Keeping the Nuclear Stockpile Safe, Secure, and Reliable

In the absence of nuclear testing, the Department of Energy's Stockpile Stewardship and Management Program will use enhanced computational and experimental capabilities to help assess the status of the stockpiled weapons and predict, detect, evaluate, and correct problems affecting them. For Lawrence Livermore, the program represents a fundamental change from its historic nuclear weapons mission.

IT is not often that the Department of Energy's Assistant Secretary of Defense Programs visits the Laboratory to deliver a pep talk on a newly announced national security program of paramount importance to the department and the country. But that's what happened last October when Vic Reis told a packed assembly of more than 350 employees that the "awesome responsibility" for decisions regarding the safety and reliability of the nation's nuclear weapon stockpile "has been put right back where it belongs—with the labs."

Reis was referring to the DOE's far-reaching plan to make every effort possible to ensure that the nation's nuclear force remains safe, secure, and reliable without new weapon development or the use of underground testing. The plan, formally called the Stockpile Stewardship and Management Program (SSMP), is the result of close collaboration among the DOE and scientists from Livermore, Los Alamos, and Sandia National Laboratories. Indeed, in his address to employees, Reis credited LLNL Director Bruce Tarter and many top Livermore managers for their work to delineate for President Clinton, the Joint Chiefs of Staff, and the Congress the viability of the program, based on the projected capabilities and resources of the DOE weapon laboratories.

The SSMP will use enhanced computational and experimental capabilities to help predict, detect, evaluate, and correct problems affecting nuclear weapons in the national arsenal but without additional nuclear testing.

For Lawrence Livermore, the program represents a fundamental change from its historic mission of nuclear weapon development, nuclear testing, and surveillance. Stewardship of the U.S. nuclear stockpile is now this laboratory's "foremost responsibility," according to Tarter.

Specifically, the ambitious goals of the nation's SSMP are to:

- Provide the capabilities for the maintenance, assessment, and certification of the stockpile, including sources of nuclear weapon expertise to provide independent, critical reviews.
- Provide the capability to address the full range of stockpile problems that may arise.
- Minimize to the greatest extent possible the risks involved in maintaining the U.S. nuclear stockpile

Vic Reis, Department of Energy's Assistant Secretary of Defense Programs, visited Lawrence Livermore last October to underscore the importance of the Stockpile Stewardship and Management Program. While at LLNL, Reis visited the preferred site of the National Ignition Facility, a key component of the program.

under the constraints of no additional nuclear testing, no new-design weapon production, and limited budgets.
- Preserve the essential technical expertise unique to nuclear weapons.
- Provide a supply of tritium to replenish the inventory reduction caused by radioactive decay of tritium in existing weapons.
- Support U.S. nonproliferation, arms control, and nuclear weapon-related intelligence efforts.
- Provide the ability to reconstitute U.S. nuclear testing and weapon production capacities, should national security so demand in the future.

This new program addresses the U.S. nuclear stockpile, which is shrinking dramatically from Cold War levels. In the desire to conclude the Comprehensive Test Ban Treaty (CTBT), the U.S. has unilaterally halted the development and deployment of new nuclear weapon systems, begun closing elements of the nuclear weapon production complex no longer needed for a much smaller stockpile, stopped underground nuclear testing, and been involved in unprecedented nuclear arms limitation agreements between the U.S. and the nations of the former Soviet Union.

The program received powerful support last fall when President Clinton said that his decision to pursue a CTBT was based on assurances that the DOE nuclear weapon labs can meet the challenge of maintaining the nuclear deterrent under a CTBT through a Stockpile Stewardship and Management Program that does not include nuclear testing. This April President Clinton reaffirmed his determination to achieve a worldwide CTBT in a joint declaration with Russian President Boris Yeltsin.

Urgency, Risk Underlie Program

An urgency underlies the program that can best be understood by realizing that the average age of the weapons in the U.S. stockpile next year will be greater than at any time in the past and will continue to increase until it soon exceeds the base of experience of the nation's weapon scientists. This is because the U.S. has no new weapons planned or in production to replace the oldest stockpile weapons.

Also, it must be anticipated that the reliability of the stockpile may degrade as the weapons age beyond their designed lifetimes. Problems could be caused, for example, by radioactive decay, slow chemical changes, or incompatible materials. Serious consequences could arise from common-mode failures, ones that occur when similar materials or fabrication processes are used in several weapon systems. Because recently concluded arms control agreements have sharply reduced the number of weapons, such common-mode failures can affect a larger portion of the stockpile than in previous eras.

