs. "There had been a lot of anecdotal evidence, but until now no one had systematically looked at how people actually work with keyboards or at the long-term effects," he says.

Livermore ergonomics experts caution that keyboards are only one factor associated with WRMSDs. For example, chairs, desks, terminals, and lighting conditions also play roles. So do pointing devices such as mice and trackballs, which the research team is planning to investigate in depth. At the very least, says Burastero, Lawrence Livermore can provide a knowledgeable perspective to manufacturers, clinicians, and workers everywhere.

—Arnie Heller

Key Words: carpal tunnel syndrome, ergonomics, industrial health, work-related musculoskeletal disorders (WRMSDs).

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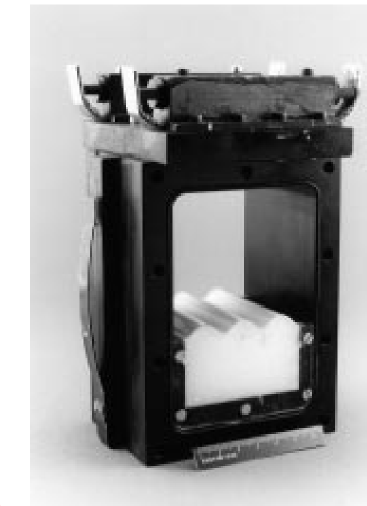
The Linear Electric Motor: Instability at 1,000 g's



WHAT do salad dressing and nuclear fusion have in common, and how can an electric motor further our understanding of both? More than one might suspect.

In both salad dressing and nuclear fusion, materials of different density will mix, which has a great bearing on such things as the uniformity of the dressing or how much energy will be achieved from an inertial confinement fusion (ICF) capsule.[1] To investigate this mixing process, Lawrence Livermore has built a linear electric motor (LEM) that can provide selected acceleration profiles up to 1,000 times Earth's gravity.

"When friends ask what I do, I like to tell them that I'm particularly concerned with what happens when you turn a bottle of salad dressing upside down," quips Guy Dimonte, the Lawrence Livermore physicist who is leading the project to study instabilities in liquids of different densities when they are accelerated by a linear electric motor. "Actually, I'm only half joking, because the principle is the same, whether it's oil mixing with vinegar or a plastic shell mixing with thermonuclear fuel in inertial confinement fusion. We need to understand how hydrodynamic instabilities enhance the mixing of different materials because this information is very important to Lawrence Livermore's stockpile stewardship work," he says.

Perturbations Grow

When fluid of high density is supported against gravity by a less dense liquid, the system is unstable, and microscopic perturbations grow at the interface between the fluids. This phenomenon, called the Rayleigh–Taylor instability, also occurs when a bottle of oil-and-vinegar salad dressing is turned upside down. The instability causes spikes of the dense fluid to penetrate the light fluid, while bubbles of the lighter fluid rise into the dense fluid. The same phenomenon occurs when a light fluid is used to accelerate a dense fluid, causing the two fluids to mix at a very high rate. For example, during the

