High-Performance Computing for National Security

Enabling Stockpile Stewardship

In the absence of nuclear testing, large-scale computations are now the most effective way to understand and integrate the many complex processes that take place in a thermonuclear weapon. This means that the continued certification of the safety and reliability of the nation's nuclear stockpile relies to a great extent on computer simulations, as well as a strong experimental program.

In the past, nuclear weapons were replaced every decade or so as military requirements changed. Today the average age of the nuclear stockpile is far greater than ever before. Aging inevitably leads to changes in materials and engineering features that manifest themselves as defects that break the three-dimensional symmetries that weapons designers have strived for in their modeling of nuclear weapons.

As the weapons are aging, so too are the designers and engineers who were responsible for developing and testing the weapons in the stockpile. Consequently, increased computational speed and memory are needed as quickly as possible, while these experts are able to apply their experience to the validation of the new simulation models on which certification depends. These experts also are mentoring the next generation of weapon scientists and engineers.

Advanced Simulation and Computing

The U.S. Department of Energy launched the Advanced Simulation and Computing program, or ASCI, in 1995 to meet the requirements of the stockpile stewardship program, whose goal is the evaluation and maintenance of the aging nuclear weapons stockpile. ASCI's mission is to manage the shift from nuclear test-based methods to computational-based methods for certification of weapon safety, reliability and performance.

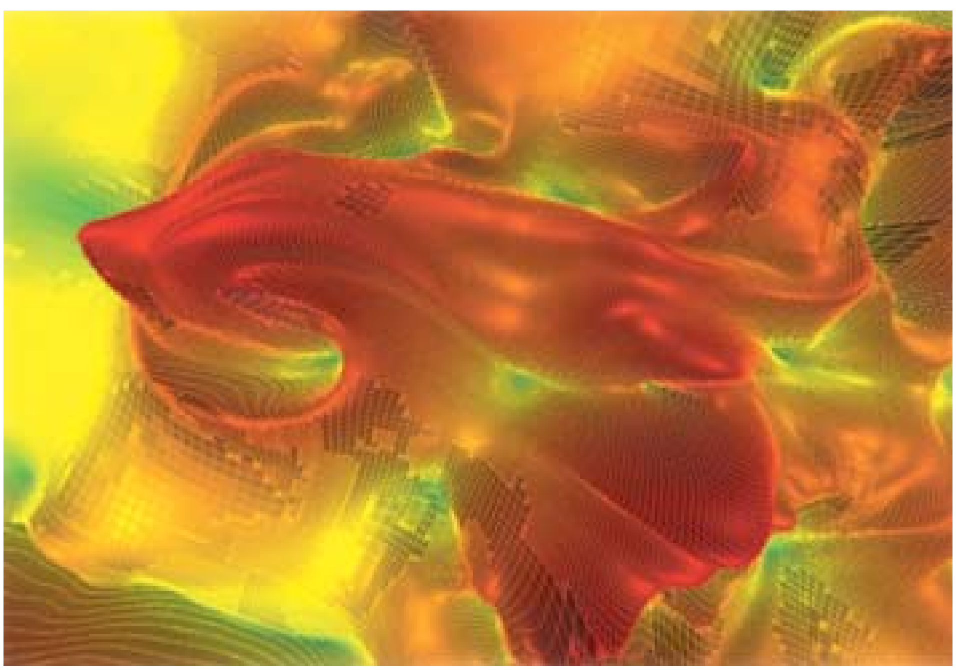
ASCI's ambitious goal is to develop simulation and modeling computer codes and hardware — speed, memory, interconnects and visualization — far more rapidly than the commercial market would achieve in the absence of a focused initiative.

These advances in hardware are key to the transition from two-dimensional codes to complex, three-dimensional predictive simulations that integrate all the physical phenomena of nuclear weapons explosions and provide virtual prototyping capabilities. These new codes are necessary to identify, diagnose and correct potential concerns about the aging U.S. stockpile. Continued certification of the stockpile relies to a great extent on these simulations. The stated goals of the ASCI program are:

- development of high-performance, full-system, high-fidelity-physics predictive codes to support weapon assessments, renewal-process analyses, accident analyses and certification;
- stimulation of the U.S. computer manufacturing industry to create the powerful high-end computing capability required by ASCI applications; and
- creation of a computational infrastructure and operating environment that makes these capabilities accessible and usable.