It seems likely that problems will arise over the next few years. Of the nuclear weapon systems introduced into the U.S. stockpile since 1970, nearly half have required post-development nuclear testing to verify whether a problem existed, or to resolve or fix ones relating to safety or reliability. Furthermore, all of the weapon systems that are candidates for the enduring stockpile (those weapons permitted as a result of the START II agreement with Russia) have already been retrofitted to some degree, including the replacement of major nuclear components in some cases.

Weapon scientists must be able to accurately evaluate the severity of problems and devise the right "fixes," whether they be a remanufactured component, modification to a component to extend its lifetime, or substitution of a more reliable or safer part. In the past, the extent of a problem or the effectiveness of a "fix" could be determined with an underground nuclear test at the Nevada Test Site. If the problem proved to be particularly severe, a new warhead or weapon system could be developed. With nuclear testing and new weapon development no longer options, stockpile stewardship must rely on an improved understanding of nuclear weapons based on greatly improved facilities and computational models.

In addition to urgency, some areas of risk were folded into the President's decision. It is known that in some cases there is no adequate substitute for nuclear testing. The weapon recertification process will take these risks into account.

Key Thrust Areas

The national stockpile stewardship program has three main thrusts: laboratory experiments, computer simulations, and stockpile inspections. In each, Lawrence Livermore has particular responsibilities.

Upgrading Experimental Facilities and Capabilities

Defining the stockpile stewardship program has required extensive cooperation and coordination among

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The Human Factor: Preserving Key Skills and Assuring Sound Judgment

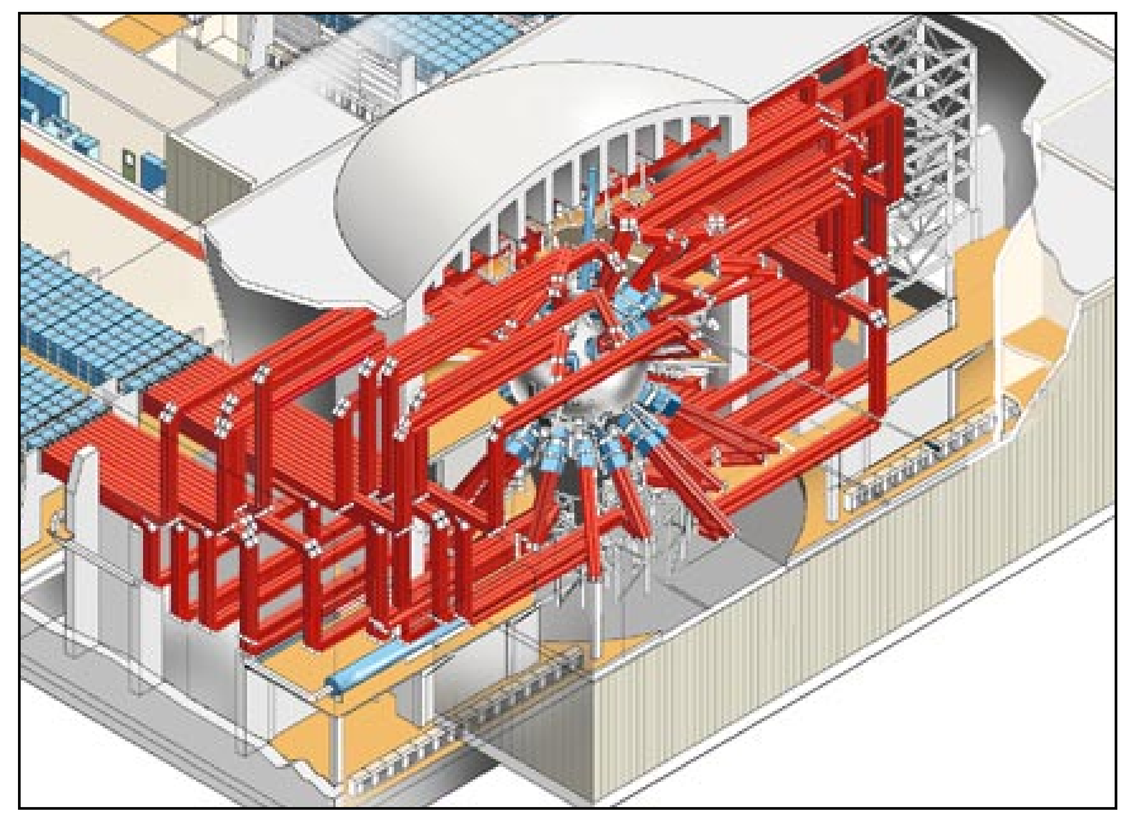
The Stockpile Stewardship and Management Program (SSMP) places a premium on skilled, experienced people. As Lawrence Livermore Director Bruce Tarter said in April, "Stewardship of an aging stockpile is a heck of a different job than innovative research and design. It will rely—even more than in the past—on people throughout the Laboratory, the universities, and industry."