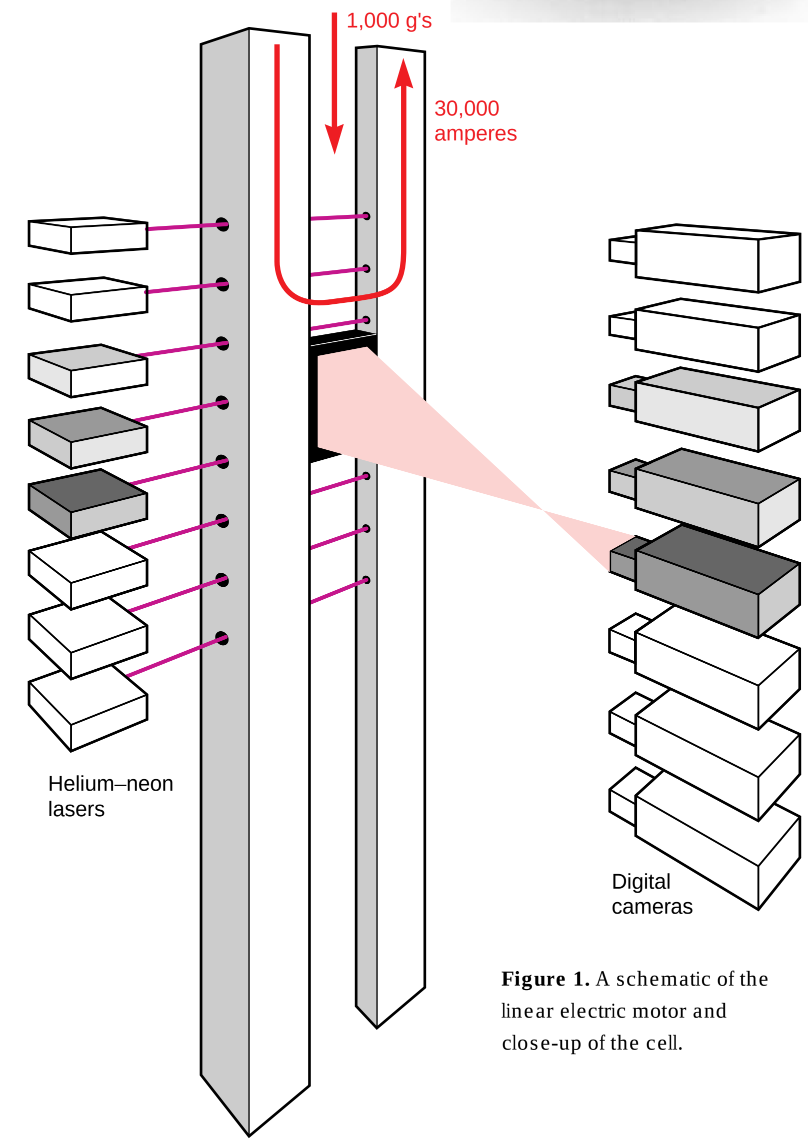


Figure 1. A schematic of the linear electric motor and close-up of the cell.

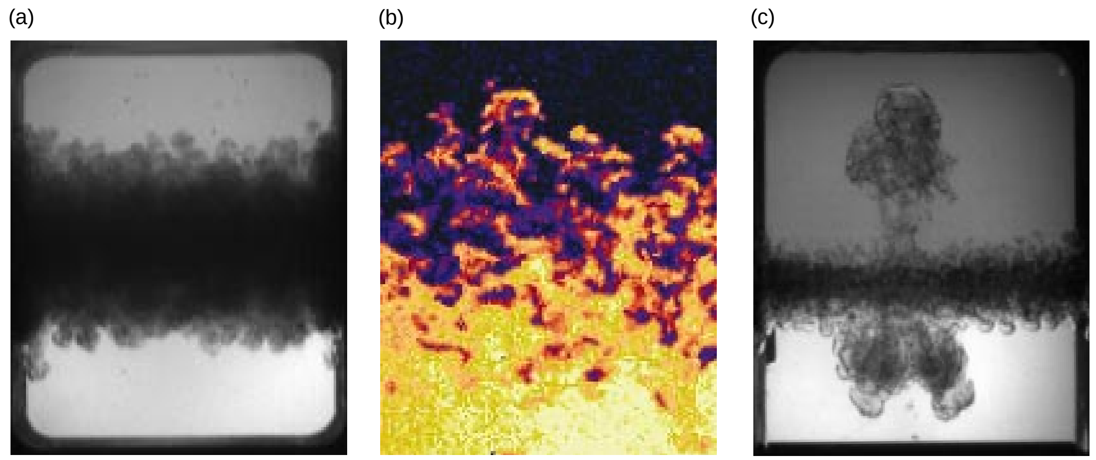


Figure 2. Sample images using (a and c) a flash backlighter and (b) a laser sheet. Images (a) and (b) have a smooth initial interface; (c) has a localized initial disturbance.

implosion of an ICF capsule, this instability can cause enough mixing to contaminate, cool, and degrade the yield of the thermonuclear fuel.

