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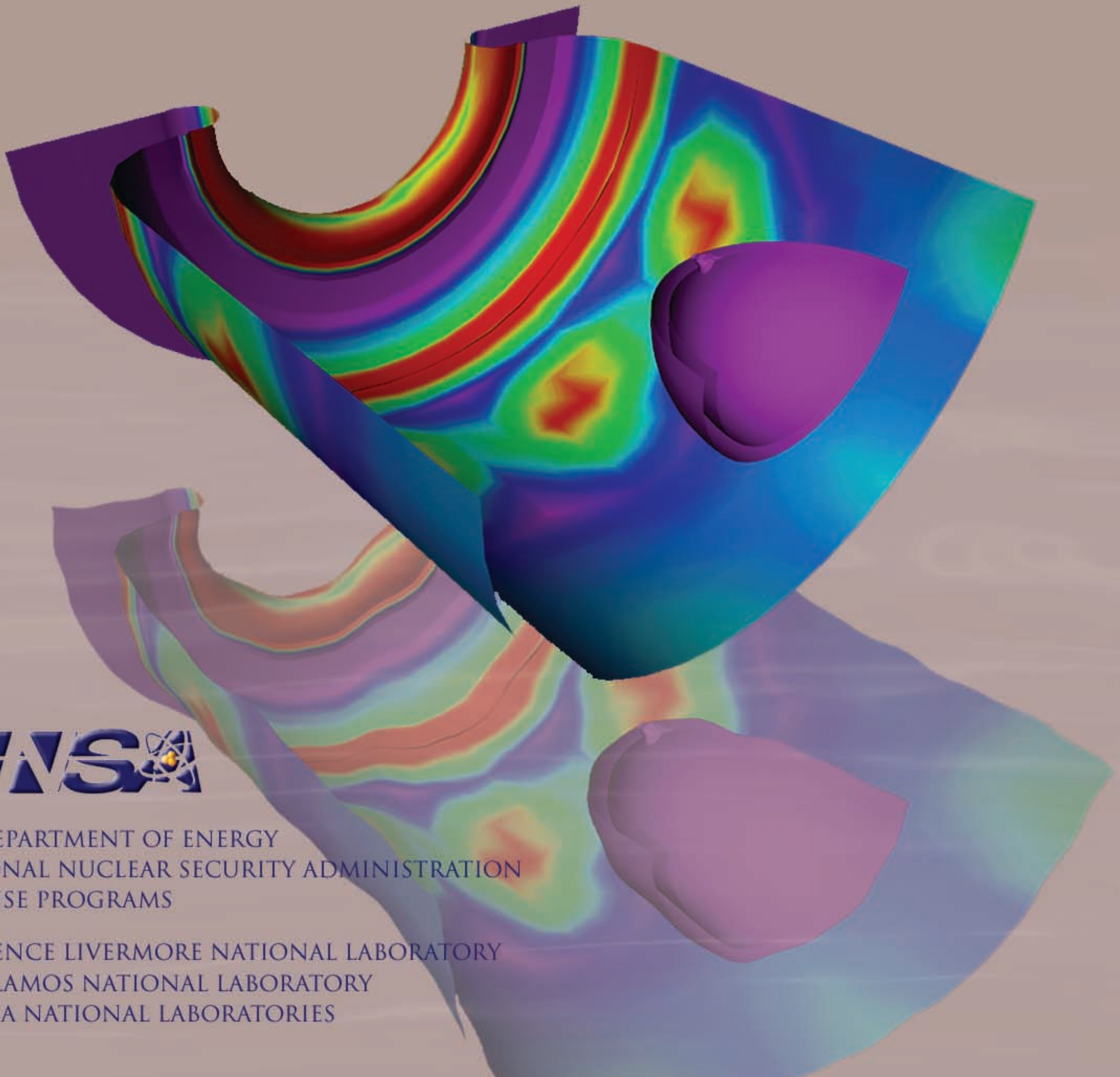
Advanced Simulation and Computing (ASCI)

PROGRAM PLAN

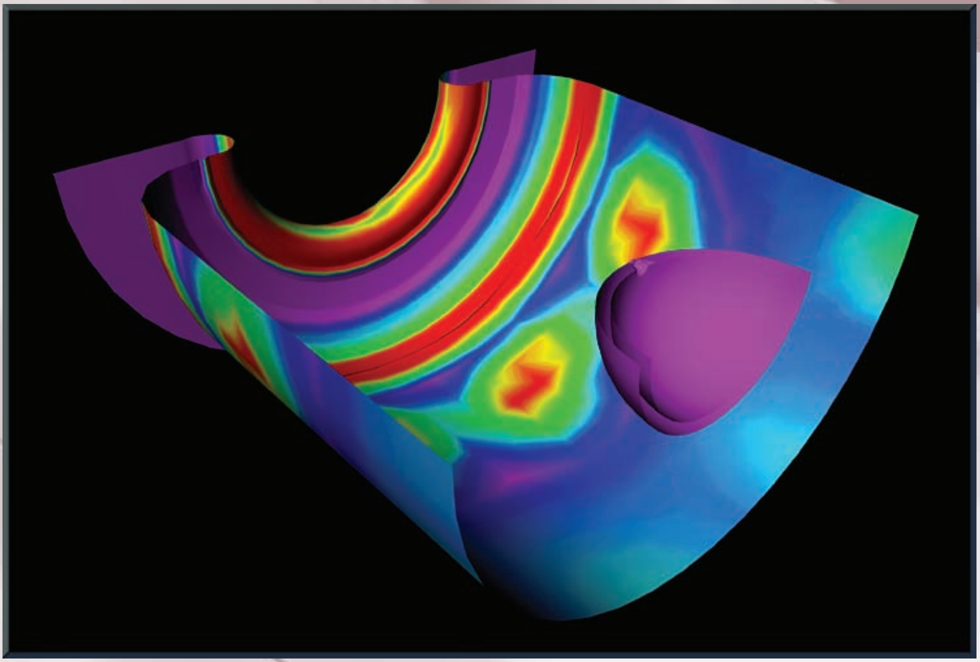


U.S. DEPARTMENT OF ENERGY
NATIONAL NUCLEAR SECURITY ADMINISTRATION
DEFENSE PROGRAMS

LAWRENCE LIVERMORE NATIONAL LABORATORY
LOS ALAMOS NATIONAL LABORATORY
SANDIA NATIONAL LABORATORIES

On the Cover—

Cutaway view of the National Ignition Facility (NIF) ignition target simulation performed with HYDRA and visualized with ASCI TeraScale Browser. The pseudocolor plot shows ion temperature on iso-density surfaces located in the cylindrical hohlraum wall and capsule.



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Advanced Simulation and Computing (ASCI)

PROGRAM PLAN

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Accelerated Strategic Computing Initiative
Lawrence Livermore

www.asci.doe.gov

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Executive Summary

As we approach the end of the first decade without nuclear testing, it is now very clear that the science-based approach used in the Stockpile Stewardship Program is essential for ensuring confidence in the safety, performance, and reliability of our nuclear stockpile. Established by the FY1994 National Defense Authorization Act, the Stockpile Stewardship Program continues to develop science-based tools and techniques for assessing the performance of nuclear weapon systems, predicting their safety and reliability, and certifying their functionality.

In the past, confidence in the nation's nuclear deterrent was a product of computation, experimental science, and weapons physics. Since the final judgments were confirmed by nuclear test results, much simpler computer models could be used with the best available supercomputers to help design, modernize, and maintain the stockpile. Now, without nuclear testing as the final arbiter of our scientific judgment, weapons scientists and engineers have a greater reliance on computers to simulate the aging process and its impact on our weapon systems, along with the impact of any required modifications.

The lack of nuclear testing is not the only challenge we face. The program is faced with additional constraints on nonnuclear testing, a downsized production capability, and the cessation of new weapon systems development to replace existing weapons. Further complicating matters, weapon components are exceeding their original design-intent lifetimes, and manufacturing issues and environmental concerns will force changes in fabrication processes and materials of new weapon components.

As time marches on, we find that virtually all of the forecasts of a decade ago have come to pass. Our weapons will exceed their original design-intent lifetimes and life extension programs have now been initiated. Retirements of our weapon scientists and engineers, who have the experience base with underground nuclear tests and nuclear weapon design, are increasing. We predicted these developments and knew that the 2004–2010 timeframe was the critical time to have usable, working computer systems and codes available so that a robust transition from "test-based" certification and assessment could be made. For these reasons, the Advanced Simulation and Computing Program (for historical reasons we continue to use the acronym ASCI—the Accelerated Strategic Computing Initiative—in this document) was created. ASCI is providing the integrating force for preserving our design and nuclear testing experience, linking experimental data from aboveground test facilities, using archival nuclear test data from 50 years of nuclear tests, and improving scientific understanding to provide high-confidence, predictive simulation capabilities that support decisions about the enduring stockpile.

We established ASCI to focus and accelerate the simulation and modeling efforts of the U.S. Department of Energy, National Nuclear Security Administration (NNSA). The program has at its core the overarching objective to meet the science and simulation requirements of the Stockpile Stewardship Program. ASCI is developing the high-fidelity numerical simulation tools required by the scientists and engineers charged with ensuring the safety, reliability and credibility of the nuclear deterrent.

Following the establishment of the program in 1995, integrated program planning has been conducted to bring together NNSA's three national security laboratories in a single national program with strategic partnerships involving computer manufacturers and several of the nation's major universities. Even though this planning pushed state-of-the-art modeling and simulation to new heights, we have successfully completed all major milestones and have created advanced simulation codes, acquired high performance computing systems, and developed the infrastructure to make the current systems usable.

ASCI is now within striking distance of achieving its initial goal of having an integrated design simulation capability running on a 100-teraOPS supercomputer. In fewer than five years, this program has produced results that may well make it the most successful high-performance computing program in U.S. history. The world's leading four systems[1] are ASCI

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[1] See, for example, the *TOP500 Supercomputing Sites* (**www.top500.org**) or *List of the World's Most Powerful Computing Sites* (**www.gapcon.com**)

Figure 1

ASCI engages many organizations throughout the nation, using the best talent from within the nuclear weapons complex, industry, and academia.

White and ASCI *Blue Pacific* at Lawrence Livermore National Laboratory, *Blue Mountain* at Los Alamos National Laboratory, and ASCI *Red* at Sandia National Laboratories. These systems in turn have been instrumental in first-time, three-dimensional simulations involving components of a nuclear weapon during an explosion and in hostile environments. Such accomplishments are based on the successes of other elements of ASCI research, such as scalable algorithms, programming techniques for thousands of processors, and unparalleled visualization capabilities. These achievements give us high confidence that we can attain our goal of having full-system simulation capability running on a 100-teraOPS system by 2005.

This document provides an update to the program planning for FY2001 through FY2005. The Advanced Simulation and Computing Program objectives in the areas of performance, safety, reliability, and sustainability remain unchanged:

- **Performance:** Create predictive simulations of nuclear weapon systems to analyze behavior and assess performance in an environment without nuclear testing.

- **Safety:** Predict with high certainty the behavior of full weapon systems in complex accident scenarios.

- **Reliability:** Achieve sufficient, validated predictive simulations to extend the lifetime of the stockpile, predict failure mechanisms, and reduce routine maintenance.

- **Sustainability:** Use virtual prototyping and modeling to understand how new production processes and materials affect performance, safety, reliability, and aging issues and help define the right configuration of production and testing facilities necessary for managing the stockpile throughout the next several decades.

ASCI is a large, complex, multifaceted, and highly integrated R&D effort. Managing such an effort, planning and implementing interrelated milestones while pursuing new developments in simulation science and technology is a great challenge. Our approach to this challenge involves the coordinated use of multiple management structures—the staff at ASCI Headquarters, the Tri-Lab Executive committee, and subject-area teams staffed from the three laboratories.

This plan is organized around major program elements and the strategies employed within those elements to achieve the program objectives. As ASCI has matured, the program elements have been restructured to reflect the changes in the current technological environment and in the challenges we face.

Overview

Nearly a decade ago, on October 2, 1992, President Bush signed into law the FY1993 Energy and Water Authorization Bill that established a moratorium on U.S. nuclear testing. President Clinton extended the moratorium on July 3, 1993. These decisions ushered in a new era in the way the U.S. ensures confidence in the safety, performance, and reliability of its nuclear stockpile.

The U.S. also decided to halt new nuclear weapon production. This decision meant that the U.S. stockpile of nuclear weapons would need to be maintained far beyond its original design lifetime.

To implement these pivotal policy decisions, the Stockpile Stewardship Program was established. The goal of this program is to provide scientists and engineers with the technical capabilities to maintain a credible nuclear deterrent without the use of the two key tools used to do that job over the past 50 years: underground nuclear testing, and modernization through development of new weapon systems. Historically, U.S. policy makers were ensured confidence in the stockpile by the use of regular nuclear tests. They never had to rely on weapon systems that had exceeded their design lifetimes because older weapons were regularly replaced with new designs. With the cessation of these two practices, the U.S. committed itself to maintaining its existing weapon systems indefinitely, well beyond their intended lifetimes. Implementing this policy with credibility requires new scientific tools. The responsibility to develop those tools resides with the Stockpile Stewardship Program.

To meet this challenge, a new set of aboveground, nonnuclear experimental capabilities was required, environmentally benign fabrication capabilities were needed, and archived data from decades of nuclear tests had to be made available to weapon scientists and engineers. An unprecedented level of computational capability was needed to serve as the integrating force to make effective use of the collective scientific understanding. This reality meant that a new and powerful role for modeling and simulation was required and the Advanced Simulation and Computing Program (for historical reasons we continue to use the acronym ASCI—the Accelerated Strategic Computing Initiative—in this document) was established to create this capability.

Figure 2

While indispensable for stockpile stewardship in the absence of nuclear testing, ASCI simulations are making critical contributions throughout the entire lifecycle of a nuclear weapon.

Test-Based Stockpile Stewardship

Over the past 50 years, the U.S. has based a significant portion of its national security on the credibility of its nuclear deterrent. To understand the significance of the Stockpile Stewardship Program and, specifically, ASCI in the context of that deterrent, we review how test-based stockpile stewardship was practiced prior to 1992 and the partnering of the weapons program with the U.S. computer industry.

The ASCI Objectives

To Meet the needs and requirements of the Stockpile Stewardship Program, ASCI has specific program objectives in performance, safety, reliability, and sustainability.

Performance: Create predictive simulations of nuclear weapon systems to analyze behavior and assess performance in an environment without nuclear testing.

Reliability: Achieve sufficient, validated predictive simulations to extend the lifetime of the stockpile, predict failure mechanisms, and reduce routine maintenance.

Sustainability: Use virtual prototyping and modeling to understand how new production processes and materials affect performance, safety, reliability, and aging. This undertanding will help define the right configuration of production and testing facilities necessary for managing the stockpile throughout the next several decades.

The U.S. has designed and maintained a stockpile of nuclear weapons for more than 50 years. Over that time, the U.S. government, through its national laboratories and production facilities, developed approaches to maintaining confidence in the performance, safety, and reliability of nuclear weapons. These approaches, both nuclear and nonnuclear, were generally test-centric. Scientists and engineers would apply the most complete physics understanding possible to designs or questions about the stockpile. Many times this would result in extensive mathematical predictions of a weapon's performance. As computer power increased, these predictions were incorporated into computer programs, which provided a higher level of information to weapon experts.

Because the physics understanding of the weapons was not complete and the existing computing systems were not up to the task, many empirically derived factors were incorporated into the computer codes to improve their fit to the test data. This led to a strong interdependence between computational simulation and testing. In the early days of the weapons program, the national laboratories consistently purchased the highest-performance supercomputers in the world. These supercomputers were needed to improve the designs of nuclear weapons, making the weapons smaller and lighter, while improving safety and reliability.

The computational power of these early supercomputer systems was limited; codes, therefore, continued to be one or two dimensional, requiring the use of many empirical factors in predicting weapon behavior. The computing systems also limited the level of geometric and physics detail that could be used. That was sufficient in an era where extensive testing was conducted. The computer codes would predict the test results, and then the test results would be used to make specific calibrations to the codes for each weapon. In this situation, code limitations were mitigated by the use of tests, which could serve as the final integrating factor.

A wide array of aboveground test facilities and laboratory-scale experiments supported this work. The decision to pursue a stockpile stewardship program without nuclear tests has now stimulated a change in the mix of scientific capabilities required to maintain the nuclear deterrent. While ASCI is intended to replace test-centric approaches with computation-centric approaches, this does not imply that nonnuclear experimental data will cease to be important to weapon scientists and engineers. Aboveground and laboratory-scale experiments will continue to be conducted in the Campaigns, as permitted by laboratory budgets. In fact, ASCI anticipates an increase in these types of tests. Experimental facilities, like hydrodynamic testing facilities, pulsed-power accelerators, and the National Ignition Facility, will produce data that will increase in importance as weapon scientists and engineers begin the essential process of validating and verifying the physics models in the codes that, in turn, will predict the behavior of weapons in the enduring stockpile.

Realizing the Vision

Established in 1995 as a critical element of the Stockpile Stewardship Program, ASCI is developing the computational capabilities to allow a smooth transition from nuclear test-based certification to science- and simulation-based certification. ASCI is a focused and balanced program that is accelerating the development of simulation capabilities needed to analyze and predict the performance, safety, and reliability of nuclear weapons and certify their functionality—far exceeding what might have been achieved in the absence of a focused initiative. These capabilities will be used directly in support of the Directed Stockpile Work (DSW) Program.

To realize its vision, ASCI is creating simulation capabilities using advanced weapon codes and high-performance computing that incorporate more complete scientific models based on experimental results from the Campaigns, past tests, and theory. The expected outcomes will be predictive simulations that enable assessment and certification of the safety, performance, and reliability of nuclear weapon systems. These simulation capabilities will also help scientists understand weapons aging, predict when components will have to be replaced, and evaluate the implications of changes in materials and fabrication processes to the design life of the aging weapon systems. This science-based understanding is essential to ensure that changes brought about through aging or remanufacturing will not adversely affect the enduring stockpile.