However, nuclear weapon science is a highly circumscribed field; there exists no broad industrial or university base from which to draw nuclear weapon expertise. U.S. weapon scientists have no true peers other than their colleagues at the three DOE weapon laboratories.

In the last few years, many of LLNL's most experienced weapon scientists and engineers have retired or left the Laboratory, and further retirements of experienced staff are expected in the next 10 years. To prepare for this situation, Livermore, Los Alamos, and Sandia are archiving their nuclear design data, knowledge, and skill bases. Lawrence Livermore, for example, is videotaping classified interviews of retired weapon designers explaining their craft and the steps leading to key design decisions. Scientists and engineers new to the weapon program will be able to draw upon archival data as well as their experienced colleagues as they acquire the expertise to maintain the enduring stockpile in a time of no nuclear testing or new weapon development.

The SSMP places a premium on expert judgment in another important way. Throughout the history of the U.S. nuclear weapon program, interlaboratory peer review has helped to compensate for incomplete knowledge about nuclear weapon physics. Without nuclear testing, an independent review process is even more important.

Livermore and Los Alamos continue to be responsible for the weapon systems each laboratory originally designed, while Sandia has responsibility for the non-nuclear components and integration of all systems. At the same time, under a process called dual revalidation, Livermore and Los Alamos (aided by Sandia) formally examine and assess the safety and reliability of each other's weapon systems under the auspices of the Project Officer Groups of the Departments of Defense and Energy. The program offers another layer of confidence in safety, security, and reliability provided by some of the best researchers in the nation.



The target chamber of the National Ignition Facility (NIF). When operational in 2002, the NIF will permit experiments with conditions of pressure, temperature, and density close to those that occur during the detonation of a nuclear weapon.

Livermore, Los Alamos, and Sandia weapon experts. They recognize that the science of nuclear explosives is extremely complex. Even after more than four decades of work by hundreds of very capable scientists, gaps remain in understanding nuclear weapon behavior.

As a result, to provide needed data and simulations capability, a major thrust of the program is to upgrade existing experimental and computational capabilities at the three weapon laboratories and to design and construct several new facilities by providing insight into specific physics regimes. These strengthened capabilities will compensate, to the greatest degree possible, for the absence of nuclear testing. Together, the facilities will give the ability to investigate most phases of nuclear weapon operation. (See the box on p. 12 for a list of key facilities.)

Enhanced experimental facilities will provide the ability to evaluate safety and performance issues that could have significant stockpile consequences. The new data will be combined with past data from experiments and nuclear tests and used to validate new and evolving computational models. Also, enhanced experimental and computational capabilities will help the weapon laboratories maintain the knowledge and skill base that are essential for training new people and assuring continued support for stockpile stewardship.

It must be remembered that laboratory experiments cannot duplicate a nuclear test. Even the most advanced non-nuclear experiment can access only a small portion of the physics regimes or materials dynamics relevant to nuclear weapons. Scientists and engineers face the new challenge of interrelating and extrapolating data from many different experiments to provide an overall evaluation of weapon safety and performance.

Also important to the DOE and its laboratories is the planning under way now to develop and build the National Ignition Facility (NIF), which will provide more than ten times the power of the Nova laser at a greatly decreased unit cost. Site selection will occur after public review of a program-wide environmental impact statement and record of decision are completed later this year. The preferred site for NIF is Livermore, although wherever it is located, all of DOE's nuclear researchers will be using NIF to further understand nuclear weapons.