The LEM is an excellent tool for studying this instability, but what is it? Think of a miniature high-speed electric train (the container) hurtling down a track (the electrodes) while diagnostic equipment (optical and laser) photographs it. The configuration is shown in Figure 1.[2]

The LEM, configured by Dimonte and his colleague, physicist Marilyn Schneider, consists of four linear electrodes, or rails, that carry an electrical current to a pair of sliding armatures on the container. A magnetic field is produced that works in concert with the rail–armature current to accelerate the container—just as in an electric motor, but in a linear fashion rather than in rotation. The magnetic field is augmented with elongated coils just as in a conventional electric motor. This configuration also helps hold the armatures against the electrodes to prevent arcing. The electrical energy (0.6 megajoules) is provided by 16 capacitor banks that can be triggered independently to produce different acceleration profiles (i.e., how the acceleration varies with time).

The container that holds the fluid is machined from a block of Delrin, a material that is corrosion-resistant, strong, and nonconducting. The container is 9 × 9 × 12 centimeters (about 4 inches on a side) and has 0.5-cm-thick Lexan windows in the front and back so the liquids can be backlit and imaged. High-resolution optical imaging diagnostics record the inter-fluid mixing. The optical source is either a flash backlighter for photography or a laser sheet for laser-induced fluorescence (Figure 2).

The container trajectory is measured with a laser position detector (LAPD) consisting of eight transverse, 1-milliwatt beams at different positions along the trajectory. When the container intersects these beams, photo diodes send electrical signals that are recorded by digitizers and then trigger the optical diagnostic system. The images are captured electronically using charge-coupled device (CCD) cameras and a desk-top computer using a LABVIEW program. Higher resolution images are taken with remote-controlled 35-millimeter cameras, and the images are digitized later with a photodensitometer. Electrical signals from the LAPD, current monitors, magnetic field loops, and crystal accelerometers are acquired on digitizing oscilloscopes and archived on another desk-top computer. Finally, the container is stopped by a mechanical brake with spring-loaded aluminum drums.

The key to successful operation of the LEM is the sliding armature because it must carry as much as 30,000 amperes of current without arcing. "When we first started, our armatures were flawed, and we melted a lot of copper electrodes with spectacular arcs. After several modifications, we developed an armature that is very reliable, capable of several hundred arc-free shots before the electrodes need to be replaced. The system now works great, but without the exciting fireworks of the early days," Dimonte says.

In a typical experiment, the container is filled with two fluids (such as freon and water) and inserted between the rail.[3] The diagnostic equipment is activated, and the laboratory is then closed and interlocked. From an adjoining control room, the capacitors are charged and fired, sending the container down the rails with a final velocity of about 30 meters per second, depending on the needs of the experiment. Higher velocities are attainable with the energy available in the banks, but they are not required for most experiments. As the container intersects the laser beams, the imaging diagnostics are triggered and electrical signals are acquired. The container then enters the brake region and stops smoothly. "When we are in high gear, technicians Don Nelson and Sam Weaver can fire a shot as quickly as every 10 minutes," Dimonte explains.

Wide Range of Acceleration

"The beauty of using the LEM for these experiments is that we can take very high resolution images of the instabilities over a wide range of acceleration profiles," Dimonte says. "Most alternative drivers like compressed gas

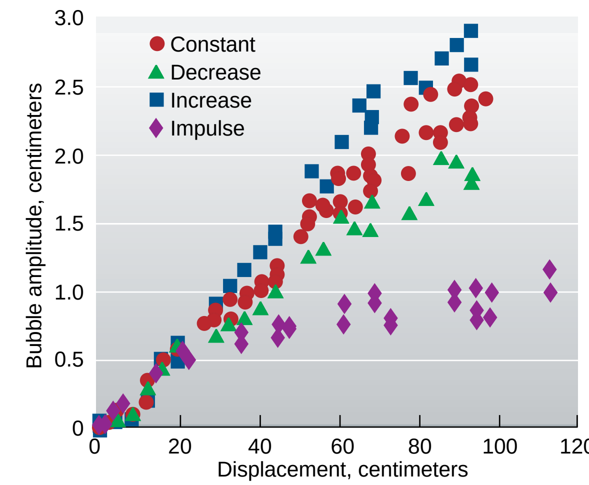


Figure 3. The bubble penetration distance versus the distance traveled by the fluids in a LEM.