Some experts have estimated that assessing the safety and performance of the stockpile will require computational power 100,000 times greater than what was needed to design new weapons. ASCI set a target date of 2004 for developing computer systems capable of 100 trillion operations per second, or 100 teraOPS. Simulations on such a system will generate data equal to the contents of the entire Library of Congress five times every second.

The 2004 target wasn't set arbitrarily. From the outset, ASCI and the rest of the DOE's stockpile stewardship program sought to use revolutionary new tools, including ASCI machines, to solve weapon problems while at least half of the weapon designers and engineers with underground test experience remained at the labs. Although aging weapons in the U.S. nuclear stockpile are a great concern, the retirement of the men and women responsible for developing and testing the existing stockpile is an even greater concern. Only they can properly validate these new simulations and knowledgably compare them with past nuclear test results and new results from experiments in physics, chemistry, materials science and engineering analysis.



Density variations as a shock wave hits an irregular interface between materials.

Three-Dimensional Codes

Scientists at Los Alamos and Lawrence Livermore national laboratories each have completed the largest computer simulation ever attempted, the first full-system three-dimensional simulation of a nuclear weapon explosion. The simulation, which ran for nearly 3,000 hours on the one of world's fastest supercomputers, is a key example of the three-dimensional codes required for the maintenance and certification of the U.S. nuclear weapon stockpile without underground nuclear testing. Calculations at this scale would not have been possible a year earlier.

Modern nuclear weapons have two stages: the primary, which is the initial source of fission energy; and the secondary, which is driven by the primary and provides additional explosive energy. Two years earlier, Los Alamos and Livermore scientists completed the first 3D simulations of, respectively, a weapon secondary and a weapon primary.

The new simulation enhances and builds on these achievements. The ability to simulate a complete weapon system will allow national lab researchers to examine key weapon physics issues through a combination of simulation, precision experiments and analysis of archived nuclear tests. It was the longest-running complex multiple physics simulation ever performed, consuming nearly the equivalent of a millenium of computer time.

The Q Computer

Los Alamos historically has led advances in experimental and high-performance computing, from the MANIAC in the 1950s — in whose design, development and use Nicholas C. Metropolis had a lead role — to the IBM Stretch in the 1960s, and from the first Cray supercomputer to early parallel machines in later decades.

Under the tri-lab ASCI program, Los Alamos procured from Silicon Graphics and helped build the three-teraOPS Blue Mountain computer to run three-dimensional weapon codes, along with the unclassified one-teraOPS Nirvana system.

Workers install the first 10-teraOps phase of the Q computer, the next-generation ASCI system. Q is planned as a 30-teraOPS computer platform.

Los Alamos researchers have met or exceeded all ASCI code milestones using existing ASCI platforms at Los Alamos, Lawrence Livermore and Sandia national laboratories. The program now requires a 30-teraOPS supercomputing system to meet upcoming milestones and for direct stockpile deliverables.

Los Alamos was designated the lead laboratory for competitive procurement of this next-generation ASCI system. From preliminary solicitations of interest and writing of specifications through final selection of Compaq Computer Corp., now Hewlett-Packard Co., in July 2000 to build the 30- teraOPS Q machine — a 21-month process — scientists and managers from DOE, NNSA and all three labs provided key input. Final reviews, both of the technical rigor of Compaq's proposal and of the business strength and risks of the contract, were conducted by all three labs and numerous outside experts.

The contract for Q was structured in a unique manner: The majority of the total contract payment price of $215 million is contingent on the Q system meeting technical performance milestones, as contrasted with a simple purchase of hardware.

The Q system is installed in the new Nicholas C. Metropolis Center for Modeling and Simulation, the most capable simulation facility in the world. The Center is capable of initially supporting a 30-teraOPS computer platform and can expand to 100 teraOPS.

ASCI Q Facts

- Q will operate at a peak speed of 30 trillion operations per second. By comparison, everyone on the planet would have to perform 5,000 calculations in one second to keep up with Q.
- Q will have 33 terabytes of memory, equivalent to 55,000 CDs.
- Q will cost $215 million.
- Q can do in one day what a current, high-end personal computer can do in 60 years.
- Q could assemble the human genome in four days, compared to Celera's 150 days on its cluster of AlphaServers.
- Q can store 600 terabytes of information, 20 times the size of the Library of Congress, and equal to a stack of paper that would circle the earth.
- Q is about 6,000 times faster than the fastest supercomputer in 1990 and about 150,000 times faster than the fastest supercomputer in 1980.

Los Alamos National Laboratory

Los Alamos National Laboratory is operated by the University of California for the U.S. Department of Energy's National Nuclear Security Administration