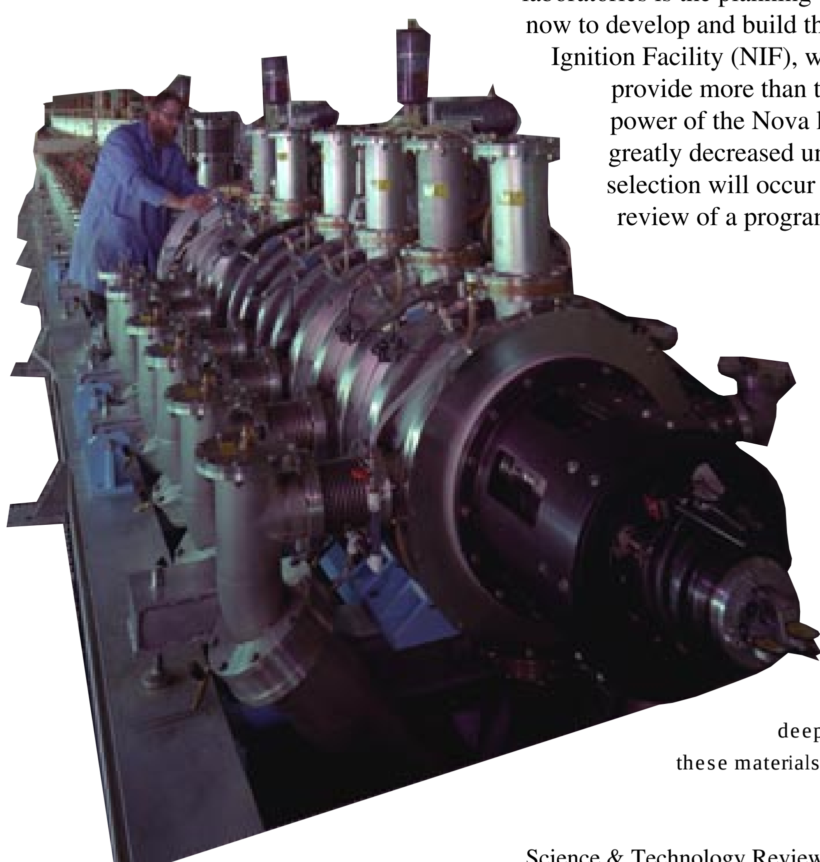
The need to obtain better data on the properties of plutonium and how it performs in an aging nuclear warhead is crucial. Experiments planned by Livermore and Los Alamos will reveal new information about the properties of plutonium at conditions close to those during weapon implosion. LLNL researchers also plan to conduct subcritical experiments on plutonium. Examples of this work include diamond-anvil-cell pressure measurements, equation-of-state studies, and metallurgical evaluations of aged plutonium.

Simulating Nuclear Testing

In the absence of nuclear testing, computer simulation is the only way to assess the performance of a complete nuclear weapon system. Numerical simulation also provides an essential tie to data from past nuclear tests and is an important means of predicting the performance and changes that might occur in the stockpile due to aging, environmental exposure, materials incompatibilities, or other reasons.

However, even today's most advanced supercomputers are not adequate to do the job. Increases of up to 10,000 times in computational speed, network speed, and data storage capacity are needed to provide simulations of weapon safety and performance of the required complexity and detail when testing is not an option. New generations of supercomputers, especially those employing many parallel processors, will greatly increase the accuracy, completeness, and resolution of computer calculations as they simulate nuclear weapon phenomena in three dimensions.

The objective of DOE's Accelerated Strategic Computing Initiative (ASCI) is to vastly improve the weapon simulation capability at the national security laboratories to the level required for stockpile stewardship. The goals are to develop advanced computational models and to work with industrial partners to develop the requisite technologies, including processors, software, and data storage to implement them.