To meet the needs of stockpile stewardship in the year 2005 and beyond, ASCI is solving progressively more difficult problems as we move away from nuclear testing. Applications must achieve higher resolution, higher fidelity, three-dimensional physics, and full-system modeling capabilities to reduce reliance on empirical judgments. This level of simulation requires high-performance computing far beyond our

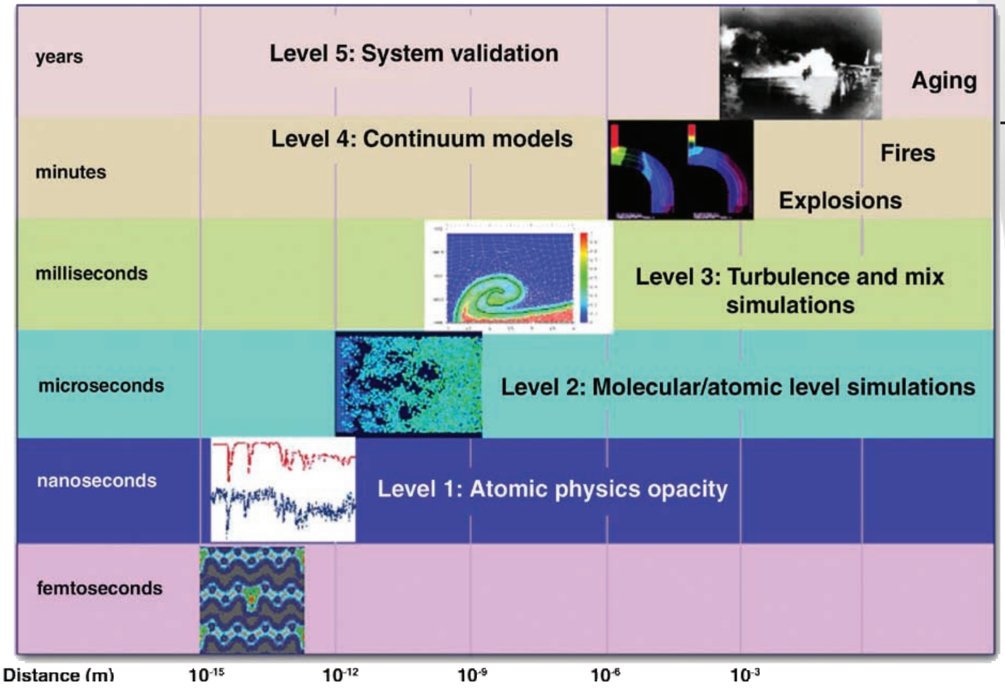


Figure 3

A hierarchy of models and modeling methods is needed to enable a predictive capability for the processes relevant to weapon performance.

current level of performance. Therefore, ASCI is partnering with industry to accelerate development of more powerful computing hardware and is investing in creating the necessary software environment. A powerful problem-solving environment must be established to support application development and enable efficient and productive use of the new computing systems. By 2005, ASCI is responsible for the following deliverables:

- Development of high-performance, full-system, high-fidelity-physics predictive codes to support weapon assessments, manufacturing 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.
- Creation of a computational infrastructure and operating environment that makes these capabilities accessible and usable.

ASCI recognizes that the creation of simulation capabilities needed for performance simulation and virtual prototyping is a significant challenge. This challenge requires the science and technology resources available at the national laboratories, and it will require close cooperation with the computer industry to accelerate their business plans to provide the computational platforms needed to support ASCI applications. Universities will also play an important role in developing new computational approaches and increasing scientific understanding needed for this unprecedented level of simulation.

The creation of sophisticated simulation capabilities also supports our need to maintain readiness to resume nuclear testing. The capability provided by ASCI significantly enhances our ability to design and understand tests in far greater detail than has been possible in the past. As a consequence, we could pursue new testing strategies, thus obtaining more useful information from each test.

The Key ASCI Drivers

To crystallize planning for ASCI to support the Stockpile Stewardship Program, several key drivers have emerged. The primary driver is that, with the cessation of underground nuclear testing in 1992, the experiment-based experience and expertise of the program is declining because of the inevitable retirements of test-experienced weapons experts and the increasing length of time since the last nuclear test. This driver imposes a crucial target period of 2004 to 2010 for having usable ASCI supercomputer systems and codes available for a smooth transition from "test-based" certification and assessment. A second key driver is the need for full, three-dimensional simulation codes, which incorporate the complex physics required to model physical phenomena such as weapon performance, aging, and accident simulation. An additional key driver is the computer system speed and software required for effective use of this three-dimensional, high-fidelity-physics and engineering modeling.

Major ASCI Objectives

The program has at its core the overarching objective to meet the science and simulation requirements of the Stockpile Stewardship Program. That relationship is described in more detail in the "Role of ASCI in Stockpile Stewardship" section.

By 2005, ASCI plans to have three-dimensional working simulation codes with a 100-teraOPS computer system to facilitate the transition to full operational capability by 2010.

In addition, ASCI will demonstrate engineering simulations of the weapon response to the full stockpile-to-target-sequence (STS) environment by 2005. Along with the capacity to store very large data sets, the program must develop the capability to transfer high volumes of data at high speeds and to provide the scientific visualization of the results of ASCI calculations to weapon scientists and engineers. Achievement of these milestones will require the integrated success of the program elements described in this document.

As part of our planning, intermediate milestones have been established; a complete list of our major milestones is provided in Appendix A. ASCI has made remarkable progress in its first five years, and all major milestones for this period have been met. A brief list of accomplishments is as follows:

- In 1996, ASCI *Red* was delivered. *Red*, the world's first teraOPS supercomputer, has since been upgraded to over 3 teraOPS (trillion floating-point operations per second).
- In 1998, final deliveries of ASCI *Blue Pacific* and ASCI *Blue Mountain* were received. These platforms were the first 3-teraOPS systems in the world.
- In December 1999, ASCI successfully demonstrated the first-ever, three-dimensional simulation of a nuclear weapon primary explosion and the visualization capability to analyze the results.
- In March 2000, ASCI successfully demonstrated the first-ever, three-dimensional hostile environments simulation.
- In April 2000, ASCI completed the first-ever, three-dimensional simulation of a nuclear weapon secondary explosion.
- In September 2000, ASCI accepted delivery of ASCI *White*, a 12.3 teraOPS supercomputer. This delivery represents the third step on the path to the 100 teraOPS system.
- In December 2000, ASCI delivered the problem-solving environment on ASCI *White*.
- In March 2001, ASCI demonstrated high bandwidth distance computing between sites. This success was highlighted by a 2.5-gigabit/second encrypted network between the three NNSA national security labs in Albuquerque, Livermore, and Los Alamos.
- In March 2001, ASCI demonstrated the initial validation methodology for early primary behavior.

These accomplishments give us high confidence that all program goals and objectives can be achieved, and they are described in more detail in the "Accomplishments" section.

ASCI Program Structure

In response to the drivers and to achieve its objectives, ASCI is organized around major program elements and the strategies employed within those elements. These are described in more detail in the "Program Elements" section. As the program has matured, the program elements have been restructured to reflect the changes in the challenges we face. The result is the following list of integrated program elements organized into five categories.

DEFENSE APPLICATIONS AND MODELING

- Advanced Applications Development
  - Accelerated development of higher performance software to implement three dimensional, high-fidelity-physics simulation and prototyping
- Verification and Validation (V&V)
  - Achieving high confidence in the computational accuracy of ASCI codes and their underlying models
- Materials and Physics Modeling
  - Promoting capabilities to predict the physical properties of matter under conditions found in nuclear explosions
  - Development of underpinning physics and prediction of material properties under STS environments through nuclear explosion

SIMULATION AND COMPUTER SCIENCE

- Problem Solving Environment (PSE)
  - A computational infrastructure enabling execution of ASCI applications and access from the desktops of scientists
- Visual Interactive Environment for Weapons Simulation (VIEWS)
  - Developing "see and understand" technologies for ASCI simulations, enabling scientists to view the three-dimensional results of their stewardship calculations

- Distance and Distributed Computing and Communication (DisCom^2)
  - Supporting high-end computing to remote sites and an integrated computing environment distributed across the nuclear weapons complex
- PathForward
  - Accelerating commercial development of technologies needed for 30-teraOPS platforms and beyond

INTEGRATED COMPUTING SYSTEMS

- Physical Infrastructure and Platforms
  - Developing powerful ASCI platforms in partnership with industry
- Ongoing Computing
  - Operating ASCI supercomputers

UNIVERSITY PARTNERSHIPS

- Academic Strategic Alliances Program (ASAP)
  - Engaging academia to accelerate simulation science
- Institutes and Fellowships
  - Involving the U.S. academic community in ASCI science and computing

PROGRAM INTEGRATION

- One Program—Three Laboratories
  - Planning and implementation of all ASCI efforts conducted in concert with participation from ASCI Headquarters and the three national security laboratories

ASCI is a large, complex, multifaceted, and highly integrated R&D effort. Managing such an effort, planning and implementing interrelated milestones while pursuing new developments in simulation science and technology, is a great challenge. Our approach to that challenge involves the coordinated use of multiple management structures—the staff at DP Headquarters, the Tri-Lab Executive committee, and technical teams staffed from the three laboratories. The "Program Management" section describes that effort.

Role of ASCI in Stockpile Stewardship

ASCI is an integral and vital element of the Stockpile Stewardship Program. ASCI provides the integrating simulation and modeling capabilities and technologies needed to combine new and old experimental data, past nuclear test data, and past design and engineering experience into a powerful tool for future design assessment and certification of nuclear weapons and their components.

ASCI simulation and modeling capability supports the Directed Stockpile Work (DSW) program activities by providing capabilities to assess stockpile surveillance significant findings investigations (SFIs) and subsequent decisions regarding the nuclear weapon system and its components. These capabilities are also vital to the stockpile life extension planned activities by providing the simulation and modeling tools needed to certify the performance, safety, and reliability of aging nuclear weapons or weapons that are modified with refurbished components.

ASCI capabilities are needed to model prior manufacturing processes for weapon components and define new, cost-effective, safe, and environmentally compliant manufacturing processes that will provide for consistent nuclear weapon performance, safety, and reliability in the future. ASCI simulation and modeling predictive capability relies on a robust experimental program to support the assessment of stockpile issues and provide materials and physics data needed to validate new scientific models and theories being implemented into the simulation codes. These simulations have been, and will continue to be, used to define experimental resolutions and configurations needed for meaningful validation data and to enhance and refine experimental capabilities.

The simulation and modeling tools have already made impacts on the assessment of stockpile issues, far in advance of the planned schedules in this program plan. Weapon designers, scientists, and engineers now require ASCI simulation and modeling capabilities and technologies to assess aging changes occurring in stockpile nuclear weapons and to assess and certify planned refurbishments of weapon system components.

ASCI must maintain a close relationship with both DSW, which contains the Stockpile Life Extension Program (SLEP), and the Defense Science Program Campaigns. In the ASCI-DSW partnership, ASCI negotiates requirements with and provides validated capabilities to DSW. ASCI in turn must look to the Defense Science Program Campaigns to provide additional science and experimental data to support the development of the validated simulation capability that meets the needs of DSW. ASCI will also provide important computational capabilities to support experiment design and to explore revalidation in a simulation environment.

The following is a short summary of the ASCI relationship with other elements of the Defense Programs Stockpile Stewardship Program.

Relationship of ASCI to Directed Stockpile Work

The DSW program conducts the surveillance, maintenance, refurbishment, and manufacturing activities for nuclear weapons in the stockpile. This program serves as the principal DP interface with the Department of Defense (DoD). DSW is responsible for activities that lead to the continuing assessment of the performance, safety, and reliability of aging nuclear weapons and the certification of weapons that are modified with refurbished components. ASCI supports the DSW program by providing advanced simulation and modeling capabilities and technologies that lead to high-confidence assessments and certification of the nuclear weapon stockpile consistent with the DSW refurbishment schedule and the discovery of surveillance findings.

ASCI simulation and modeling capabilities are currently being used to assess several unresolved surveillance SFIs. Typically, these unresolved investigations concern aging or poor original manufacturing of weapon components. Assessing the impact of current surveillance findings on weapon performance and safety requires three-dimensional simulations, and in some situations, the use of new numerical techniques in the ASCI simulation codes that are not available in the legacy codes. However, these simulations cannot currently be carried out with the desired resolution or materials and physics models on the current *Blue Mountain*, *Red*, and *Blue Pacific* platforms because of the processor speed and memory limitations of the platforms. Our estimates indicate we require a factor of 25 increase in both resolution (memory) and speed (teraOPS) to perform these simulations with adequate resolution, and improved materials and physics models in a timely fashion (one to two weeks). New surveillance findings will occur in the future for our aging weapons, and ASCI simulation capabilities will be needed for an assessment of the weapon performance, safety and reliability.

ASCI simulation tools have also been used to support the physics and engineering certification of the B61 Mod 11. Recently, an analysis of the performance of the physics package has been completed with details not possible using the legacy tools. Engineering certification of the structural integrity of the earth penetration of this weapon was strongly supported by ASCI structural analysis simulations for both the nonnuclear and nuclear weapon components. The initial simulations were compared with and validated with B61 Mod 11 drop-test data. Extremely detailed simulations of the dynamic response of the weapon were carried out with various angles of entry, frozen soil depth, and velocities at impact. These simulations could not be carried out on previous, less capable computing platforms.

There are many other cases where ASCI tools have been used to support DSW. For example, ASCI simulation tools supported the certification of the neutron generator performance in radiation environments. Sandia completed a series of three-dimensional simulations of the response of the MC4380 neutron generator in a radiation field. This component is being fielded in the W76, and it is one of the first major components in the stockpile where ASCI simulation tools played a critical role in the certification process.

In another case, ASCI simulation capabilities are being used to refine and optimize the casting processes needed to produce manufactured plutonium pits and uranium shells.

Our simulation capabilities will be used to support the planned W80 (2006 FPU) and W76 (2007 FPU) stockpile refurbishment assessment and certification. Engineering analysis capabilities will be used to model high fidelity flight tests for several nuclear weapon systems.

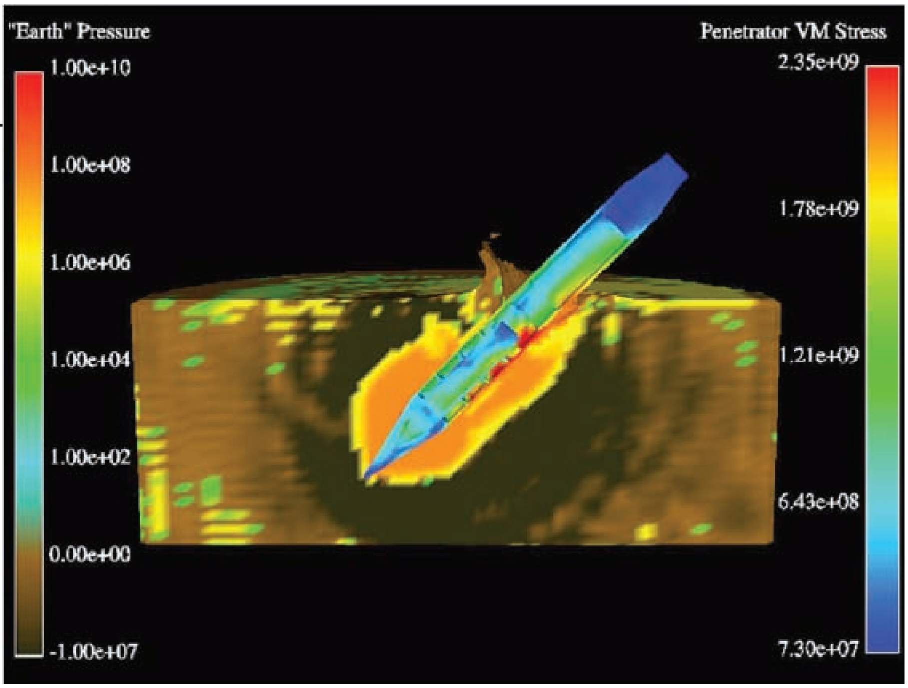


Figure 4

ASCI is developing high-fidelity computer codes needed to predict the safety, reliability, performance, and manufacturability of weapon systems. In this example, high-fidelity simulations were important to the certification of the structural integrity of B61 Mod 11.

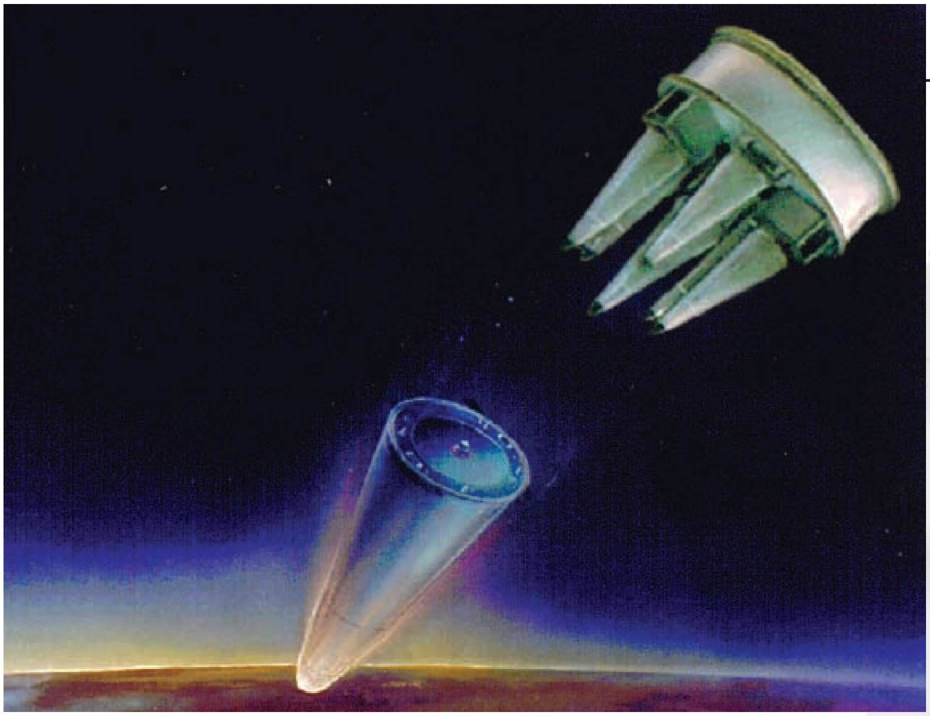


Figure 5

ASCI's advanced simulation capabilities will support DSW in the W76 life extension program.

