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.

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."

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

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

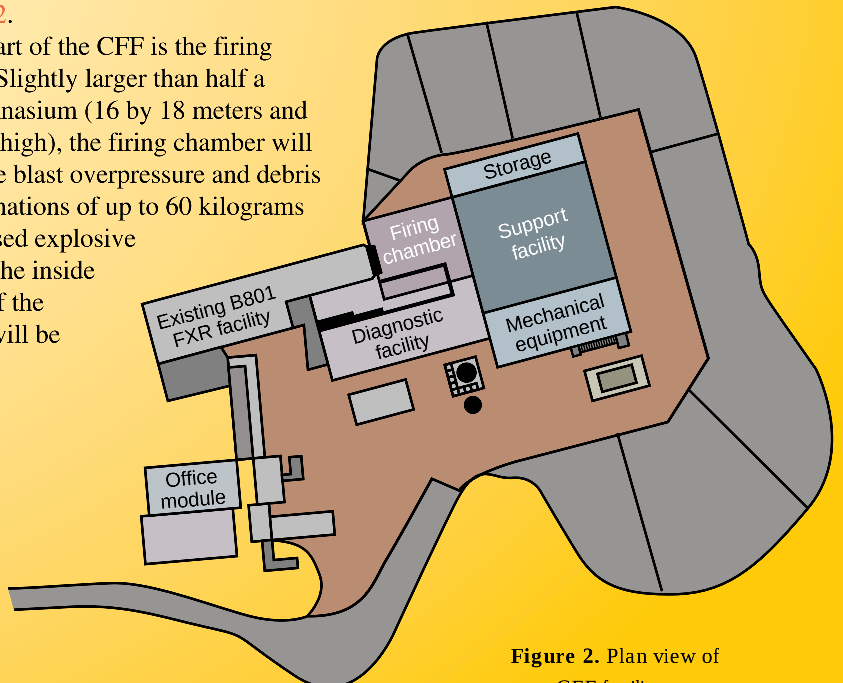

Figure 2. Plan view of new CFF facility.

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* 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 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.

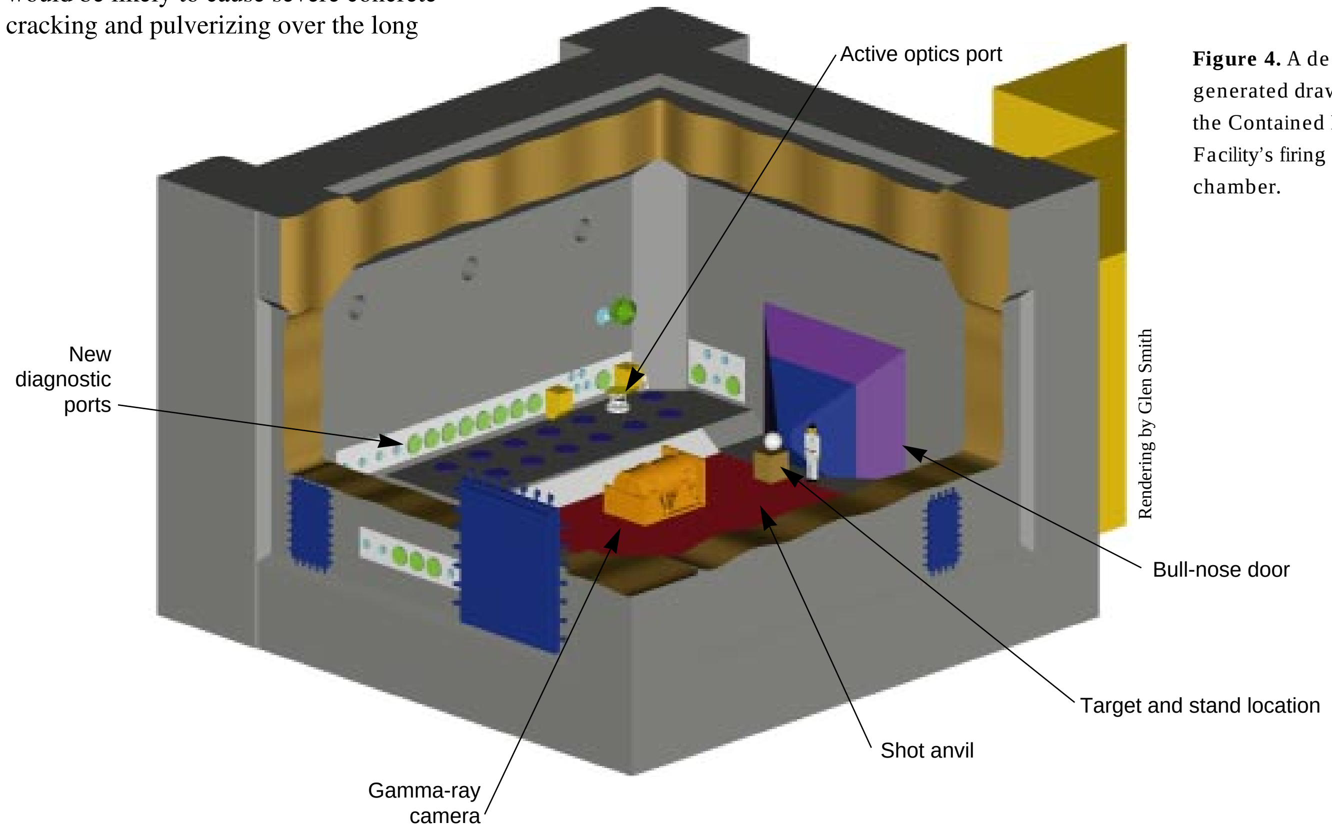
During these tests, measured strains on the reinforcement, the bolts, and the anvil were all within elastic limits for steel. But tensile strains in the concrete were 10 times those allowable and would be likely to cause severe concrete cracking and pulverizing over the long term. To reduce the measured 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 3. Shrapnel damage to a steel plate after a test to determine how much shielding is necessary for the firing chamber.