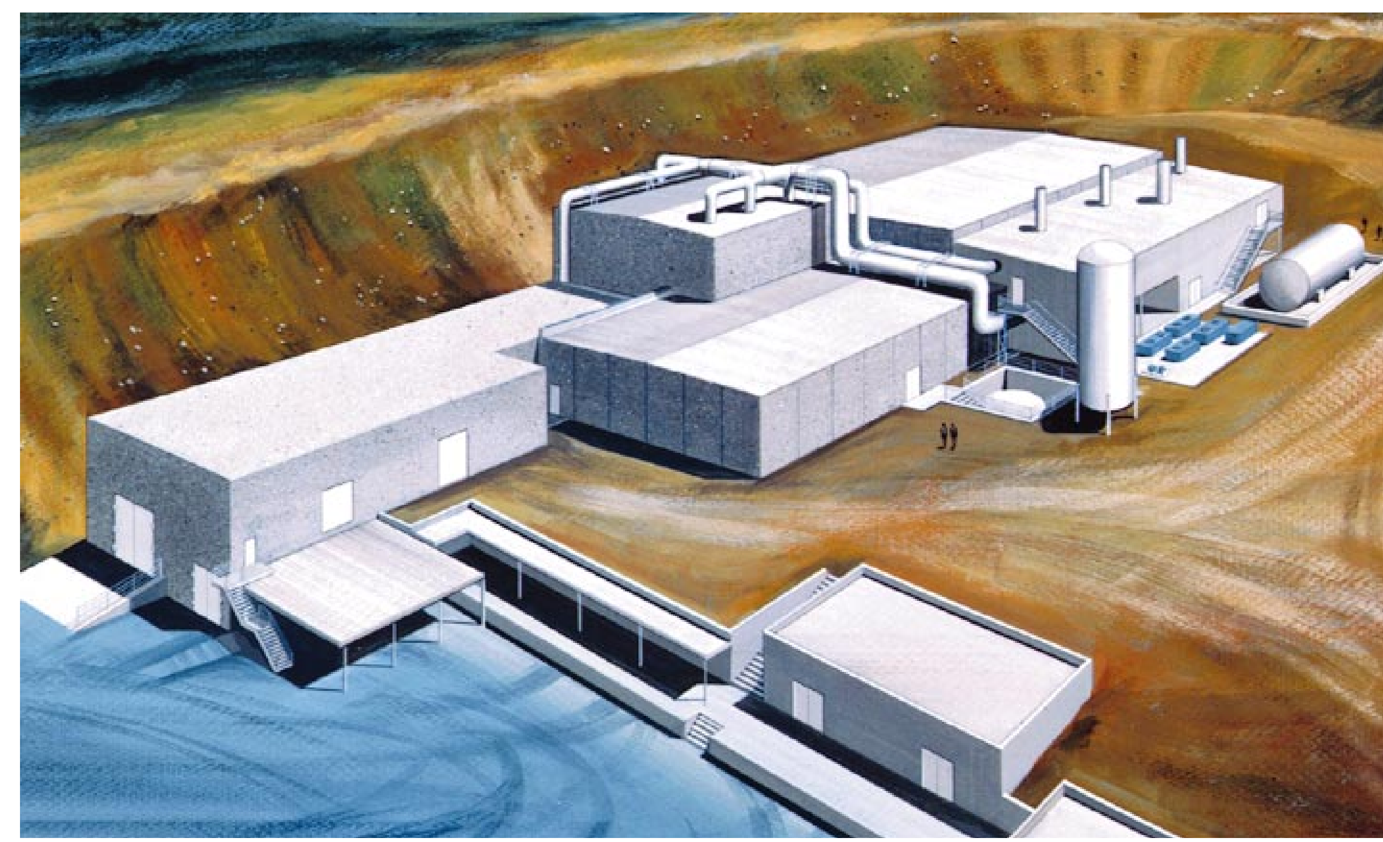


LLNL's Flash X-Ray (FXR) machine, located at Site 300, is a part of the most capable high-explosives test facility in the world. The facility uses powerful x rays to penetrate deeply into dense materials and record the configuration of these materials at a chosen time during the operation of a test device.

Enhancing Stockpile Surveillance and Maintenance

The standard surveillance effort of the SSMP is focusing on the real-time status of weapon components in the stockpile through inspections and testing. Scientists also need a better understanding of how materials change and interact over time and how such changes affect weapon reliability and safety. An improved understanding of aging and material compatibility will help experts predict which parts need to be replaced or refurbished long before they severely impact weapon performance.

Stockpile weapons will be disassembled, examined, and evaluated. Some components will be remanufactured in order to fix problems that will inevitably arise. In past years a large weapon production complex



An addition to the FXR, the Contained Firing Facility, at Livermore's Site 300, will permit fully contained high-explosive tests with up to 60 kilograms of energetic explosives. This upgrade is desirable in light of increasingly restrictive environmental regulations.