Relationship of ASCI to the Defense Science Program (the Campaigns)

The Defense Science Program is the primary source of science development, testing (including, in the past, underground tests), and experiments needed to support the U.S. nuclear stockpile. In the previous era of test-based confidence, this program provided direct answers about the performance, safety, and reliability of the stockpile. In the current era without underground testing, with reduced aboveground tests, and with new manufacturing processes, the focus is shifting to computation-based confidence, which requires a strong relationship between ASCI and the Defense Science Program.

The Campaigns provide the understanding in science and the data for improving physics models needed to understand weapon performance. ASCI provides the verified and validated codes, supercomputer platforms, and simulation environment that make it possible to simulate the operation and aging of U.S. weapon systems. Stockpile stewardship will also provide the experimental facilities, like the National Ignition Facility (NIF) and the Dual Axis Hydrodynamic Testing (DARHT) Facility, which will be used to develop new physics models and provide validation data. In addition, the Microsystems and Engineering Sciences Applications (MESA) Facility will provide new engineering design and development capabilities. Finally, the Stockpile Stewardship Program will maintain and continue to develop and understand the archival data from past underground tests, which provide a critical link back to full-scale weapon tests.

EXPERIMENTAL DATA NEEDED BY ASCI

The ability of ASCI to supply validated physics and materials models in the next-generation simulation codes depends critically on the availability of high-quality, fundamental experimental data for use in our verification and validation efforts. In other instances, the theory and model development benefit greatly from experimental guidance to direct our efforts. It is essential that sufficient integration and coordination occur between the experimental campaigns to ensure that the ASCI data requirements are part of the Defense Programs (DP) planning process.

There are several areas of the physics and materials modeling effort where existing data and the current state of the theory and modeling permit the implementation of physics and materials models into the ASCI simulation codes, and for significant validation efforts to be under way. In some of these areas additional data may be necessary to complete the validation, but enough data is in hand to begin the process of validation. The materials and physics models initially implemented do not in all cases represent the ultimate expression of the physics; they are generally significant improvements over models available in the legacy codes. Over time as our computing systems become more capable, additional higher-fidelity models will be implemented. The higher-fidelity physics and materials model implementation will generate additional requirements for validation data.

Two principal types of data are required: (1) fundamental data in simplified geometry to validate the physics and materials models without conflicting effects, and (2) integral or system data from larger-scale, more traditional capabilities, for example hydrodynamic testing.

There are several sets of existing data that have not yet been fully incorporated into the ASCI modeling efforts, including data from subcritical experiments, and a large number of plutonium gas-gun shots. A recent release of a new plutonium equation-of-state table draws from the subcritical experimental data. The gas-gun data is very rich and has just begun to be incorporated, initially as low-pressure equation-of-state data. In the future, the gas-gun data will be incorporated to address related issues of melt, spall, elastic properties, etc. Similar data exists for weapon surrogate materials, and the development work in ASCI permits higher-fidelity models for all materials. Some neutron scattering experimental data exist for elastic constants, permitting more accurate potentials for the various elements, including plutonium. Refinements to the equation of state, especially with plutonium, will require additional data in the future. The details of phase transitions and melt are very important but not well explained by the current models. While an emphasis is placed on plutonium experimental data, several metals in common use in the nuclear weapons also need additional data, including uranium and surrogates of these materials. Proton-radiography and subcritical experiments are being used to provide validation data for modeling ejecta creation and transport.

Past nuclear test data is an important way of assessing details of the explosion phase of a nuclear weapon. A reevaluation and reanalysis of past nuclear test radiochemistry data is under way. The nuclear data evaluations used in both the legacy and the ASCI advanced simulation codes are constrained by experimental data. Recently completed measurements of (n,2n) cross section at high energies (^{235}U(n,2n), ^{238}U(n,2n) and ^{239}Pu(n,2n)) have been incorporated into improved evaluations. Experimental data for other isotopes used in past nuclear tests are also being incorporated into nuclear data evaluations. The new evaluations have changed the interpretation of weapon performance in past nuclear tests.

High-explosive experimental data-measuring detonation curvature during burn have been obtained over the past few years for various types of high explosives under different environmental conditions. Improved high explosives models have been developed that are intended to replace the very crude programmed burn treatments used in the past. The Detonation Shock Dynamics model has already been implemented into ASCI simulation tools. Experiments such as the embedded gauge shots and interface velocity measurements provide quantitative shock-initiation/reactivity experimental data that are important for our development of physically based reaction models for our next-generation reactive burn treatments. Significant refinement of high explosives equations of state have been made possible through extremely accurate and very elegant plate-push experiments on conventional and insensitive high explosives. Measurements of the multiaxial stress-strain of high explosives (up to failure) have been made to improve our dynamic structural analysis modeling of the stockpile-to-target sequence for weapon systems.

Significant progress has been made in the measurements of fundamental weapons materials properties. Experimental data for grain orientation and texture have been measured to validate the modeling of microstructural phenomena. Resonant ultrasound measurements have provided validation

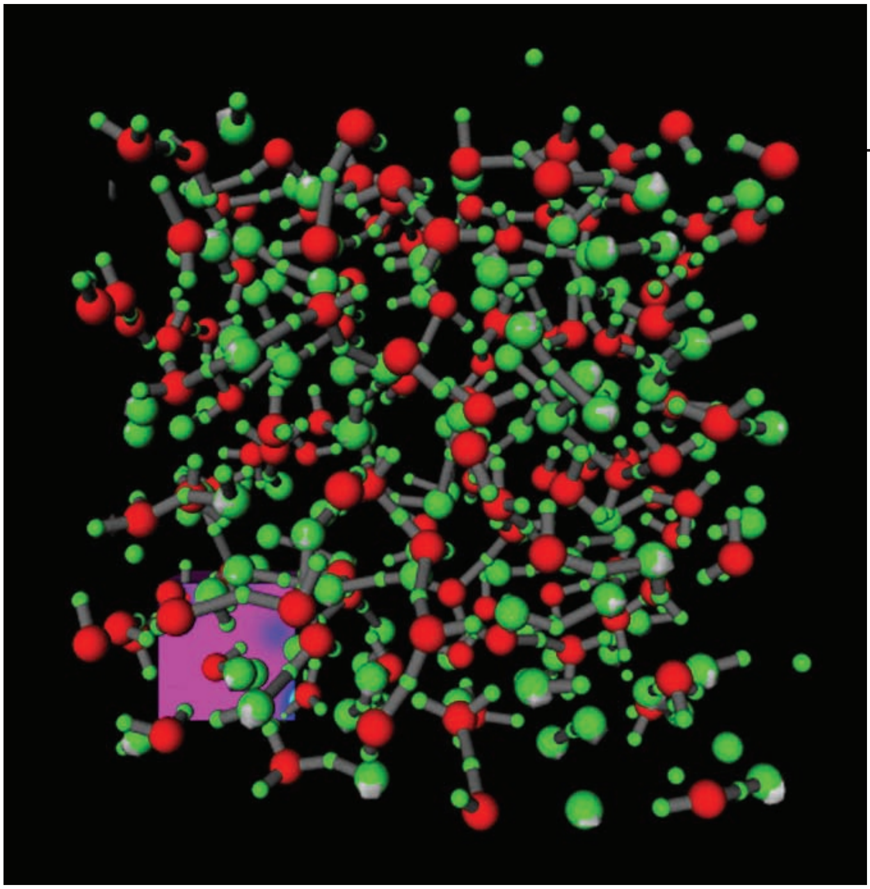


Figure 6

The JEEP molecular dynamics calculation adds to our understanding the performance of insensitive high explosives. This calculation (involving 600 atoms with 1,920 electrons, using about 3,840 processors on ASCI *White*) is providing crucial insight into mesoscale phenomenon through simulations of systems utilizing high-fidelity microscale physics. Science calculations such as this were performed during the testing and stabilization of ASCI *White.*

data for the modeling the elastic behavior of weapons materials. Dynamic testing (e.g. split Hopkinson Bar) has provided high-strain and strain-rate experimental data for the validation of materials stress-strain behavior. In addition, flyer-plate experiments provide experimental data needed to validate material damage generation and spall. These data have allowed us to develop models of weapons materials that are significantly better than historical models. Modeling the stockpile-to-target sequence of a weapon system requires low strain-rate-material-behavior models describing the materials dynamic response. Experimental data have been taken that provide validation of significant improvements in crush-up models for several weapons materials to significantly enhance our engineering assessment capabilities.

The loss of underground testing has curtailed the ability to perform qualification experiments on components in nuclear radiation environments. Aboveground radiation facilities (SPHINX, SATURN, Z-Machine, Annular Core Research Reactor) provide radiation sources for measurement of material properties and response to develop models for System Generated Electromagnetic Pulse (SGEMP), to study physical phenomena such as radiation-induced conductivity, and for validation of the ASCI physical models.

Much of the experimental evidence used to validate instability and mix models is legacy data from rocket-rigs, linear electric motors, shock tubes, pulsed-power machines, and past nuclear tests. More recently, new gas-curtain shock tube and two-stage gas-gun experimental data have been measured to provide validation data for the modeling of Richtmyer-Meshkov instabilities in fluids and solids. Experimental data from laser (Nova, Omega, and Trident) and pulsed power (Z and Atlas) facilities have provided validation data for the modeling of instabilities in plasmas. Experimental data were obtained on the NOVA laser that contributed valuable constraints for the development of higher-fidelity opacity tables.

There are numerous examples where the ASCI simulation capabilities have made significant contributions to the design of experimental facilities. ASCI simulations were used to design an optimized collimator system for the DARHT hydrodynamic testing facility that significantly increased the resolution of this facility.

Future facilities such as the Advanced Hydrodynamic facility, and the NIF will provide validation data for ASCI simulation capabilities. The advanced hydrodynamic capability will provide multiple spatial views at various times in the implosion phase of a primary. These experimental data will be used to validate the predictive capability of primary implosions. The National Ignition Facility will provide data regarding thermonuclear ignition and burn of deuterium-tritium.

Accomplishments

ASCI has, in fewer than five years, produced results that may well make it the most successful high-performance computing program in U.S. history. The world's leading four systems are *White* and *Blue Pacific* at Lawrence Livermore National Laboratory, *Blue Mountain* at Los Alamos National Laboratory, and *Red* at Sandia National Laboratories. These systems in turn have been instrumental in first-time, three-dimensional simulations involving components of a nuclear weapon during an explosion and in hostile environments. Such accomplishments are based on the successes of other elements of ASCI research, such as scalable algorithms, programming techniques for thousands of processors, and unparalleled visualization capabilities.

The achievements presented here represent one of the Stockpile Stewardship Program's key responses to presidential directions to ensure the safety and performance of the nation's nuclear arsenal without nuclear testing.

Integrated Computing Systems

ASCI *Red*, developed in a partnership between Sandia and Intel, was the first supercomputer to break the one trillion operations per second (teraOPS) barrier. The system was originally configured with 9,072 Pentium Pro processors, and nearly six billion bytes of memory. Delivered in 1996, ASCI *Red* was at least ten times and, in some applications, 100 times more powerful than the fastest machine previously used.

The mantle for the world's fastest supercomputer passed from ASCI *Red* to Livermore's IBM system, ASCI *Blue Pacific*, when its final-stage upgrade was completed in 1998. As the second step in the ASCI platforms strategy, *Blue Pacific* performs 3.9 teraOPS and has over 2.6 trillion bytes of memory. It is a distributed memory, multiple-instruction, multiple-data, message-passing SP2 supercomputer with 512 nodes.

In November 1998, the ASCI *Blue Mountain* supercomputer at Los Alamos came on line. *Blue Mountain* has 48 commercially available Silicon Graphics Cray Origin 2000 servers containing a total of 6,144 processors. These processors are organized into 48, 128-processor shared memory multiprocessors and give the integrated system a peak speed of 3.1 teraOPS.

ASCI *Red* has since received both hardware and software upgrades and now has a peak speed exceeding 3 teraOPS.

Significant strides have been made in the stabilization and the utilization of the ASCI platforms as the production computational engines for the Stockpile Stewardship Program. The above systems are now full-production systems and critical elements in stockpile stewardship effort.

The current flagship system is IBM's ASCI *White*. This IBM system is a 12.3-teraOPS computer system with a total of 512 16-CPU nodes,

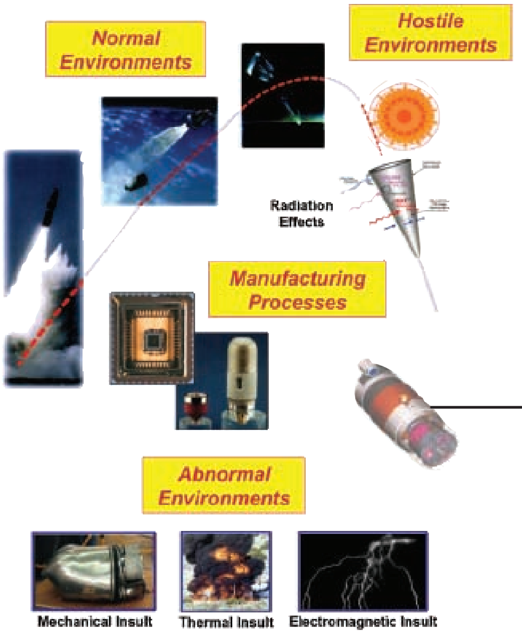


Figure 7

Nonnuclear applications are being developed to simulate weapon performance for normal, hostile, and abnormal environments and for modeling manufacturing processes.

6 terabytes of main memory, and 150 terabytes of disk storage. The memory will be upgraded to 8 terabytes this fiscal year. Delivery of the system began in June 2000 and was complete in September 2000. All three NNSA national security laboratories in support of their stewardship activities are currently using ASCI *White*. Its large memory-per-node, 16 gigabytes has proven particularly useful for a large class of stewardship problems.

Compaq has been selected to develop the next ASCI flagship after *White*, the 30-teraOPS ASCI Q. Located at Los Alamos, it will soon to be the largest supercomputer in the U.S. and capable of 30 teraOPS. Q will have 600 terabytes of disk space and over 12,000 processors. This will be the highest processor-count system to date. The Compaq partnership represents the fourth step on the path to the 100 teraOPS. Q is scheduled to be completed and operational in 2002.

Defense Applications and Modeling

These major advances in supercomputer technology have enabled unprecedented modeling and simulation achievements. In 1999, the first-ever, three-dimensional simulation of a nuclear weapon primary explosion was successfully completed on the IBM *Blue Pacific* supercomputer at Livermore. This simulation demonstrated significant advancements in science-based stockpile work to ensure the safety and reliability of the nuclear weapons arsenal. The simulation required about 300,000 megabytes of memory and ran for 20 days. Only a few years ago, it would not have been possible to run this calculation.

Soon thereafter, Sandia successfully completed the first-ever, three-dimensional computer simulations of a weapon system exposed to hostile radiation and blast environments. The simulations predicted the weapon's response to a variety of blast and impulse loading and calculated photon radiation transport; these pose both thermal-mechanical and electrical threats to the weapon system and components. As part of this milestone, Sandia also completed a series of three-dimensional simulations of the performance of the neutron generator in a radiation field.

In April 2000, Los Alamos completed a three-dimensional secondary burn prototype simulation eight months ahead of schedule. The simulation contained hundreds of millions of mesh elements and ran for over a month on over 2,000 processors, generating nearly 15 terabytes of information. This simulation was unique in that it was run on two different supercomputing platforms. The total simulation run time was about a month, running on an average of 2,020 processors for 820 hours on the Los Alamos *Blue Mountain* platform. A restart file was generated at Los Alamos and transferred to the Sandia ASCI *Red* platform. The problem was then completed on the Sandia platform using 2,048 processors for 196 hours. The fact that this remarkable achievement was accomplished seamlessly on two significantly different supercomputing platforms represents a unique and major step in simulation and computer science.

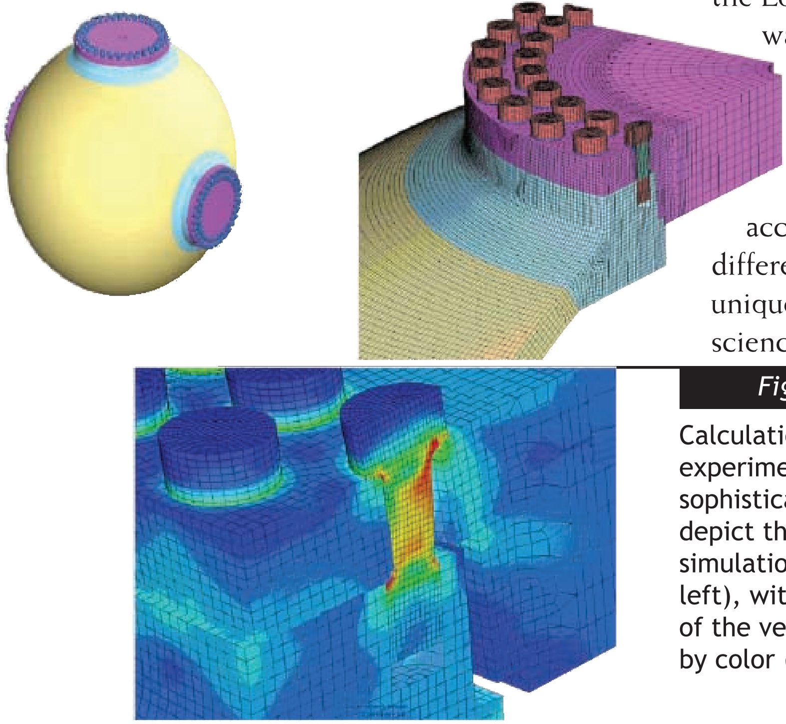


Figure 8

Calculations in support of the Stockpile Stewardship's experimental program attest to the increasing sophistication of ASCI simulations. These images depict the computational mesh for a multimillion-zone simulation of a hydrodynamics pressure vessel (top left), with details of the port (top right), and motion of the vessel around the port with the stresses shown by color (bottom).