Figure 4. Yogurt perturbations after being accelerated by 30 g's. Initial undulations at the interface were 1 millimeter; here they grew to 40 millimeters.

or rocket motors do not provide this flexibility. Mixing experiments are performed on Livermore's Nova laser under realistic conditions, but with less relative detail than on the LEM. The LEM is complementary to Nova and a very reliable and cost-effective tool for investigating the fine details of turbulent mixing."

In the example of Figure 2, the fluids have very little viscosity and the mixing is fast and turbulent. Here, scientists are interested in how the random bubbles of light fluid (on top) penetrate the heavy fluid (on bottom) and how the corresponding spikes of heavy fluid penetrate the light fluid. (Remember, gravity has been turned upside down because of the downward acceleration.) The amount of fluid mixing is indicated in Figure 3, which shows the bubble amplitude versus the distance traveled by the container for different acceleration profiles. From these data, Dimonte and Schneider can test turbulent mixing models and full hydrodynamic computer simulations.[3]

In another set of experiments, Dimonte and Schneider are investigating the mixing when the "fluids" have material strength. For example, when an aluminum plate is accelerated by high explosives, the driving pressure is comparable to the yield strength, or the point at which the material would become plastic. In this case, a smooth surface is expected to remain stable indefinitely, whereas a very rough surface would be unstable. They are testing this hypothesis by doing experiments using yogurt because it has enough yield strength to show the effect at the reduced g-forces of the LEM.

Figure 4 shows an image of yogurt accelerated in the LEM when the initial undulations at the interface were about 1 millimeter in amplitude. The perturbations became very large because of the instability. When the experiment was repeated with a smooth interface, the instability was inhibited by the material strength.

Many more experiments are possible on the LEM with different fluids, diagnostics, and acceleration profiles. "Our strategy is to use small-scale experiments like the LEM, with high-quality optical diagnostics, to investigate the micro-physics of turbulent mixing. Over the next five years, we will test the mixing models with data of unprecedented resolution. When the National Ignition Facility becomes available, the mixing models can then be applied to more realistic conditions in an integrated sense, that is, including the other issues relevant to stockpile stewardship, such as radiation flow and material equation of state," Dimonte says.

—Sam Hunter

Key Words: acceleration, linear electric motor (LEM), Rayleigh–Taylor instability.