Stockpile Stewardship: Advanced Experimental Facilities Needed by the program

A number of current and proposed experimental facilities are needed by the DOE-wide program to support assessments about weapon safety and reliability in the absence of nuclear testing. These include:

Laser Facilities

- *Nova Laser.* The Nova laser, located at Livermore, is used for weapon physics and weapon effects experiments in addition to research on inertial confinement fusion (ICF).
- *National Ignition Facility (NIF).* NIF, a 192-beam laser facility planned for Livermore, will simulate on a small but diagnosable scale conditions of pressure, temperature, and energy density close to those that occur during a nuclear explosion. It will also serve ICF researchers.

High-Explosives Facilities

- *Contained Firing Facility (CFF).* The CFF, an addition to the Flash X-Ray (FXR) facility at Livermore, will provide for well-diagnosed, fully contained high-explosives testing of up to 60 kilograms of energetic explosives.
- *Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility.* The DARHT Facility at Los Alamos will provide enhanced radiography of the high-explosive implosion, including data on implosion symmetry as a function of time.
- *Sub-Critical Experimental Facility (SCSS).* This facility at the Nevada Test Site will provide capability to gather data on fissile materials in explosive-driven experimental geometries.
- *Advanced Hydrotest Facility (AHF).* An AHF would provide three-dimensional time-radiography of high-explosive implosions. Its location is not yet determined.

Accelerator and Pulsed-Power Facilities

- *Los Alamos Neutron Science Center (LANSCE).* LANSCE provides an accelerator-based neutron science capability for materials science studies of weapon components and for development of the technology for accelerator production of tritium.
- *Atlas Facility.* The Atlas pulsed-power facility at Los Alamos will provide implosions of cylindrical assemblies to obtain physics information that apply to weapons.
- *High-Explosive Pulsed-Power Facility (HEPPF).* HEPPF will be used to study weapon physics issues of shock pressures and velocities close to actual weapon conditions.
- *Advanced Radiation Source (ARS).* An ARS facility would provide high-energy, high-temperature, x-ray pulses for experiments in weapon physics, radiation effects, ICF, and pulsed power technology.

provided the means to rapidly fix any problems with new stockpile weapons. Today significant elements of the production complex have been shut down, and manufacturing capabilities are being consolidated at fewer sites because it is not practical or cost effective to meet manufacturing needs by keeping many of the old processes or facilities on standby. These new practices differ considerably from those in the past.

Clearly, investment is needed to develop manufacturing processes that are flexible, that minimize the production of hazardous waste, and that do not require extensive facilities and infrastructure. Concurrent engineering, in which the development of advanced manufacturing and material processing proceeds apace with the development of weapon components, is under active study. Where warranted, some production responsibilities are being reconfigured to rely on the laboratories' capabilities in manufacturing technology and their facilities for handling nuclear materials.

The Challenges for LLNL

For LLNL, says Associate Director for Defense and Nuclear Technologies Michael Anastasio, the job of stockpile stewardship will be "as challenging as anything we have done." The work at Lawrence Livermore centers on seven major efforts: extension of weapon lifetimes, enhanced stockpile surveillance, revalidation of existing weapon systems, flexible manufacturing, high-explosives experiments, the NIF, and supercomputers (including ASCI).

Extending Weapon Lifetimes

The Department of Defense (DoD) typically has expected weapons to be fielded in the stockpile for 20 years. Now weapons will remain there longer, and more importantly, many will soon reach an age that exceeds our operating experience. At the same time, substantive reductions in the size and redundancy of the nuclear weapon complex are occurring. These substantial changes throughout the complex led to the need to integrate support for sustaining all weapon types in the stockpile. The Stockpile Life Extension Program meets this need by integrating programs and activities across the DOE complex.

The W87 life extension program, begun in September 1994, works to enhance and refurbish the structural integrity of the warhead to extend its lifetime. In 1995, with the DoD, LLNL conducted a successful flight test of a W87 test unit on a Peacekeeper missile launched from Vandenburg Air Force Base. Livermore also conducted ground tests to evaluate the performance of refurbished design options when exposed to environmental extremes. Physics analysis of the refurbished design options is continuing, and information has been transferred to Los Alamos for their independent technical review.