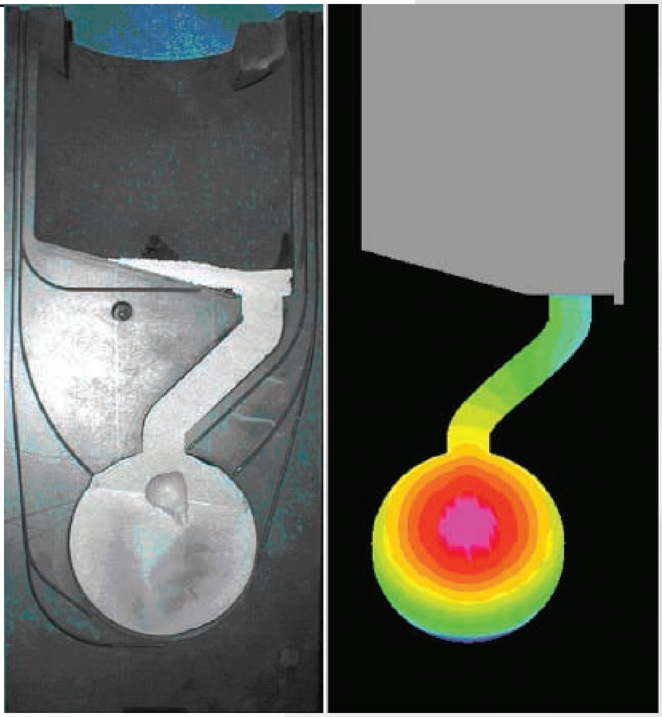


Figure 9

Significant progress in the Telluride materials properties and casting project is demonstrated by the completion of a Np/Al cast ball experiment. The experimental result (left) shows excellent qualitative agreement with the computational result (right).

In addition to these accomplishments, there were a number of other notable achievements. For example, Los Alamos completed a three-dimensional radiation flow simulation ahead of schedule. The simulation ran for more than 18 days and generated 11 terabytes of data. This simulation produced relevant information that can be compared to nuclear test data.

Both Los Alamos and Livermore completed three-dimensional nuclear safety simulations on schedule. The Los Alamos simulation used hundreds of millions of mesh elements and over 2000 processors on the Los Alamos *Blue Mountain* platform. The total run time, including problem setup, was 486 hours. The simulation used an advanced "windowing" technique, which allowed the number of processors to vary as the problem progressed and required more (and less) computational resources. The Livermore simulation used the arbitrary Lagrange-Eulerian hydrodynamic approach to achieve high spatial resolution with ~20 million spatial zones. It was run on 512 processors of the ASCI *Blue Pacific* platform.

The structural integrity of the B61 Mod 11 was simulated as a function of the probability of occurrence of three environmental variables. The predicted reliability distribution was validated via comparison to full-system test data. Over 23,000 simulations, each lasting 10 CPU-hours, were executed on *Blue Mountain* over a three-week period in February 2000 (reflecting 30 CPU years). The analyses generated response surfaces for critical weapon components as a function of environmental input conditions. The simulations were the major basis for the engineering certification of the B61 Mod 11.

The dynamic response of a pressure vessel, used in hydrodynamics tests, was simulated using a dynamic multimillion-zone, finite-element calculation on ASCI *Blue Mountain*—allowing simulations at the level of the vessel port bolts. Figure 10 highlights the simulations that were done in support of the experimental program to provide high-fidelity data for the validation of simulation codes.

The SIERRA team at Sandia completed a major milestone for ASCI with demonstration of the successful execution of the SIERRA framework on three ASCI platforms. Researchers were able to use the ASCI distributed computing environment to process remote jobs and post-process data using the ASCI visualization resources with only a single authentication. This accomplishment required support from the entire ASCI program, including algorithms, parallel input/output, fluid/structural/thermal mechanics, and problem decomposition and setup. This milestone represented the first-release of the ASCI architecture for adaptive, coupled mechanics applications for engineering analysis of stockpile-to-target-sequence environments. The SIERRA architecture software is running at all Nuclear Weapon Complex sites.

Advances were also made in the material science, engineering, and physics-modeling program. For example, the materials properties and casting project, Telluride, made excellent progress during 2000.

Accomplishments include the complete porting of the project's parallel computing environment and software to the Linux operating system, ASCI *Blue Pacific*, and to ASCI *White*. Telluride also added significant algorithm enhancements, including a generalized three-dimensional interface tracking capability for nonhexahedral meshes (tets, prisms, pyramids, etc.). Finally, Telluride completed the simulation of a Np/Al cast ball experiment conducted in the Chemical and Metallurgy Research facility at Los Alamos and continues to support casting simulations important to the casting process used for weapon components.

Additional accomplishments in the material science, engineering, and physics-modeling program include the following:

- Implemented and validated a rate-dependent ductile damage model suitable for large-scale, three-dimensional simulations.
- Evaluated the modified embedded-atom model for plutonium system with comparisons to tight binding potential methods and first-principal electronic structure calculations.
- Created a high-explosive detonation shock dynamics model.
- Created the first-principles multiphase equation of state for plutonium.
- Created a prototype multiphase equation of state for tantalum through an advanced atomistic simulation of high-temperature thermal properties and melting, which has been validated by high-pressure experiments.
- Improved the plutonium strength model.
- Created a parallel opacity model.
- Demonstrated the mechanism by which voids act to greatly increase the ignition rate of composite high explosives through grain-scale simulations of high-explosive detonation, including hydrodynamics, thermal conduction, and chemical reactions.

Simulation and Computer Science

Hand in hand with supercomputing capability, the Simulation and Computer Science Program has developed capabilities that continue to underpin all of the accomplishments in ASCI. Some of these achievements are presented here.

In 1998 and 1999, state-of-the-art data visualization corridors (DVCs) were completed at all laboratories. The DVCs are based on a similar architecture with a few differences to meet special lab needs. Sandia opened the Visualization Design Center at its California site and the Weapon Engineering Product Realization Environment Center at its New Mexico site. At the same time, Livermore opened its new Assessment Theater, and Los Alamos opened its Collaboratory. The DVC systems at the laboratories can display, with three high-resolution video projectors, three indepen-

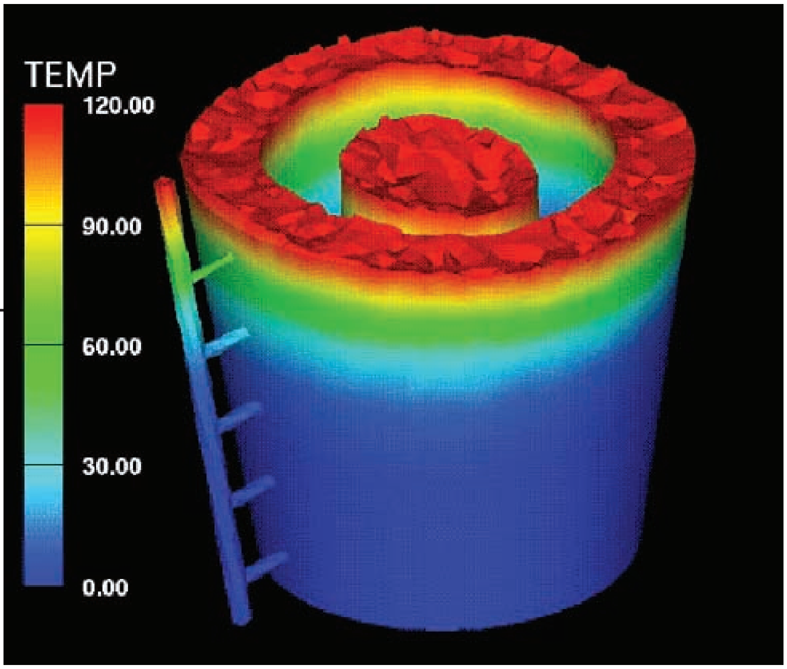


Figure 10

This simulation of the epoxy foaming process was run on the ASCI Heartland system, yielding prediction of flow-front fill, cavity size, pressures, and air traps on the W76 arming, fusing, and firing device. ASCI has contributed to stimulating science-based manufacturing at the plants with modest investments in Heartland (Kansas City Plant) and Manhattan (Y-12).

Figure 11

DVCs provide advanced facilities for high-end visualization and shared, collaborative data analysis. Shown here is the DVC at Sandia California.

dent images or one continuous image on a large curved screen. The screen's dimensions and cylindrical shape create an image that fully envelops the viewer's field of view, effectively immersing the viewer in the data. These corridors provide the capability to gain new insight from ASCI calculations, showing a level of detail of important phenomena that was previously unavailable. The large screens and integrated hardware and software systems support interactive access, display, and manipulation of terascale, three-dimensional scientific simulation data. These features make the DVCs useful for groups of scientists to conduct reviews of weapons designs and to actively evaluate and modify the designs in real time. The collaborative tools also enable people at different locations to share visualizations simultaneously.

These high-quality visualization and analysis capabilities allowed weapons analysts to see and understand results from three-dimensional simulations. This capability directly supported the three-dimensional primary and secondary burn prototype simulations at Livermore and Los Alamos and the hostile environment simulations at Sandia.

ASCI has also made great strides in distributed, scalable, commodity computing. Cplant™ is Sandia's alternative to commercial capacity supercomputers. This supercomputer is built entirely from commercially available components. Software is available under open-source licensing, which enables the world community to share and leverage this accomplishment.

At the end of 2000, a tri-laboratory effort in the PSE program completed a major milestone on schedule. Researchers at all three laboratories successfully implemented the initial software development environment on ASCI *White*.

During the five years of ASCI, our achievements have been recognized around the world as being outstanding contributions to high-performance computing. Many awards have been presented to ASCI researchers and teams including four Gordon Bell Prizes, a Sidney Fernbach Award, a State of Utah Governor's Medal for Science and Technology, the SuPar Cup '99 Award, and several R&D 100 Awards.

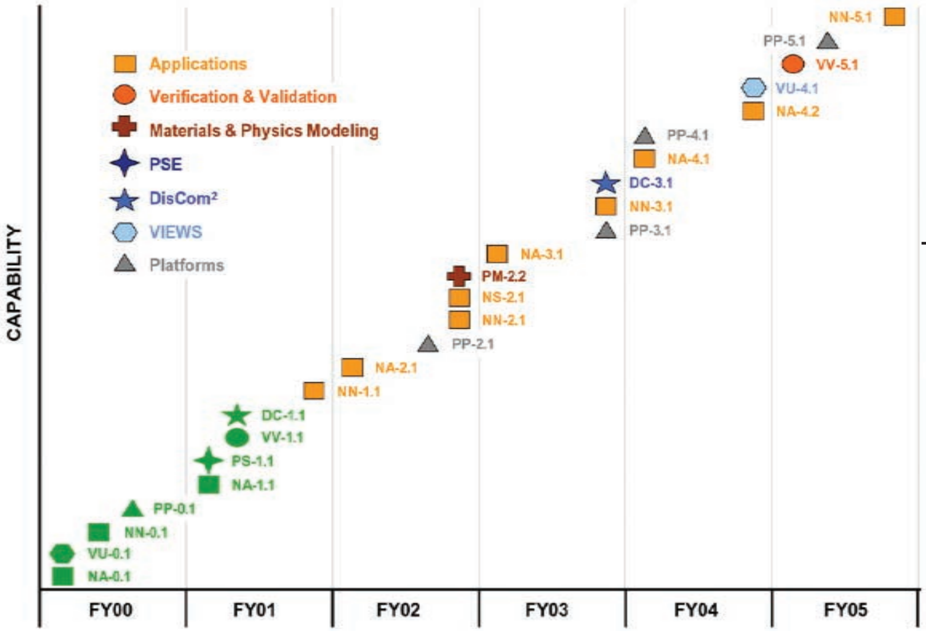


Figure 12

ASCI's success is rooted in an integrated, Tri-Lab planning process. Continued accomplishment of our level-1 milestones is evidence of our ongoing planning efforts. (Completed milestone titles are shown here in green. See Appendix A for detailed description of the milestones.)

Program Elements

This section provides a description of each of ASCI elements followed by the top-level strategies each element is using to contribute to overall ASCI goals. The relative sizes of these program elements are illustrated in Figure 13. The high-level milestones for these program elements are listed and described in Appendix A.

Defense Applications and Modeling:

ADVANCED APPLICATIONS DEVELOPMENT

ASCI is developing the progressively higher performance software applications needed to provide the simulation tools and underpinnings for the Stockpile Stewardship Program (SSP). The key to reaching SSP objectives for initial implementation in 2004 and full implementation in 2010 is the ability to achieve ASCI's critical simulation and applications code milestones in the intervening years. ASCI will provide simulation tools and capabilities embodying the physical and chemical processes needed to predict the safety, reliability, performance, and manufacturability of weapon systems. It is a formidable challenge to replace the empirical factors and adjustable parameters used in current calculations with predictive physical models.

Meeting this challenge will require large, complex computer applications codes; this drives the scale of computing hardware and infrastructure. However, increased capability in hardware and infrastructure alone is insufficient. Much of the increased computational capability to be provided by ASCI must come from advances in the applications codes themselves.

These applications will integrate three-dimensional capability, finer spatial resolution, and more accurate and robust physics. Adding these new capabilities, however, will strain the limits of the algorithms used in today's simulation codes. In addition, the necessity to do full-system or scenario simulations will require the development of new algorithms for coupled systems. As a consequence, the development and implementation of improved numerical algorithms to address these new capabilities will be a critical component of the applications strategies. Tightly integrated code teams—large interdisciplinary work groups consisting of scientists and engineers, along with computational mathematicians and computer scientists, devoted to producing coherent software for efficient predictive simulations—will develop these codes.

APPLICATIONS STRATEGIES

- Focus on three-dimensional, high-fidelity physics and geometry.
- Focus on full-system, component, or scenario simulations.
- Focus on coupling of multiple high-fidelity physics models (coupled multiphysics) for end-to-end simulations without empirical correlations or designer intervention.
- Design and implement numerical algorithms to meet the ASCI application requirements.
- Accelerate code performance by developing computational techniques that efficiently exploit the new computer architectures.

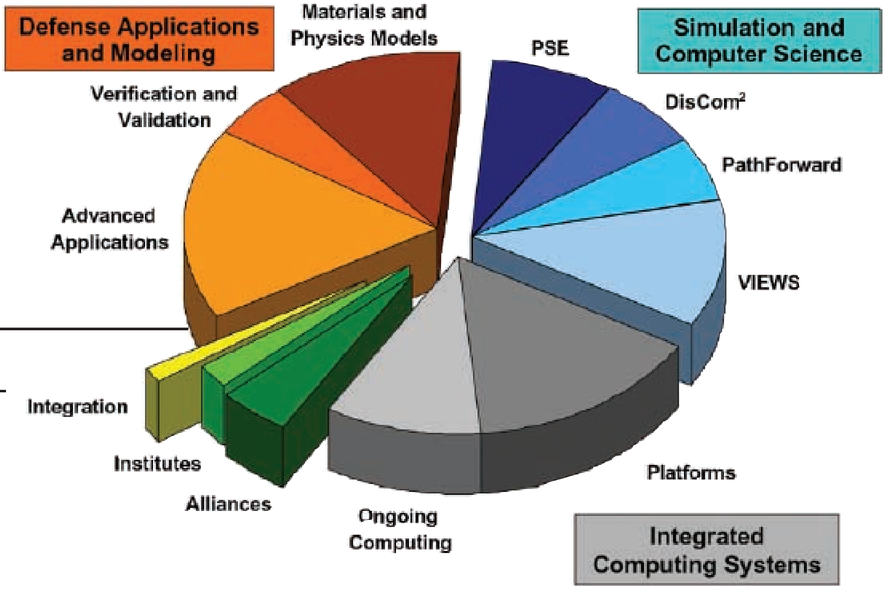


Figure 13

ASCI's integrated development of high-fidelity, three-dimensional weapons simulations requires a diverse collection of program elements. The relative FY2001 budgets for these elements are shown here.

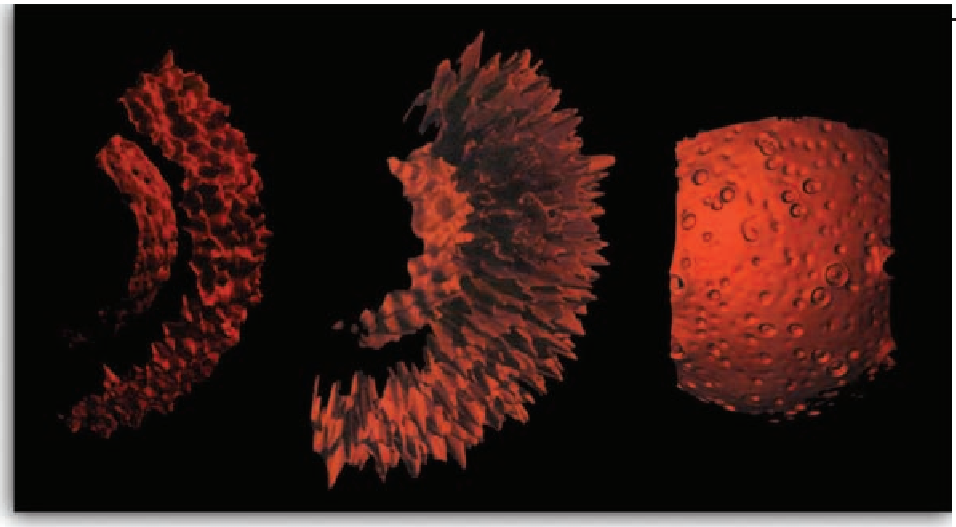


Figure 14

ASCI is developing sophisticated three-dimensional computer simulations based on predictive physical models. Here, isodensity surfaces of a NIF ignition capsule bounding the shell are shown at 200 ps (picoseconds or 10^{-12} seconds, left) and 100 ps (center) prior to ignition. Density contours of rebounding shock near ignition time are shown (right).