Rendering by Glen Smith

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.

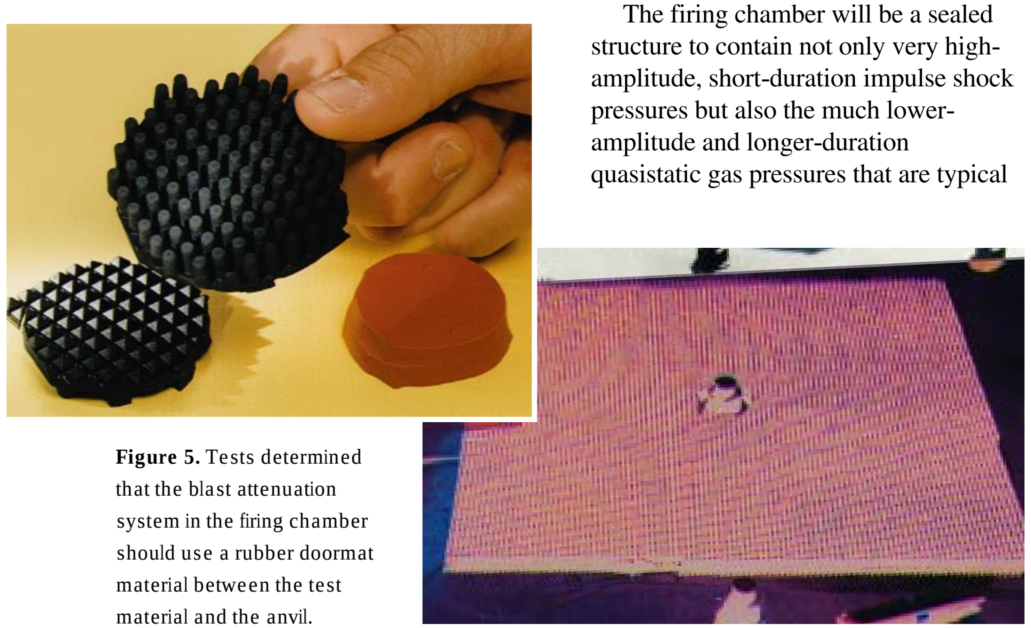


Figure 5. Tests determined that the blast attenuation system in the firing chamber should use a rubber doormat material between the test material and the anvil.

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.

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.

References

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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.