Enhancing Stockpile Surveillance

Surveillance and evaluation of the safety and reliability of U.S. nuclear weapons have been essential Lawrence Livermore responsibilities ever since the first LLNL-designed weapon entered the stockpile. A major current focus for LLNL weapon scientists is on surveillance responsibilities for the B83 bomb, the W84 cruise missile warhead, and the W62 and W87 ICBM warheads. Livermore weapon experts are developing comprehensive plans to extend the life of these systems through an expanded program of surveillance, maintenance, and refurbishment.

LLNL experts are working to increase knowledge in the science of surveillance to better understand and predict the effects of age on metals, high explosives, polymers, and other materials under realistic service environments. The program is developing new surveillance technologies, such as new sensors that will allow extensive self-diagnosis of weapon components.

Other nondestructive evaluation and imaging techniques involve tools like scanning tunneling microscopes to examine, on an atomic level, the effects of corrosion on critical weapon parts.

Enhanced stockpile surveillance requires more detailed computer models of materials, from the atomic level to the systems level. Advanced models will help experts anticipate the onset of potential safety or reliability problems as well as reveal the likely effects of substituting different materials or manufacturing processes. This ambitious modeling effort, one of the keys to stockpile stewardship success, involves researchers in Livermore's Chemistry and Materials Science, Physics and Space Technology, and Engineering Directorates, as well as colleagues at several universities (see the June 1996 *S&TR*, pp.6–13).

Assessing with Dual Revalidation

Resolving stockpile issues without nuclear testing requires a much better understanding of the physical processes that determine the safety, reliability, and performance of weapon systems. Part of the SSMP will include dual revalidation, in which two independent teams will assess a weapon system to revalidate its ability to meet its current military characteristics and stockpile-to-target-sequence requirements. The two independent teams, working with the coordination of the DoD/DOE Project Officers Group, are the original design team (made up of the weapons laboratories that were involved with the original weapon development) and the independent review team (laboratories not involved with original development).

The assessments will include analysis of historical development and nuclear and high explosives test data, surveillance data, and recent test data. Where new experimental and computational capabilities have become available since development, they will be applied to the weapon system being evaluated. The first weapon system to undergo such an assessment will be the W76, a Los Alamos system. Because the W76 is deployed on both the C4 and the D5 missiles, it will be assessed for both delivery systems.

Flexible, Affordable Manufacturing

An allied effort is providing the flexible, affordable manufacturing capabilities needed to replace and refurbish aging and defective weapon components. This streamlined manufacturing capability will use modern commercial methods whenever possible to build a systematic refurbishment and preventive maintenance program for stockpile weapons. Much of this work is being done as part of the DOE-wide Advanced Design and Production Technologies (ADaPT) program aimed at developing innovative manufacturing processes that reduce cost and waste, improve efficiency, and are environmentally friendly.

LLNL researchers are testing several new fabrication technologies that generate less hazardous waste and are less costly than previous methods. One example is precision casting of plutonium, which requires little or no subsequent machining and thus significantly reduces cost, waste, and

Lawrence Livermore computational scientists are using three massively parallel supercomputers—two Meiko CS-2s (one is pictured here) and a Cray T3D—to develop codes that will represent three-dimensional simulations of nonlinear high-explosive and plasma-physics phenomena present in a nuclear detonation. However, in the future, the equivalent of thousands of these machines will be required.

personnel exposure to radiation. Another innovative concept is reusing certain old components that already contain plutonium, instead of manufacturing new parts.

Lawrence Livermore experts are developing precision casting, spinforming, and machining techniques to replace the current methods of rebuilding uranium parts destroyed in the surveillance program. For example, a project is under way to demonstrate the feasibility of using lasers to cut uranium parts with very little waste and almost no damage to the remaining material. The process uses laser expertise developed in LLNL's Inertial Confinement Fusion program and Atomic Vapor Laser Isotope Separation program.

Remanufacturing of critical parts requires a process of recertification, based on detailed tracking of the remanufacturing process as well as experimental and computational tools. Even more important, recertification requires expert judgment to provide confidence that the remanufactured component or weapon will perform as designed. Such judgment is essential because it is impossible to exactly duplicate past processes and practices. Researchers must reconsider how to remanufacture many of the old components and weapons because they are considered unacceptable today for environmental, safety, and health reasons.