- Focus on highest priority applications needed to support Directed Stockpile Work.

VERIFICATION AND VALIDATION

The Verification and Validation (V&V) Program will provide high confidence in the computational accuracy of ASCI and stockpile computing simulations supporting stewardship programs by systematically measuring, documenting, and demonstrating the predictive capability of the codes and their underlying models. Verification is the process of determining that a computational software implementation correctly represents a model of a physical process. The verification program will evaluate current software engineering practices for application to the ASCI-scale simulations and establish requirements for software projects. The most essential goal of the verification portion of ASCI V&V is to ensure that the models from Advanced Applications do in fact give the analytically correct answers as they are implemented. Validation is the process of determining the degree to which a computer model is an accurate representation of the real world from the perspective of the intended model applications. Validation makes use of physical data and results from previously validated legacy codes.

ASCI has placed special emphasis on V&V by establishing it as an independent program element. In the absence of new nuclear tests, the program requires systematic, rigorous V&V methodologies to establish the increased confidence that will be expected of weapon simulations. This element has many interfaces with other stewardship elements and activities, requiring a great deal of coordination. For example, V&V will develop verification technologies and process guidelines, which in turn must be implemented by the Advanced Applications Development program element. The development and prototyping of verification tools supported by V&V will be supplemented by many PSE activities. These multiple interfaces represent a significant management integration challenge to bring ASCI applications and platforms to bear on stockpile stewardship problems of interest to weapons experts. The link between V&V activities and the experimental program (i.e., the Campaigns) is crucial to the success of this effort.

V&V STRATEGIES

- Provide high confidence in weapons simulations supporting stewardship programs by systematically measuring, documenting, and demonstrating the predictive capability of the codes and their underlying models.

- Provide requirements for, and compare calculations against, experimental validation data within the Stockpile Stewardship Program.

- Provide the basis by which computational uncertainties are evaluated and assessed.

- Evaluate current software engineering tools and practices for application to ASCI simulations and establish minimum requirements for the code development projects.

MATERIALS AND PHYSICS MODELING

In the past, physical properties of materials significant to the nuclear weapons program were often inferred from integral test data. Without the ability to conduct such integral tests, there is a high premium on the development of advanced capabilities—experimental, theoretical, and computational—to predict the physical properties of materials under conditions found in nuclear explosions and stockpile-to-target sequences.

At the heart of the development of these predictive capabilities is the determination of the physical properties of materials in regimes relevant to processes governing the performance, safety, and reliability of the nuclear stockpile. Of particular interest are turbulence, instabilities and mix, hydrodynamics, equations of state, and the dynamic properties of materials under conditions of high strain and high-strain rates. In nonnuclear applications the fundamental behavior of physical processes governing turbulence, friction and fracture occur at subgrid scales where experimental measurements are difficult. This is a topic of considerable scope that requires fundamental knowledge of materials properties and response, not only at vastly different length and time scales, but also in the linkage across these scales.

Laboratory experiments conducted by the Defense Science Program and high-performance simulations using ASCI codes will provide the basis for the development of predictive models and validated physical data of stockpile materials. Consequently, ultrascale scientific computing platforms, multiphysics application codes, and unique experimental facilities have been deployed and integrated to establish these predictive capabilities. For example, the high-pressure, high-temperature properties of key stockpile materials have already been resolved and have led to the partial resolution of longstanding anomalies observed in certain nuclear tests. This example illustrates the powerful synergy between high-performance scientific computing and advanced experimental facilities as a strategy to provide a rigorous scientific basis for the development of predictive models and validated materials properties data. Timely insertion of these materials models and properties data into the ASCI codes needs to occur in a partnership with ASCI V&V for verification and validation to material properties data obtained through the campaigns. This will provide DSW with the basis to ensure confidence in the performance, safety, and reliability of the stockpile without nuclear testing.

High-performance simulations linking atomistic to continuum scales will lead to reliability predictions and lifetime assessment for corrosion, organic degradation, and thermal-mechanical fatigue of weapon electronic subsystems. Similarly, quantum-scale simulations and laser-driven shock compression experiments have validated the equation of state of hydrogen up to several megabars, providing valuable insight both into weapons performance and inertial confinement fusion.

MATERIALS AND PHYSICS MODELING STRATEGIES

- Determine the multiphase equation of state for plutonium and other relevant metals, including melting, solid-solid phase transformations, and dynamic response.
- Develop physics-based models predicting the properties of plutonium under aging due to self-irradiation.
- Develop physics-based models of high explosives thermal and mechanical properties, including decomposition kinetics, detonation performance, properties of reaction products, and constitutive properties.
- Develop physics-based models for corrosion, polymer degradation, and thermal-mechanical fatigue of weapon electronics.
- Develop physics-based models of melting and decomposition of foams and polymers in safety-critical components.

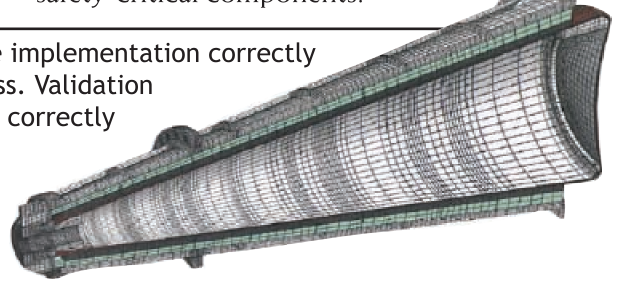


Figure 15 Verification determines that a software implementation correctly represents a model of a physical process. Validation determines whether a computer model correctly representation the real world.

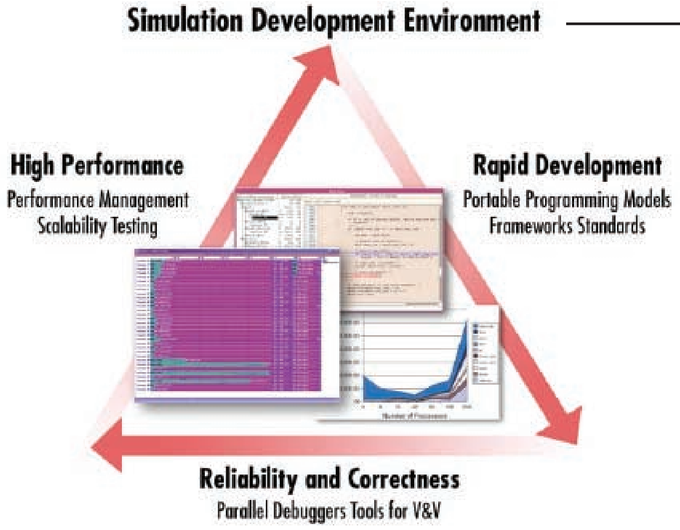


Figure 16

Rapid development of robust computing environments enables ASCI simulations to run on our terascale platforms.

- Develop physics-based models of microelectronic and photonic materials under aging and hostile environments

Simulation and Computer Science:

PROBLEM SOLVING ENVIRONMENT

ASCI's unprecedented code development effort will require robust computing and development environments (as illustrated in Figure 16), enabling codes to be developed rapidly. Through the Problem Solving Environment (PSE) program, ASCI is developing a computational infrastructure to allow applications to execute efficiently on the ASCI supercomputer platforms and to provide accessibility from the desktops of scientists and engineers. This computational infrastructure will include software development tools, run-time libraries, frameworks, solvers, archival storage, high speed interconnects, scalable I/O, local area networks, distributed computing environments, software engineering, etc.

The ASCI Defense Applications and Modeling program is the main driver for the PSE program requirements and the primary customer for PSE products and services. Thus, PSE is responsible for providing the weapon scientists and engineers, and the application developers the computational tools they need for the development and execution of applications on ASCI platforms. Furthermore, in collaboration with third-party and platform partners, PSE is responsible for deploying system software on all ASCI platforms. PSE's program objective is to provide a complete software environment where products come from a variety of suppliers, including the platform partners, third-party independent software vendors, alliance partners, and laboratory R&D. PSE works closely with platform partners to define software requirements and priorities and engages in collaborative development in critical areas where the platform providers may not have access to machine resources.

PSE STRATEGIES:

- Create a common and usable application development environment for ASCI computing platforms, enabling code developers to quickly meet the computational needs of weapons designers.

- Produce an end-to-end, high-performance I/O and storage infrastructure, encompassing ASCI platforms, large-scale simulations, and data exploration to enable improved code execution.

- Ensure appropriate access to ASCI supercomputers and other ASCI resources across the three weapons labs so that ASCI compute platforms are fully usable for local code development and execution and integrated well into the tri-lab distributed computing environment.

DISTANCE AND DISTRIBUTED COMPUTING AND COMMUNICATION (DISCOM^2)

DisCom^2 will assist in the development of an integrated secure information, simulation, and modeling capability to support the design, analysis, manufacturing, and certification functions of the Defense Programs complex through developments in two key strategic areas: Distance Computing and Distributed Computing. Distance Computing will extend the environments required to support high-end computing to all sites. It will partner with the National Security Administration (NSA) to develop the high-speed encryptors required to interconnect the laboratories securely. Distributed Computing will develop an enterprise-wide integrated supercomputing architecture that will support nuclear-weapon science and engineering requirements for stockpile stewardship. It will take advantage of the ongoing revolution in commodity, cluster-based, distributed high-performance computing. It will adopt, support, and augment the open software approach to distributed cluster computing. A product will be an evolving set of commodity computing systems that compliment the ASCI terascale, supercomputing platforms. These solutions will fit seamlessly into the secure ASCI computing environment as in the example of Figure 17.

DisCom^2 Strategies

- Extend the environments required to support high-end computing to the entire nuclear weapons complex.

- Develop and deploy an integrated distributed computing environment.

- Develop an enterprise-wide integrated commodity supercomputing architecture that will support nuclear weapon science and engineering requirements for stockpile stewardship.

PathForward

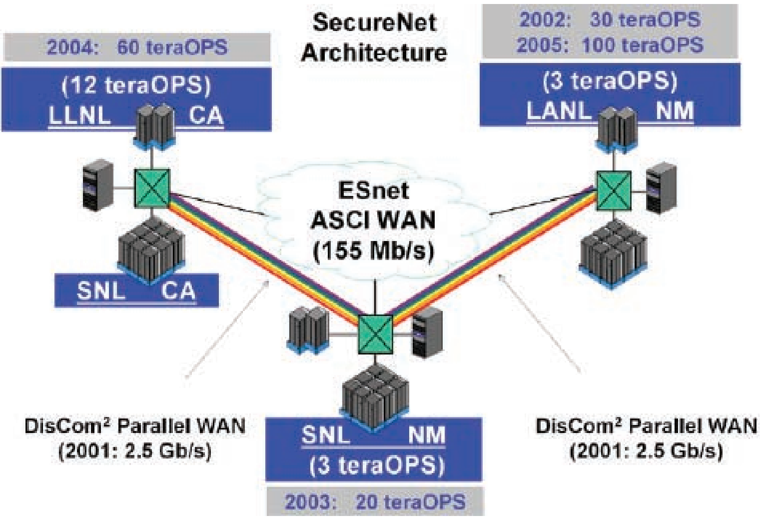
A key ASCI strategy is to construct future high-end computing systems and environments by scaling commercially viable building blocks, both hardware and software. PathForward is the program designed to achieve such goals by entering into partnerships with U.S. industry to develop the key technologies necessary to accelerate the development of balanced 100-teraOPS-computer systems, and beyond. These partnerships develop and accelerate technologies in the vendors' current business plans, but are not available in either the time frame or the scale required by ASCI. Starting in 1998, PathForward focused on interconnect and data storage technologies, as well as systems software and tools for large-scale computing systems. These technologies were considered the most critical components in the construction of the 30-teraOPS-machine environment in 2001. These are the essential scaling and integrating technologies that will enable ultrascale computing systems to be engineered and developed out of both hardware and software commodity computing building blocks. In FY2001, new projects in the areas of visualization and runtime system software were added to the PathForward portfolio.

PathForward Strategies:

- Stimulate development of commercially viable building blocks for construction of future ASCI supercomputer systems.

- Focus on opportunities that expand the capabilities, performance, availability, expertise and products currently being considered within the normal business plans of the U.S. computer industry.

Figure 17 The bandwidth of the Tri-Lab wide area network is being significantly increased in 2001 by the DisCom^2 program element, providing much improved access to the information within the nuclear weapons complex, wherever it is located.



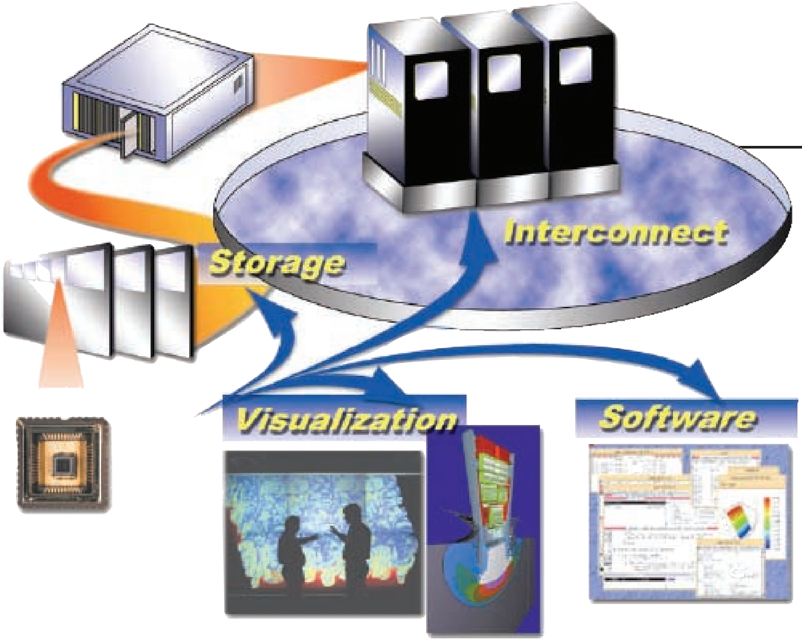


Figure 18

Developing key technologies for future platforms, PathForward partners with U.S. industry to accelerate availability or scaling of products required by ASCI.

Visual Interactive Environment for Weapons Simulation (VIEWS)

VIEWS (Visual Interactive Environment for Weapons Simulation) is focused on the problem of "seeing and understanding" the results of multiteraOPS simulations and comparing results across simulations and between simulations and experiments. VIEWS brings together ASCI-supported research, development, engineering, deployment, and applications support in visualization, data management, and data exploration. VIEWS provides increased attention on the problem of exploring and understanding multiterabyte scientific datasets. As mathematician R. W. Hamming (best known for his work on error-detecting and error-correcting codes) succinctly stated, "The purpose of computing is *insight*, not numbers."

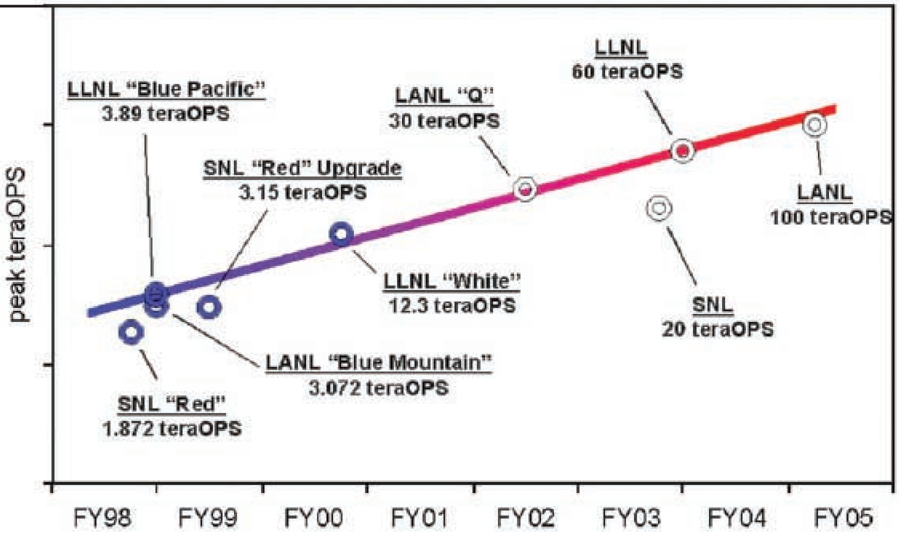
The goal of VIEWS is the creation of an infrastructure called Data and Visualization Corridor (DVC). The viewing area of Lawrence Livermore's DVC facility is shown in Figure 19. One often thinks of the storage and I/O systems of supercomputers, and the graphics workstations attached to them, as a thin pipe through which data must be pumped. The idea of a corridor is meant to suggest the opposite metaphor, a wide path through which massive quantities of data can easily flow and through which scientists and engineers can explore data and collaborate. Data will be delivered to offices and assessment theaters. Thus, the corridor is precisely the kind of infrastructure needed to fully support the ASCI see-and-understand mission.

Figure 19

DVC facilities, like this one at Lawrence Livermore, enable scientists to view and use the results of high-fidelity, three-dimensional simulation. Driven by a multiprocessor visualization server, interactive applications can display images at very high resolution on this 15-projector display wall.

Figure 20

To satisfy the simulation requirements of the Stockpile Stewardship Program, ASCI is stimulating the computer industry to develop high-performance computers with speeds and memory capacities hundreds of times greater than currently available.