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Patents and Awards

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Thomas E. McEwan	**Body Monitoring and Imaging Apparatus and Method** U.S. Patent 5,573,012 November 12, 1996	A monitor for detecting motion of heart, lung, vocal chord, or other organs based on the emission and detection of very-short-voltage pulses. A pulse-echo radar mode is employed repetitively to average a large number of reflected pulses. The voltage produced can modulate an audio oscillator to produce a tone that corresponds to the organ motion. The antenna can be formed of two flat copper foils, permitting the antenna to be housed in a flat housing. The monitor converts the detected voltage to an audible signal with both amplitude modulation and Doppler effect and uses a dual-time constant to reduce the effect of gross sensor-to-surface movement.
Conrad M. Yu Wing C. Hui	**Method for Making Circular Tubular Channels with Two Silicon Wafers** U.S. Patent 5,575,929 November 19, 1996	A method for fabricating semicircular microchannels in the surface of silicon wafers. A protective layer of boron nitride or silicon nitride is deposited on two wafers. Photolithography and plasma etching are used to form a narrow trench to the underlying silicon. An isotropic etch erodes the silicon through the trench in the protective layer to form a channel with a half-circular cross section. Wet etching removes the protective layer. The two silicon wafers are aligned and bonded together to complete the microcapillary.
Thomas E. McEwan	**Narrow Field Electromagnetic Sensor System and Method** U.S. Patent 5,576,627 November 19, 1996	A sensor system that emits a sequence of electromagnetic signals in response to a transmit timing signal. The receiver samples the sequence of electromagnetic signals in response to receive a timing signal and generates a sampled signal. The timing circuit supplies the timing signals to the transmitter and receiver. The receiver timing signal causes the receiver to sample a portion of each electromagnetic signal that travels along a direct RF path between the transmitter and the receiver. The signal processor coupled to the output of the receiver and responsive to the sampled signal provides an indication of a characteristic, such as the presence of an object, in the narrow field.
Alexander R. Mitchell Janis D. Young	**Polypeptide Having an Amino Acid Replaced with N-Benzylglycine** U.S. Patent 5,527,882 June 18, 1996	A method of obtaining a potent agonist or antagonist polypeptide by the replacement of selected amino acids with synthetic achiral amino acids. The method is used when selected amino acids in a polypeptide are replaced with N-benzylglycine or N-cyclohexylmethylglycine or the ring-substituted derivatives thereof. The synthetic peptides are designed to have enhanced agonist or antagonist properties compared to the natural material, with a minimum of undesirable side effects.

Awards

The **President's Early Career Award** was presented in December to **Christine Hartmann Siantar** by the National Science and Technology Council. She was also one of six DOE employees to receive the DOE Energy Research Young Independent Scientist Award. Siantar is the principal investigator of PEREGRINE, an advanced modeling system that will better calculate radiation treatment plans, leading to higher cure rates in cancer patients.

Martyn Adamson was elected **Fellow of the ASM International**, (formerly the American Society for Metals) for pioneering and sustained developments of materials and material systems used in nuclear reactors and for the active promotion of international information exchange on the thermodynamics of nuclear materials. He is a senior staff member in the Chemistry and Materials Science Directorate and a group leader in Environmental Programs Directorate responsible for researching, developing, and demonstrating advanced systems for processing nuclear and hazardous wastes.

Marshall Blann was awarded an honorary doctorate in physics by the University of Frankfurt, Germany, and received the prestigious **Alexander von Humboldt Award**, which funds a year of research at a German university.

Stuart Marshall was named a **Fellow of the Institute for Geophysics and Planetary Physics** by the University of California for his work on the MACHO Project.

William Nellis and **Arthur Mitchell** will receive the American Physical Society's **Shock Compression Award** this summer for finding metallic hydrogen in their gas gun experiments and also for a number of other contributions to the field.

Abstracts

Site 300's New Contained Firing Facility

Lawrence Livermore National Laboratory is preparing to construct a Contained Firing Facility to provide containment for much of Site 300's high-explosives testing, which is now done in the open air. This new facility, in the final design stage, is scheduled to be completed and operational in 2000. The facility incorporates numerous features to enable continued stockpile-stewardship-related tests while ensuring the health and safety of workers and protecting the outside environment. The firing chamber will be a rectangular, conventionally reinforced concrete structure. To assure that the design adequately addresses the effects of blasting in the firing chamber, Laboratory engineers and scientists have performed a series of tests, including several with a one-quarter-scale model of the firing chamber.

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Computational Electromagnetics: Codes and Capabilities

The computational electronics and electromagnetics thrust area has a very direct mission: give researchers the best electromagnetic modeling tools available. Livermore's EM experts study and model wave phenomena covering almost the entire electromagnetic spectrum. The focal point for Livermore's electronics and EM computer modeling activities is the computational electronics and electromagnetics thrust area.

This thrust area has created a variety of production computer codes such as BEEMER, SPHERE2, AMOS, TSAR, and NEC-4. For example, they are using their expertise and codes to support development of an advanced accelerator, which will help assure the safety and reliability of the nation's stockpiled nuclear weapons. They also support the Department of Defense in assessing EM vulnerabilities in conventional military systems.

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