High-Explosives Tests Critical

High-explosives testing is the only currently available way of experimentally testing part of the operation of a nuclear weapon's primary stage. In the test units, the nuclear materials are replaced by inert, surrogate materials. LLNL's Flash X-Ray (FXR) facility, located at Site 300, is a part of the most capable high-explosives test facility in the world. The facility uses powerful x rays to penetrate deeply into dense materials and record the configuration of these materials at a chosen time during the operation of the test device.

A three-year upgrade of FXR is in progress. The upgrade is expected to increase x-ray output by 50% and decrease x-ray spot size by 50%, allowing examination of implosion phenomena in much greater detail. The replacement of film by a digital gamma-ray camera has also provided images of greater resolution. The camera paves the way for an upgrade that will provide two images of an imploding device a few millionths of a second apart during a high-explosives test.

An addition to the FXR, the Contained Firing Facility, will permit fully contained high-explosives tests with up to 60 kilograms of energetic explosives. This facility is desirable in light of increasingly restrictive environmental regulations.

Lawrence Livermore researchers also are working with colleagues from other national labs, Bechtel Nevada, and Britain's nuclear weapon community to develop plans for an Advanced Hydrotest Facility, which would yield three-dimensional movies and data of the interior of an imploding device. (The site of this new facility is not yet determined, but it is not expected to be at Lawrence Livermore.)

NIF for Critical Physics Data

When operational in 2002, the NIF will permit experiments with conditions of pressure, temperature, and density closer to those that occur during the detonation of a nuclear weapon. By addressing the high-energy-density and fusion aspects of stockpile weapons, researchers will obtain critical, fundamental physics data that are essential for refining advanced computer simulation codes. We will need these codes to assess potential stockpile problems, certify fixes to stockpile systems, and continue certifying LLNL-designed warheads. Also, by using NIF-heated targets, scientists will sharpen their ability to predict the effects of radiation on weapon components.

Last year LLNL began the detailed design work for the NIF, identified by DOE's Reis as "the most important new facility" in the Defense Programs' budget request for Fiscal Year 1996. Lawrence Livermore has been designated the preferred site for this $1-billion project because of resident technical expertise and infrastructure.

Until the NIF comes on line, Lawrence Livermore's Nova laser will provide essential data on many aspects of weapon physics. In 1995, more than 200 ICF experiments were conducted with Nova by weapon scientists from Livermore and Los Alamos. (See Dec. 1994 *Energy & Technology Review*, pp. 23–32 for an in-depth look at the national security aspects of research using NIF.)

Moving to New Supercomputers

Lawrence Livermore weapon scientists emphasize that greatly enhanced modeling and simulation capabilities are critical to their ability to assess the status of nuclear stockpile weapons, predict weapon performance, analyze refurbishment options, and evaluate potential accident scenarios. Major improvements are needed in the fineness of detail, especially in three-dimensional calculations and in the physics incorporated into the codes. These codes must replicate existing nuclear test data before we can confidently use them for assessing stockpile problems.

Meeting these challenges requires computers with thousands of processors working together to rapidly solve a single problem. At Livermore, there are three of these so-called massively parallel supercomputers—two Meiko CS-2s and a Cray T3D. In these efforts, LLNL experts are using these computers to develop three-dimensional simulations that include the wide range of nonlinear high-explosive, nuclear, and plasma-physics phenomena present in a nuclear detonation. These efforts also require development of new numerical algorithms and programming techniques.

At the same time, Livermore computational experts are incorporating improved data from non-nuclear tests, developing a secure high-speed network to interconnect Livermore and Los Alamos supercomputer resources, and collaborating with universities and supercomputer companies to hasten the arrival of new generations of machines.

"Sustaining confidence in the stockpile in the post-Cold War world will be extremely difficult," says Associate Director Anastasio. "It's going to require us to adapt our skills to different approaches and different teaming across the Laboratory and throughout the DOE complex. That's the changing culture we face. There is plenty for everyone to do. We need the whole Laboratory working together to help pull it off. But this is something the Laboratory is very good at."

Key Words: Accelerated Strategic Computing Initiative (ASCI), Advanced Design and Production Technologies (ADaPT), Advanced Hydrotest Facility (AHF), Comprehensive Test Ban Treaty, (CTBT), flash x-ray (FXR), National Ignition Facility (NIF), Nova, Stockpile Stewardship and Management Program (SSMP), stockpile surveillance.

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