The corridor concept was outlined through a collaboration of weapons scientists and engineers, researchers from academia and industry, and leaders of other federal agencies. While the data exploration needs of a variety of agencies were taken into account, the ASCI imperative to understand the massive datasets resulting from teraOPS scientific simulation was, from the beginning, the driving force. The VIEWS program will implement the DVC concept within the three NNSA national security laboratories.

There are several steps involved in implementing successful DVCs. In many cases, needed hardware and software technologies do not exist or are in their infancy. Hence, a major part of the VIEWS program has targeted research and development to create innovative technologies for scientific collaboration, data exploration, visualization, and understanding.

Keys to progress are well-defined technology roadmaps and well-engineered architectures. In general, the development of the DVC concept is focused on promising technologies that can have direct impacts on ASCI in a two- to four-year timeframe. Once prototype technologies exist, they need to be integrated, tested, and evaluated by a representative set of users. Finally, these technologies need to be deployed in a generally available, operational and reliable environment for direct, day-to-day use by ASCI users and applications.

VIEWS Strategies

VIEWS provides scientific understanding and insight through qualitative and quantitative data discovery, analysis, and assimilation by means of:

- Partnering with academia, industry, federal agency research and development.
- Visual exploration and interactive manipulation of massive, complex data to offices and assessment theaters.
- Orchestrated, effective data management, data extraction, and data delivery.
- Efficient solutions for remote and collaborative scientific data exploration.
- Deployment of highest-performance DVCs.

Integrated Computing Systems:

Physical Infrastructure and Platforms

The first supercomputers were developed for weapon applications in the 1960s as a partnership between the computer industry and the nuclear weapons laboratories. Throughout the 1970s and 1980s, this relationship continued. The Defense Programs laboratories were early user sites and a primary customer for new state-of-the-art, high-performance computers and computing simulation capability.

In the late 1980s and early 1990s this relationship changed. The NNSA national security laboratories

Figure 21

ASCI has the four fastest supercomputers in the world. Intel's ASCI *Red* machine (top left), located at Sandia New Mexico, was the world's first teraOPS supercomputer and was recently upgraded to more than 3 teraOPS. ASCI *Blue Mountain* (top right) was installed at Los Alamos by SGI and has achieved a peak speed of over 3 teraOPS. ASCI *Blue Pacific* (middle) was installed by IBM at Lawrence Livermore and has also broken the 3-teraOPS barrier. ASCI *White* (bottom) was installed by IBM at Lawrence Livermore in 2000 and is the world's fastest at 12.3 teraOPS.

drastically reduced their partnerships with industry in developing computer systems. Because of significant budget reductions, they greatly reduced their purchases of supercomputers. This was also a period of momentous change within the computing industry, as minicomputers eroded the marketplace of mainframes, followed in turn by the cannibalization of the minicomputer market by microcomputers. As a result, the computing industry as a whole no longer viewed the NNSA laboratories as a primary customer for their most advanced computer designs.

Today, more powerful computing platforms are needed to achieve the performance simulation and virtual prototyping applications that the Stockpile Stewardship Program requires. ASCI has stimulated the U.S. computing industry to develop high-performance computers with speeds and memory capacities hundreds of times greater than currently available models and ten to several hundred times greater than the largest computers that were likely to result from recent development trends. ASCI will continue to partner with various U.S. computer manufacturers to accelerate development of larger, faster computer systems and software required to run Defense Programs' demanding applications.

ASCI partnerships have brought about development and installation of the world's first teraOPS supercomputer (the 1.8-teraOPS Intel machine at Sandia New Mexico), three 3-teraOPS machines (at Los Alamos, in partnership with SGI; at Livermore, in partnership with IBM; and at Sandia, upgraded in 1999 to 3 teraOPS by Intel). An extension of the Lawrence Livermore/IBM contract allowed the development of a 12-teraOPS machine that was installed in Livermore in 2000.

ASCI has recently placed a contract with Compaq to develop Q, a balanced 30-teraOPS system to be delivered to Los Alamos National Laboratory in 2002.

The original post-30-teraOPS strategy[2] called for an upgrade of the 30-teraOPS system to 50 teraOPS in 2002, and a 100-teraOPS system in 2003. This strategy was revised[3] to a separate 50-teraOPS system in 2003 and a 100-teraOPS system in 2004. The congressional funding was (and the current budget projections are) not adequate to implement this plan.

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[2] *Accelerated Strategic Computing Initiative (ASCI) Program Plan,* available from the Office of Advanced Simulation and Computing, DP-14, October 1996.

[3] *Accelerated Strategic Computing Initiative (ASCI) Program Plan,* DOE/DP-99-000010592, available from the Office of Advanced Simulation and Computing, DP-14, January 2000.

Given the current budget projections, the plan is now to replace the 50-teraOPS system in 2003 with a 20-teraOPS system, and replace the 100-teraOPS system in 2004 with a 60-teraOPS system (see Figure 20). Additionally, current budget projections do not allow for the upgrade of the 30-teraOPS system.

This strategy is based on the plan to locate these systems at all three laboratories in a complementary fashion, ensuring that each site will have a high-end computing capability and capacity to support the stewardship mission.

A 100-teraOPS machine represents the minimum capability required by ASCI to begin to address the significant processing requirements of the program. From the beginning of the program, ASCI has been focused on achieving a 100-teraOPS machine in the 2004 timeframe and has a well-defined and delineated roadmap to this end. ASCI has met all of its milestones for delivery of machines up to and including the 12-teraOPS *White* machine at Lawrence Livermore. We also believe that the 30-teraOPS *Q* machine will be completed on schedule next year at Los Alamos. While the delivery of a 100-teraOPS in 2004 is thought to be technically feasible, budgetary pressures have caused ASCI to scale the planned 2004 machine back to 60 teraOPS. In the fast-paced world of computer technology, it is difficult to project the cost of such a machine to be delivered three years in the future precisely. In 2004 we will purchase a machine that is consistent with our budget profile.

The current platform strategy calls for the acquisition of "commodity" systems. This has typically resulted in architectures consisting of commodity processors tied together by a communication fabric via a network interface switch. In examining the prospects for future high-end systems, we have recognized that accelerating research into advanced computing architectures is important and could pay off by providing substantial leverage for future ASCI platforms. As a result, we have introduced *Advanced Architectures,* a new program subelement in 2001, to promote research and development efforts exploring alternative high-performance-computing architectures with implications beyond 2004. The goal is to explore architectural alternatives that are not constrained by today's market forces. During the next five years, architectural approaches that directly address inadequacies in today's high-end systems that make it difficult for ASCI's complex applications to achieve high performance are of particular interest.

Because of the nature of the *Advanced Architectures* program element, we expect that industrial research organizations or academia would be the principal participants in this initiative. The laboratories are expected to serve as architecture evaluators in the context of the ASCI processing needs.

Platform Strategies

- Accelerate the acquisition of scalable commercial high-end systems.

- Develop partnerships with multiple computer companies to ensure appropriate technology and system development.

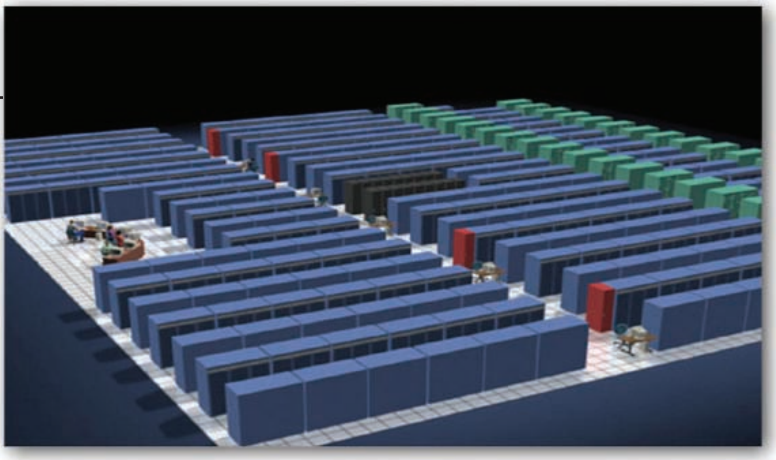

Figure 22

ASCI *Q*, a 30-teraOPS supercomputer developed in partnership with Compaq, is to be installed at Los Alamos in the spring of 2002. *Q* will have nearly 12,000 processors and occupy about 25,000 square feet of machine room floor space.

- Through *Advanced Architectures,* stimulate R&D efforts that explore alternative computer designs that promise dramatic improvements in performance, scalability, reliability, packaging or cost.

ONGOING COMPUTING

The Ongoing Computing element is focused on making the computing resources needed to support stewardship available to the laboratories. This element is structured somewhat differently at each of the laboratories, but program-wide it is focused on the operation of the computer centers at the three laboratories. In general, that effort has two mission elements: (1) to provide ongoing stable production computing services to laboratory programs, and (2) to foster the evolution of simulation capabilities towards a production terascale environment as ASCI supercomputer platforms evolve towards the 100-teraOPS level. This effort consists of software infrastructure, the networks, data storage, and output systems.

ONGOING COMPUTING STRATEGIES

- Operate and maintain laboratory computing centers.
- Maintain existing production codes for near-term Stockpile Stewardship use.
- Provide the production simulation capabilities that support the enduring stockpile and serve as the foundation of future ASCI code development.
- Maintain the skills/knowledge base that ASCI will leverage to meet stewardship goals.
- Maintain preparedness to apply ASCI's advanced simulation capabilities as they develop.

University Partnerships:

ACADEMIC STRATEGIC ALLIANCES PROGRAM (ASAP)

The major goals of ASAP are:

- Solve science and engineering problems of national importance through the use of large-scale, multidisciplinary modeling and simulation.
- Establish and validate large-scale modeling and simulation as a viable scientific methodology across scientific applications requiring integration across disciplines and complex simulation sequences.
- Enhance overall ASCI effort by engaging academic experts in computer science, computational mathematics, and simulations of science and engineering.
- Leverage relevant research in the academic community, including basic science, high-performance computing systems, and computational environments.
- Strengthen education and research in areas critical to the long-term success of ASCI and the Stockpile Stewardship Program.
- Strengthen ties among the NNSA national security laboratories and participating U.S. universities.
- Foster computational science as an academic discipline.

Historically, parts of the academic community have always had a close relationship with the NNSA laboratories. In fact, the University of California has managed Los Alamos and Lawrence Livermore for many years. ASCI and universities share a new common and critical interest.

The success of ASCI depends on the ability to demonstrate that simulations can be used credibly as a means of ensuring stockpile confidence. Universities have a strong interest in improving the ability of simulations to reflect reality. Simulation has already proven valuable in exploring and developing new scientific ideas. Thus, ASCI's efforts to revitalize this historic relationship between the national laboratories and the wider academic community have become an important part of the stockpile stewardship philosophy.

ASCI will require the technical skills of the best scientists and engineers working in academia, industry, and other government agencies in addition to those working in the national laboratories. The need to develop an unprecedented level of simulation capability requires strategic alliances with other leading research organizations. The purpose of the Alliances program is to engage the best minds in the U.S. academic community to help accelerate the emergence of new unclassified simulation science and methodology and associated supporting technology for high-performance computer modeling and simulation. These alliances will support the development and credible validation of this simulation capability. ASCI will also work with the entire computing community to develop and apply commercially acceptable standards. ASCI plans to initiate exchange programs to bring top researchers directly into the project while allowing laboratory personnel to expand their experience base in external projects. Finally, ASAP is viewed as an important step toward developing the next generation of scientists needed for the national security programs at the NNSA laboratories.

These research projects are being implemented in three levels:

1. **Level-One Strategic Alliances** established five major centers (see Figure 23) engaged in long-term, large-scale, unclassified, integrated multidisciplinary simulation and supporting science and computational mathematics representing ASCI-class problems. The centers have a five-year funding commitment. During FY2001 ASAP will conduct an external, peer review of each of the five centers to support the ASCI decision regarding an extension of the centers for an additional five years. Presently these centers collectively have access to up to 10% of the ASCI-class computing resources at the NNSA national security laboratories and 10% of the computing resources of the NSF National Partnership for Advanced Computational Infrastructure center at University of California at San Diego. The centers are:
   - California Institute of Technology: Center for Simulating Dynamic Response of Materials.
   - Stanford University: Center for Integrated Turbulence Simulation.
   - University of Chicago: Center for Astrophysics Flash Phenomena.
   - University of Illinois, Urbana-Champaign: Center for Simulation of Advanced Rockets.
   - University of Utah: Center for Simulation of Accident and Fire Environments.
2. **Level-Two Strategic Investigations** established smaller discipline-oriented projects working in computer science and computational mathematics areas identified as critical to ASCI success. There were 13 Strategic Investigation projects established in FY1999, each targeted for three years. As for the Level-One Alliances, an open, peer-reviewed solicitation process was used.
3. **Level-Three Individual Collaborations** establish focused projects initiated by individual ASCI researchers working on near-term ASCI-related problems. Typically, these specific projects are funded out of individual laboratory ASCI budgets.

Figure 23

The Academic Strategic Alliances Program is designed to engage the best minds in the U.S. academic community to help accelerate the emergence of new unclassified simulation science and methodology. ASCI's Level-One Strategic Alliances involve five of the nation's top research universities in the simulation effort.

ASCI INSTITUTES

In addition to the three-level Alliances Program, ASCI's academic collaborations added a new component in FY2000: the ASCI Institutes. The charter of the ASCI Institutes at the three NNSA national security laboratories is to create an environment for collaboration with academia on research topics in computer science, computational mathematics, and scientific computing that are relevant to the Stockpile Stewardship Program. These collaborations are conducted through a variety of mechanisms, ranging from one-day seminars to multimonth sabbaticals at the laboratories.

Each of the three institutes has different topics of emphasis, depending on laboratory needs; however, they all coordinate and leverage their activities to ensure maximum benefit to ASCI.

Hiring qualified and experienced computer and computational scientists is extremely challenging in today's job market. One of the objectives of this effort is to enhance the laboratories' ability to attract top-notch academicians to the laboratories.

ALLIANCES/INSTITUTES STRATEGIES

- Encourage strategic alliances and collaboration.
- Leverage other national initiatives.
- Collaborate with the best R&D programs of other departmental offices, other agencies, universities, and industry.
- Attract top researchers in key disciplines for weapon applications.
- Form long-term strategic alliances with a small number of universities and academic consortia to fund critical efforts dedicated to long-term ASCI issues, such as high-confidence simulations.
- Establish smaller scale collaborations with individual investigators and research groups to work on more narrowly focused problems, such as turbulence.
- Expose students and postdocs to opportunities at the NNSA national security laboratories.

Program Integration:

ONE PROGRAM—THREE LABORATORIES

The problems that ASCI will solve for the Stockpile Stewardship Program span the activities and responsibilities of the three Defense Programs national security laboratories (Los Alamos, Sandia, and Lawrence Livermore). Cooperation among the Defense Programs laboratories is essential to solving these problems in an efficient and effective manner. In accordance with this cooperative philosophy, representatives of the laboratories participated in the development of this plan. There has been and will continue to be unprecedented cooperation among the three Defense Programs laboratories. ASCI will be implemented by project leaders at each of the laboratories guided by DP's Office of Research, Development, and Simulation through its Office of Advanced Simulation and Computing, under the Deputy Administrator for Defense Programs. The Defense Programs laboratories will share ASCI code development, computing, storage, visualization, and communication resources across laboratory boundaries in joint development efforts.

INTEGRATION STRATEGIES

- Operate ASCI as a single, three-laboratory program activity with seamless management and execution across the laboratories.
- Sponsor annual principal investigator meetings.
- Collaborate on development and share hardware and software resources.
- Take maximum advantage of standard tools, common system structures, and code portability to enable interlaboratory collaboration.

Figure 24 Four unique facilities are being built for ASCI. The Strategic Computing Complex (SCC—upper left, currently under construction) will house *Q* and follow-on platforms at Los Alamos. The Terascale Simulation Facility (TSF—upper right) will be built at Lawrence Livermore to house future platforms starting with the 60-teraOPS machine in 2004. The Joint Computational and Engineering Laboratory (JCEL—lower left) will house equipment and activities associated with high-performance computing, communications, and computer-aided design and engineering at Sandia's New Mexico site. The Distributed Information Systems Laboratory (DISL—lower right) will allow seamless, secure, and reliable access to information at Sandia's California site.

ASCI Facilities

The unprecedented reliance put upon numerical simulation by the Stockpile Stewardship Program and the resulting demands on ASCI are forcing a transformation in the way computing is viewed, employed, and advanced. Simulation environments are needed that develop a seamless partnership between the ability to generate data and the ability to assimilate it at the terascale. The simulations being developed by ASCI today promise a level of physical and numerical accuracy that will provide a credible substitute for large-scale experiments. To this end, four unique new facilities are planned to create the simulation environments that will go beyond traditional computer centers.

Strategic Computing Complex (SCC), Los Alamos National Laboratory, NM

The SCC is a three-story structure with approximately 303,000 gross square feet that will initially house ASCI Q in a specially designed 43,500 net square-foot computer room. Electrical and mechanical rooms occupying over 60,000 square feet will support the computer room. SCC can be upgraded to accommodate a 100-teraOPS-class system. The SCC and its associated infrastructure of high-speed networks, workstations, visualization centers, interactive data-analysis tools, and collaborative laboratories will support the Stockpile Stewardship Program through simulations of complex phenomena of national importance.

The SCC will provide a dynamic environment for approximately 300 nuclear weapons designers, computer scientists, and code developers to collaborate to extend the cutting edge of simulation and modeling development in support of nuclear weapons stockpile stewardship requirements. These scientists and engineers will work together, with support personnel, in simulation laboratories. The facility will be located in Technical Area 3 (TA-3) at the Los Alamos National Laboratory.

SCC is currently under construction. The computer room is expected to be ready in September 2001, and the offices ready for occupancy in December 2001.

TERASCALE SIMULATION FACILITY (TSF), LAWRENCE LIVERMORE NATIONAL LABORATORY, CA

The TSF will consist of a two-story computing facility with power and space capable needed to accommodate the next ASCI "flagship" systems in the 2004 timeframe; assessment areas and networking control areas necessary for direction and assimilation of data; a four-story office structure for staff to manage and utilize the simulation environment. The TSF is designed to provide a uniquely capable simulation environment both to generate and to assess the petabytes (1015 bytes) of data that will be the product of the emerging ASCI three-dimensional weapons science codes. This is necessary to ensure the safety and reliability of America's nuclear stockpile.

The TSF features two 23,000-square-foot machine rooms to allow for siting and stabilization of a new system, while an existing system continues to provide user access. The TSF will guarantee our capability to site any system required by the program, and ultimately (after its final implementation phase) have the capability of siting two such systems simultaneously.

The TSF will feature the Advanced Simulation Laboratory. The center will function more like an experimental facility than a computer center, supporting intense cooperation between staff and analysts. Round-the-clock support for major runs, restart capability for huge images, and on-the-fly troubleshooting will support a mode of operations where "runs" will be viewed as "shots," requiring intense support to succeed.

The TSF will house a consolidated Networking Operations Center integrated into Lawrence Livermore backbone, providing for the scalable system area networks to permit smooth functioning of remote DVC assessment theaters

TSF is currently in design; Title I design is scheduled to be complete in May 2001. Availability of the first computer area has been scheduled for December 2003 but may be delayed pending resolution of the FY2002 budget.

JOINT COMPUTATIONAL ENGINEERING LABORATORY (JCEL), SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM

JCEL is a critical element for Sandia to achieve validated, full-physics, high-fidelity computational analyses for nuclear weapons. The need for JCEL lies with our ASCI requirement to provide computational analyses from concept through design through aboveground component and subsystem testing to achieve safety, reliability, and security of the nuclear stockpile. JCEL will house equipment and activities associated with ASCI high-performance computing, communications, and computer-aided design and engineering. JCEL will promote rapid development and application of modeling and simulation tools needed to support science-based stockpile stewardship and stockpile management. The facility will meet top secret restricted data (TSRD) classification requirements.

JCEL is currently in design; Title I design is scheduled to be complete in June 2001. The facility has been scheduled for completion in September 2003 but may be delayed pending resolution of the FY2002 budget.

DISTRIBUTED INFORMATION SYSTEMS LABORATORY (DISL), SANDIA NATIONAL LABORATORIES, LIVERMORE, CA

The Distributed Information Systems Laboratory (DISL) will house research and development activities focused on information and network technologies at Sandia's site in California. This facility will be used to provide technologies to allow seamless, secure, and reliable access to information and allow integration and preservation of that information throughout the nuclear weapons complex. It will provide special facilities to enable development of a distributed information systems infrastructure that will later be deployed across the Nuclear Weapons Complex to enable collaborative design and manufacturing utilizing ASCI-scale computational capabilities. The facility will meet TSRD classification requirements.

DISL is currently in design; Title I design is scheduled to be complete in April 2001. The facility has been scheduled for completion and acceptance in April 2004 but may be delayed pending resolution of the FY2002 budget.

Program Management

Program Management Objectives

ASCI program management has two important objectives:

- **Provide leadership.** ASCI is developing computational capabilities that are critical to the Stockpile Stewardship Program. It must accomplish its mission on time and on budget. The ASCI management structure must enhance the work at the Defense Programs laboratories, keeping it focused on the ASCI mission. It must also ensure that resources are properly directed. The success of the program depends on the laboratories, the computer industry, and universities. The ASCI management structure must provide leadership to engage the computer industry and universities in the quest for simulation capabilities that can be incorporated into laboratory capabilities that will replace nuclear testing.

- **Facilitate the interactions among the laboratories.** ASCI is breaking new ground in the degree of collaboration among the laboratories. The ASCI management structure must understand and eliminate barriers that inhibit collaboration.

Program Management Planning Process

ASCI program management uses the following planning process:

- **ASCI Program Plan.** The Program Plan (this document) provides the overall direction and policy for ASCI. It serves as the strategic plan for the program and identifies the key issues and work areas for ASCI.

- **ASCI Implementation Plan.** This plan is prepared annually and describes the work planned at each laboratory to support the overall ASCI objectives. The program element management teams ensure that the work at each laboratory is closely coupled with that of the other labs and prepare the implementation plans. The implementation planning effort begins in April and includes a coordination meeting in July in anticipation of the beginning of the fiscal year on October 1.

- **Program Milestones.** ASCI milestones are established using a tiered approach and consist of level-1, -2, and -3 milestones. The ASCI Executive Committee has established the most important milestones (level-1 milestones) of the program. Level-1 milestones demonstrate the completion of a major new capability by the program and are structured to provide integration across ASCI. The descriptions of the level-1 milestones are given in Appendix A. The Executive Committee reviews the schedule and content of the level-1 milestones at least annually to ensure alignment with the needs of DSW and the other Campaigns. As part of its review, the Executive Committee solicits feedback from the external peer review panel assigned to each level-1 milestone. The Executive Committee must approve changes to level-1 milestones before inclusion in the Program Plan. A formal external peer review is required for a level-1 milestone to determine whether the milestone was completed satisfactorily.

Level-2 milestones demonstrate the completion of advanced capabilities by the program. These milestones directly support the completion of a level-1 ASCI milestone, a major Campaign milestone, or a DSW deliverable. The cognizant program-element management team establishes level-2 milestones. The level-2 milestones are reviewed annually and revised as part of the development of the annual Implementation Plan. Descriptions of the level-2 milestones are included in the Implementation Plan. Appropriate internal or external review of the level-2 milestones is encouraged, but formal review is not required.

Level-3 milestones demonstrate the completion of important capabilities within a program element and measure technical progress at the subprogram level. Typically, level-3 milestones directly contribute to level-2 milestones. Subprogram leaders working closely with the program element managers establish level-3 milestones. These milestones are updated periodically and are documented in the internal laboratory plans.

Progress on level-1 and -2 milestones, as listed in the published Implementation Plan, is reported quarterly. Internal tracking and progress at the

Figure 25

The Executive Committee quarterly meetings and biweekly teleconferences are critical to our integrated, Tri-Lab management of the program. Shown here are the attendees of the October 10, 2000 meeting in Washington, D.C.

level-3 milestone phase enables the more visible level-1 and level-2 milestone progress to be tracked externally.

Performance Measurement

ASCI managers realize that the successful development of modeling and simulation capabilities depends, in part, upon an effective and suitable performance-measurement program. Yet, measuring the overall impact of a collection of research and development activities has been challenging because there is no widely recognized metric to measure their effectiveness. ASCI has adopted an approach that addresses this need by comparing actual output with planned output within a given year. This metric is referred to as the R&D Effectiveness Metric (EM).

This method is not only consistent with the University of California approach to developing performance metrics, but is also aligned with the Government Performance and Results Act of 1993. Developing realistic, but challenging, project milestones is the first step toward producing a meaningful EM. ASCI's annual implementation planning process ensures that project milestones are both cost-effective and fully integrated with all other ongoing and planned activities. Project metrics within a particular ASCI program element or strategy are aggregated showing overall performance for that strategy. Progress over time is demonstrated through the use of indexed metrics. Laboratory managers are responsible for both measuring and managing the performance of the projects within their purview. Each laboratory reports performance to ASCI Headquarters quarterly in the form of accomplishments and progress toward milestones.

The budget is reported and analyzed monthly by ASCI's laboratory-level resource analysts and by laboratory management. DP's cost-tracking procedures for ASCI projects are consistent with ASCI's fundamentally developmental nature. Funding and costs are tracked and reported at the program element level using DP's official Budget and Reporting classification codes and Financial Information System. These tracking systems are extended in greater detail down to the level of individual projects.

Organization

ASCI's structure is designed to foster a focused collaborative effort to achieve program objectives:

- **Executive Committee.** This body consists of two high-level representatives (a primary and alternate) from each laboratory and from ASCI Headquarters. The Executive Committee sets overall policy for ASCI, develops programmatic budgets, and provides oversight for the execution of the program.
- **Program Element Management Teams.** These teams are responsible for the planning and execution (through the management structures of individual laboratories) of the implementation plans for

each of the program elements: Applications, V&V, Materials and Physics Modeling, Problem-Solving Environment, DisCom², PathForward, VIEWS, Physical Infrastructure and Platforms, Ongoing Computing, Alliances, Institutes, and One Program/3 Labs. The program element management teams consist of two representatives (a primary and alternate) from each laboratory, and the corresponding program area manager from ASCI Headquarters.

- **ASCI Headquarters Team.** This team consists of Defense Programs Federal employees supported by representatives from the Defense Programs laboratories and plants. The ASCI Headquarters team is responsible for ensuring that the program supports the overall Stockpile Stewardship Program. The ASCI Headquarters team facilitates the program's interactions with other government agencies, the computer industry, and universities. Finally, the team sets programmatic requirements for the laboratories and reviews management and operating contractor performance.

Program Collaboration Meetings

ASCI holds the following meetings as part of its leadership role and to facilitate collaboration among the three laboratories, industry, and universities:

- **Principal Investigator meetings.** These meetings are held annually and provide a forum for ASCI principal investigators to meet and discuss progress on their research areas. These meetings foster collaborations by allowing principal investigators at each laboratory to present and discuss their work with their peers at the other laboratories. The meetings (which include participants from outside of the weapon labs) also serve a peer-review function. These meetings provide an annual technical review for the ASCI HQ team.

- **Executive Committee meetings.** Every two weeks, the ASCI Executive Committee meets via teleconference to discuss important issues. These meetings will ensure that relevant issues are identified, discussed, and resolved in a timely manner. The biweekly teleconferences are supplemented with quarterly face-to-face meetings.

Program Reviews

ASCI regularly conducts external technical reviews of the program. These reviews add immense value by providing critical insights into the technical progress of the program. A Blue Ribbon Panel, currently chaired by Dr. Venkatesh Narayanamurti of Harvard, has been formed to conduct periodic reviews of the program. In addition, an external peer review panel has been formed for each major technical element of the program. These panels consist of experts in the technical fields relevant for each level-1 milestone. A principal role for these panels is to verify the completion of level-1 milestones.

Appendix A: Level-1 Milestones

Appendix A: Level-1 Milestones

ASCI level-1 milestones are first listed in this section by an identification label, the quarter in which they are to be completed, and a title. Following that list, a brief description is provided of each milestone. Completed milestones are displayed as grayed text to show accomplishments. The identification label identifies the milestone in the following way: milestone "NA-2.1" is the first (".1") milestone to be completed in the area of Nuclear Applications ("NA") in the year 2002 ("2").

Nuclear Applications

NA-0.1	FY2000 Q1	Three-dimensional primary-burn prototype simulation (review completed January 10, 2000)
NA-1.1	FY2001 Q1	Three-dimensional secondary-burn prototype simulation (review completed August 1–4, 2000)
NA-2.1	FY2002 Q1	Three-dimensional prototype full-system coupled simulation
NA-3.1	FY2003 Q1	Three-dimensional high-fidelity-physics primary-burn simulation, initial capability
NA-4.1	FY2004 Q1	Three-dimensional high-fidelity-physics secondary-burn simulation, initial capability
NA-4.2	FY2004 Q4	Three-dimensional high-fidelity-physics full-system simulation, initial capability

Nuclear Safety

NS-2.1	FY2002 Q4	Three-dimensional safety simulation of a complex abnormal explosive-initiation scenario

Nonnuclear Applications

NN-0.1	FY2000 Q2	Three-dimensional prototype hostile-environment simulation (review completed May 23–24, 2000)
NN-1.1	FY2001 Q4	STS normal environment prototype simulation
NN-2.1	FY2002 Q4	STS abnormal environment prototype simulation
NN-3.1	FY2003 Q4	Coupled STS hostile environment simulation
NN-5.1	FY2005 Q4	Full-system STS environment simulation

Verification and Validation

VV-1.1	FY2001 Q2	Demonstrate initial validation methodology on the then-current state of application modeling of early-time primary behavior
VV-5.1	FY2005 Q1	Demonstrate initial uncertainty quantification assessments of ASCI nuclear and nonnuclear simulation codes

Materials and Physics Modeling

PM-2.2	FY2002 Q4	Delivery of initial macro-scale reactive flow model for high-explosive detonation derived from grain-scale dynamics

VIEWS

VU-0.1	FY2000 Q1	Prototype system that allows weapons analysts to see and understand results from three-dimensional prototype primary-burn simulations (review completed January 10, 2000)
VU-4.1	FY2004 Q4	Ability to do real-time analysis on an ASCI dataset

PSE

PS-1.1	FY2001 Q1	Initial software development environment extended to the 10-teraOPS system (completed pending review scheduled April, 2001)

DisCom^2

DC-1.1	FY2001 Q2	Distance-computing environment available for use on the 10- teraOPS ASCI system
DC-3.1	FY2003 Q4	Complex-wide infrastructure that integrates all ASCI resources

Physical Infrastructure and Platforms

PP-0.1	FY2000 Q3	10-teraOPS system (*White*), final delivery and checkout (completed 09/00)
PP-2.1	FY2002 Q3	30-teraOPS system (*Q*), final delivery and checkout
PP-3.1	FY2003 Q4	20-teraOPS system (*Red Storm*), final delivery and checkout
PP-4.1	FY2004 Q1	60-teraOPS system (Lawrence Livermore), final delivery and checkout
PP-5.1	FY2005 Q2	100-teraOPS system (Los Alamos), final delivery and checkout

Nuclear Applications

NA-0.1 FY2000 Q1 review completed January 10, 2000

Three-dimensional primary-burn prototype simulation

By December 31, 1999, the ASCI project will make a prototype calculation of the explosion of a primary with three-dimensional engineering features. The simulation will produce relevant information, including a yield that will be compared to a nuclear test.

(A more detailed description of this milepost is available on request from the DP Office of Advanced Simulation and Modeling.)

NA-1.1 FY2001 Q1 review completed August 1–4, 2000

Three-dimensional secondary-burn prototype simulation

By December 31, 2000, the ASCI project will make a prototype calculation of the explosion of a secondary with three-dimensional engineering features. The simulation will produce relevant information, including a yield that will be compared to a nuclear test.

(A more detailed description of this milestone is available on request from the DP Office of Advanced Simulation and Modeling.)

NA-2.1 FY2002 Q1

Three-dimensional prototype full-system coupled simulation

By December 31, 2001, the ASCI project will make a prototype calculation of the explosion of a full weapon system (primary + secondary) with three-dimensional features. The simulation will produce relevant information, including the primary and secondary yields that will be compared to a nuclear test.

(A more detailed description of this milestone is available on request from the DP Office of Advanced Simulation and Modeling.)

NA-3.1 FY2003 Q1

Three-dimensional high-fidelity-physics primary-burn simulation, initial capability

By December 31, 2002, the ASCI project will make a high-fidelity-physics calculation of the explosion of a primary system with three-dimensional features. The simulation will produce relevant information, including the primary yield, that be compared to a nuclear test.

(A more detailed description of this milestone is available on request from the DP Office of Advanced Simulation and Modeling.)

NA-4.1 FY2004 Q1

Three-dimensional high-fidelity-physics secondary-burn simulation, initial capability

By December 31, 2003, the ASCI project will make a high-fidelity-physics calculation of the explosion of a secondary system with three-dimensional features. The simulation will produce relevant information, including the secondary yield that will be compared to a nuclear test.

(A more detailed description of this milestone is available on request from the DP Office of Advanced Simulation and Modeling.)

NA-4.2 FY2004 Q4

Three-dimensional high-fidelity-physics full-system simulation, initial capability

By September 30, 2004, the ASCI project will make a high-fidelity-physics calculation of the explosion of a full weapon system (primary + secondary) with three-dimensional features. The simulation will produce relevant information, including primary and secondary yields that will be compared to a nuclear test.

(A more detailed description of this milestone is available on request from the DP Office of Advanced Simulation and Modeling.)

(The development of this milestone was based on the original platform strategy that featured the availability of a 100-teraOPS platform for one year. As noted in the discussion under the Physical Infrastructure and Platforms section of this document, current budget projections have resulted in a new platform strategy wherein the 100-teraOPS system assumed to be available for this milestone has been replaced with a 60-teraOPS system available for much less than one year. The program is still reviewing the impact on this milestone of the revised platform strategy.)

Nuclear Safety

NS-2.1 FY2002 Q4

Three-dimensional safety simulation of a complex abnormal explosive-initiation scenario

By the third quarter of fiscal 2002, the ASCI project will calculate a three-dimensional nuclear safety simulation of a complex abnormal initiation of the high explosive in a nuclear weapon using advanced high explosive models. The hypothetical initiation scenario will be more complex than in previous nuclear safety simulations. The simulation will produce information that will be compared with relevant nuclear and nonnuclear test data.

(A more detailed description of this milestone is available on request from the DP Office of Advanced Simulation and Modeling.)

Nonnuclear Applications

NN-0.1 FY2000 Q2 review completed May 23-24, 2000

Three-dimensional prototype hostile environment simulation

This milepost will be a demonstration of ASCI software for three-dimensional dynamic response of a re-entry vehicle system to hostile radiation and blast environments. This initial simulation capability will include three-dimensional weapon geometry, but with limited physics, and limited physics and mechanics coupling. Included are models for the following hostile environments: (1) blast and impulse loading which can potentially result in structural damage to the weapon system and components; (2) photon radiation transport which can penetrate the weapon structure, depositing energy at critical component locations which can potentially result in thermal-mechanical damage; and (3) photon radiation transport which can penetrate the weapon structure, producing electrons which can potentially result in electrical damage to the components.

In this simulation we will demonstrate ASCI software for a typical re-entry vehicle in nuclear environments, but with limited physics to three scenarios above:

- Full three-dimensional re-entry vehicle structural response to blast and impulse loading with mesh discretization in sufficient detail to predict internal component shock response.
- Three-dimensional Monte Carlo determination of dose, and thermal-mechanical response of a typical weapon component.
- Simulations will be performed on the ASCI Red TOPS Supercomputer utilizing at least 2000 processors.

Verification of software will continue within ASCI Applications code team, and gathering of experimental data for mechanics and physics validation will continue as the central thrust of the Hostile Certification Campaign. This milepost is critical to successful completion of a succeeding milepost for full STS hostile simulation capability.

NN-1.1 FY2001 Q4

STS normal environment prototype simulation

This level-1 milestone will be a demonstration of ASCI software for key three-dimensional mechanical responses of a re-entry vehicle system to normal flight environments. Supporting this milestone will be level-2 milestones that demonstrate the electrical response and other mechanical responses of a re-entry vehicle system to normal flight environments. This initial simulation capability will include three-dimensional weapon geometry, but with limited mechanics and physics. Level-1 milestone capabilities include:

- **Launch & Re-Entry:** Three-dimensional vehicle structural response including eigen-solutions for launch, nonlinear implicit transient dynamics for re-entry body separation shock, and re-entry random vibration. Key nonlinear features such as joint interface models required to capture the essential dominant structural response will be included.
- **Impact:** Three-dimensional shock physics and electromechanical response of contact fuse operation at termination of flight.

Simulations should be performed on an ASCI supercomputer using a processor count that is appropriate for the size of the selected problem. In this context, "appropriate" means that enough processors have been used so as to obtain an acceptable execution time while maintaining reasonable parallel efficiency of the entire calculation. In addition, studies should be performed to determine the overall computational efficiency for a selection of problem sizes and processor counts. To minimize execution times, these studies may be performed for brief time intervals or subsets of the problem's physical models, or both. The intent of these studies should be to reveal what ranges of processor counts yield efficient machine utilization as a function of problem size.

Supporting the level-1 milestone are level-2 milestones that include:

- Subsystem electrical circuit simulation of AF.
- Three-dimensional electromagnetic response of the radar fusing for radar front end and height of burst.
- Three-dimensional nonlinear dynamics for physics package response during re-entry.

In addition, this milestone will require support from all of the ASCI program elements. These activities include:

- From ASCI Platforms, support and availability on ASCI White. A stable production capable machine must exist three months prior to the completion of the level-1 aspects of this milestone.
- From ASCI DisCom^2, high speed network connectivity from Sandia to ASCI White.
- From ASCI PSE, stable DFS.
- From ASCI V&V, initial validation calculations of the existing material models.
- From ASCI M&PM, integration of subgrid models into ASCI codes.
- From ASCI Algorithms, mesh support from Cubit.
- From ASCI VIEWS, visualization support for large data sets and desktop visualization.
- From Weapon System Engineering Certification Campaign, support for validation experiments.

Verification of software will continue within ASCI Applications code team, and gathering of experimental data for mechanics and physics validation will continue as the central thrust of the Weapon System Engineering Certification Campaign. This level-1 milestone is critical to successful completion of a succeeding milestone for full STS simulation capability.

NN-2.1 FY2002 Q4

STS Abnormal Environment Prototype Simulation

(Thermal and Structural Safety Analyses [Crash and Burn])

This level-1 milestone will consist of a set of three three-dimensional calculations for an STS Abnormal Environment crash and burn accident involving a nuclear weapon. The level-1 milestone simulations will include three-dimensional system and component geometry, with subgrid physics models that have been validated at a preliminary level.

Calculations will be performed at certification resolution. The certification-level analyses will expand the accuracy of previous analyses via new capabilities such as mesh adaptivity, robust contact algorithms, and improved coupling of enclosure radiation and conduction.

The simulation capabilities will be under the software control of the Sandia ASCI application SIERRA framework. Three calculations addressing different aspects of a crash and burn accident will be completed.

1. Accidental Drop of Warhead: demonstrate transient dynamics capability for nonlinear multimaterials with robust contact to predict deformations resulting from an accidental drop for assessment of system structural integrity.
2. Pool Fire Accident (Weak Link/Strong Link Thermal Race): demonstrate nonlinear, multimaterial, multielement thermal conduction coupled with enclosure radiation to evaluate the weak link/strong link thermal race during a fire accident consisting of an engulfing or directed fire environment to be specified in terms of a heat flux. This simulation will include foam decomposition, robust contact, and adaptivity.
3. Pool Fire Accident (HE Chemistry Issues): demonstrate nonlinear, multimaterial thermal conduction coupled with enclosure radiation and HE chemistry to evaluate HE thermal decomposition during a fire accident to be specified in terms of a heat flux. This simulation will include robust contact and adaptivity.

Simulations should be performed on an ASCI supercomputer using a processor count that is appropriate for the size of the selected problem. In this context, "appropriate" means that enough processors have been used so as to obtain an acceptable execution time while maintaining reasonable parallel efficiency of the entire calculation. In addition, studies should be performed to determine the overall computational efficiency for a selection of problem sizes and processor counts. To minimize execution times, these studies may be performed for brief time intervals or subsets of the problem's physical models, or both. The intent of these studies should be to reveal what ranges of processor counts yield efficient machine utilization as a function of problem size.

Level-2 milestones that will support this level-1 milestone are:

- Validation of the polyurethane foam decomposition model and HE decomposition models including V&V support for validation simulations and Weapon System Engineering Certification Campaign support for experiments.
- Mesh support from Cubit for detailed structural and thermal models.
- Visualization support for large data sets and desktop visualization.
- ASCI code development for Calore (thermal analysis: parallel contact, adaptivity, element death).
- ASCI code development for Presto (explicit dynamics: material models, element death, parallel contact).
- ASCI code development for Sierra framework (load balancing, I/O for topological changes in mesh, element death with inherited boundary conditions for meshes including shells).

In addition, this milestone will require support from all of the ASCI program elements. These activities include:

- From ASCI Platforms, a stable production capable machine must exist three months prior to the completion of the level-1 aspects of this milestone.
- From ASCI DisCom^2, high speed network connectivity from Sandia to other ASCI platforms.
- From ASCI PSE, stable DFS.
- From ASCI V&V, initial validation calculations of the existing material models.
- From ASCI M&PM, integration of subgrid models into ASCI codes.
- From ASCI Algorithms, mesh support from Cubit.
- From ASCI VIEWS, visualization support for large data sets and desktop visualization.
- From Weapon System Engineering Certification Campaign, support for validation experiments.

Verification of software will continue within ASCI Applications code team, and gathering of experimental data for mechanics and physics validation will continue as the central thrust of the Weapon System Engineering Certification Campaign. This level-1 milestone is critical to successful completion of the FY2005 milestone for full STS simulation capability.

NN-3.1 FY2003 Q4

Coupled STS hostile environment simulation

This level-1 milestone will be a demonstration of ASCI software to compute the three-dimensional coupled mechanical response of a weapon system in hostile (nuclear) environments. The level-1 milestone capabilities will be demonstrated in four types of calculations:

1. Three-dimensional blast.
2. Three-dimensional impulse.
3. Thermo-structural response coupled with three-dimensional Monte Carlo radiation transport determination of energy deposition.
4. Three-dimensional adjoint Monte Carlo radiation transport determination of dose.

For blast, impulse, and thermo-structural response, a full three-dimensional model of the re-entry vehicle will be used with mesh discretization sufficient to resolve shock response and thermo-structural response in critical weapon components. For radiation transport, geometry information will be obtained from full three-dimensional CAD models of the weapon system.

Integration into an architectural framework, to accommodate alternative solver strategies and datasets employed, will be demonstrated for the coupled-physics simulations.

Simulations should be performed on an ASCI supercomputer using a processor count that is appropriate for the size of the selected problem. In this context, "appropriate" means that enough processors have been used so as to obtain an acceptable execution time while maintaining reasonable parallel efficiency of the entire calculation. In addition, studies should be performed to determine the overall computational efficiency for a selection of problem sizes and processor counts. To minimize execution times, these studies may be performed for brief time intervals or subsets of the problem's physical models, or both. The intent of these studies should be to reveal what ranges of processor counts yield efficient machine utilization as a function of problem size.

Supporting this milestone will be a level-2 milestone that demonstrates the ability of ASCI software to compute the electrical response of a weapon system with limited physics, neutron-gamma radiation environments, and laboratory radiation sources that will be used for validation. The level-2 milestone will include:

- Cable SGEMP coupled with deterministic radiation transport evaluation of charge deposition.
- Three-dimensional electromagnetic response for cavity SGEMP.
- Response of an electrical circuit coupled with radiation transport.
- Coherent fratricide (neutron-gamma) radiation environment.
- Z-pinch wire array initiation for code validation.

In addition, both the level-1 and level-2 milestones will require support from all of the ASCI program elements. These activities include:

- From ASCI Platforms, stable production environments.
- From ASCI DisCom^2, high speed network connectivity.
- From ASCI PSE, stable DFS.
- From ASCI V&V, initial validation calculations.
- From ASCI M&PM integration of physics models into ASCI codes.
- From Radiation Effects Science, radiation-induced conductivity models for SGEMP.
- From ASCI Algorithms, mesh support from Cubit.
- From ASCI Views, visualization support for large data sets and desktop visualization.
- From Radiation Effects Science and Weapon System Engineering Certification Campaign, support for validation experiments and material property measurements.

Verification of software will continue within ASCI Applications code team, and gathering of experimental data for mechanics and physics validation will continue as the central thrust of the Weapon System Engineering Certification Campaign. Both the level-1 milestone and the level-2 milestone are critical to the successful completion of succeeding milestone for full STS hostile environment simulation capability.

NN-5.1 FY2005 Q4

Full-system STS environment simulation

This level-1 milestone will be a demonstration of ASCI software to compute the complete response of a weapon system in hostile (nuclear), abnormal, and normal environments. This level-1 milestone will complete a set of coupled physics calculations with three-dimensional-weapon system and component geometry. Significant validation of key subgrid physics models for each environment simulation will be completed, and physics coupling will be achieved through the SIERRA and ALEGRA frameworks. Accompanying this milestone will be level-2 milestones that support other elements of the electrical and mechanical responses to the STS environments. Level-1 milestone capabilities include:

- **Hostile:** Simulation of the response of subsystem electrical circuits of the AF during a hostile attack. Hostile simulation will include three-dimensional cavity SGEMP coupled with three-dimensional radiation transport in the re-entry system to evaluate photoemission from cavity surfaces, cable SGEMP coupled with three-dimensional deterministic radiation transport, and three-dimensional Monte Carlo radiation transport determination of x-ray fluence levels at circuit-board locations.

- **Abnormal:** Coupled thermal response to a pool fire environment simulation for both engulfing and directed fuel fires. Fire simulation will include turbulent, buoyantly driven flow and combustion, with soot formation and participating media radiation. Nonlinear, multimaterial thermal conduction coupled with enclosure radiation will be used to evaluate the weak link/strong link thermal race in the fire environment. Simulations will include validated ablefoam replacement decomposition model, robust contact, and adaptivity. Sensitivity coefficients will be calculated for thermal material properties.
- **Normal:** Determination of NEP response to steady and unsteady boundary conditions including simulation of nonlinear dynamics and damping, characterization of pyroshock loading, re-entry random pressure fields, and launch random base acceleration mechanics. Key single mechanics validation will include elasticity and plasticity of NEP materials, friction modeling and sliding contact.

Simulations should be performed on an ASCI supercomputer using a processor count that is appropriate for the size of the selected problem. In this context, "appropriate" means that enough processors have been used so as to obtain an acceptable execution time while maintaining reasonable parallel efficiency of the entire calculation. In addition, studies should be performed to determine the overall computational efficiency for a selection of problem sizes and processor counts. To minimize execution times, these studies may be performed for brief time intervals or subsets of the problem's physical models, or both. The intent of these studies should be to reveal what ranges of processor counts yield efficient machine utilization as a function of problem size.

Supporting the level-1 milestone are level-2 milestones that include:

- Mechanical response to hostile attack, including the effects of blast and impulse modeling. Thermostructural response will be modeling with an end-to-end coupling of three-dimensional Monte Carlo radiation transport evaluation of energy deposition, followed by transient dynamics and structural mechanics. Thermomechanical response will be modeled with an end-to-end coupling of three-dimensional Monte Carlo radiation transport with transient dynamics.
- Simulation of the radiation response of semiconductor devices using a device physics code coupled to three-dimensional deterministic radiation transport to evaluate energy deposition in active areas and neutron-gamma radiation transport to evaluate charge deposition in semiconductor active areas.
- Z-pinch wire array initiation for code validation.
- Transient dynamics capability for nonlinear, multielement, multimaterials to predict deformations resulting from an accidental drop to evaluate new fireset fasteners. Deformed geometry will be used in fire-accident analysis.
- Quasistatics coupled with conduction, enclosure radiation, and HE chemistry to evaluate confined HE thermal decomposition during a fire accident. Simulations will include a validated HE chemistry model, robust contact, and adaptivity.
- Determination of component shock and vibration environments from simulation of the weapon system response. Key features include nonlinear dynamics of bolted joints, and component mechanical interfaces including energy dissipation, internal dynamics of AF&F including ablefoam confinement of components and mechanical interfaces.
- Coupled H-Adaptive arbitrary Lagrangian Eulerian simulation to predict output voltage of Impact Fuse Assembly followed by neutron generator standoff with validated constitutive models for structural alloys, and polymeric foams. This includes predicting the effects of piece-part and assembly variability.
- Determination of electrical system response including thermal effects for the weapon system AF&F. Key electrical and single mechanics validation includes thermal properties (including radiative) of key materials; effective properties of multilayered circuit boards and electronic components; heat dissipation from high heat flux components; convection in enclosures; and effective treatment of contact resistance.
- Three-dimensional electromagnetic response of the radar fusing for radar front end and height of burst. Response (i.e., induced pin-level voltages at the AF) of the weapon system to a range of high-frequency STS electromagnetic environments. Validated wire, slot, cable, and connector models will be used.

Validation data will be presented, but will be limited to single physics. Integration into architectural frameworks, which will accommodate the various alternative solver strategies and datasets employed, will be demonstrated for both the electrical and the mechanical simulations.

In addition, the level-1 and level-2 milestones will require support from all of the ASCI program elements. These activities include:

- From ASCI DisCom^2, high speed network connectivity from Sandia to ASCI platforms.
- From ASCI V&V, validation calculations of the subgrid physics models.
- From ASCI M&PM support for heat shield decomposition model development, ablefoam replacement decomposition model development, level set methods to describe foam recession, joint and friction models.
- From ASCI M&PM, integration of subgrid models into ASCI codes.
- From Radiation Effects Science, radiation-induced conductivity models for SGEMP.
- From ASCI Algorithms, mesh support from Cubit, new view factor algorithms and robust multi-level/multigrid solvers.
- From ASCI Apps, code development support for STS codes, geometry in Sierra and Sierra-based mechanics codes, and SIERRA, ALEGRA, and COMET framework support.
- From ASCI VIEWS, visualization support for large data sets and desktop visualization.
- From Weapon System Engineering Certification Campaign and Radiation Effects Science, support for validation experiments in support of M&PM and V&V activities.
- From DSW, support for staff to generate meshes and assist in running calculations as part of 6.2 and 6.3 programs.

Verification of software will continue within ASCI Applications code team, and gathering of experimental data for mechanics and physics validation will continue as the central thrust of the Weapon System Engineering Certification Campaign. This milestone is critical to successful completion of a succeeding milestone for fully validated STS simulation capability.

Verification and Validation

VV1.1 FY2001 Q2 review scheduled for July 2001

Demonstrate initial validation methodology of the current state of ASCI code modeling for early-time primary behavior

This milestone is a demonstration of the validation assessment methodology of the current state of ASCI code modeling capabilities applied to modeling of early primary behavior. The intent of the milestone is to demonstrate a validation assessment methodology early enough in the ASCI Code V&V process that this type of process can be productively applied to other modeling areas in the early phases of the FY2000–FY2005 ASCI Applications development timeframe. This assessment will involve one ASCI code at each nuclear laboratory.

This assessment will include comparisons of the code results to an agreed upon data suite. The current state of the physical models will be employed, and because the milestone occurs fairly early in the ASCI timeline, the models may not yet have many of the advanced physics or materials models in place. Quality of comparisons will be measured against current design/analysis standards for legacy codes.

Validation is a continuous process that occurs as new physics models and code features are incorporated and tested against theory or data. Therefore, the validation methodology is expected to evolve and improve over the course of ASCI.

The validation methodology and the results of the application of this process to the primary modeling capabilities will be documented.

VV-5.1 FY2005 Q1

Demonstrate initial uncertainty quantification assessments of ASCI nuclear and nonnuclear simulation codes

This milestone represents a demonstration of the process of uncertainty quantification of predictive capability based on several validation studies for selected ASCI nuclear and nonnuclear simulation codes. Such analysis would be physics domain specific and would involve sets of ongoing validation comparisons that drive uncertainty quantification analysis. Nuclear performance and nuclear safety codes would concentrate on NTS experiments, local experiments, and their diagnostics, while the nonnuclear codes would use appropriate engineering tests and experiments. These sets of validation studies would provide a basis for estimates of error bounds in ASCI simulations of selected problems of direct programmatic importance.

Materials and Physics Modeling

PM-2.2 FY2002 Q4

Delivery of initial macro-scale reactive flow model for high-explosive detonation derived from grain-scale dynamics

High explosives can have reactions resulting from external stimuli ranging from mild pressure bursts to full detonation. The ability to predict these responses is important for understanding the performance as well as the safety and the reliability of these materials. Currently, we have only relatively simple phenomenological computational models for the behavior of high explosives under these conditions. These models are limited by the assumption that the explosive is homogeneous. In reality the high explosive is a highly heterogeneous composite of irregular crystallites and plastic binder. The heterogeneous nature of explosives is responsible for many of their mechanical and chemical properties.

We will use computational models to simulate the response of explosives to external mechanical stimuli at the grain level. The ultimate goal of this work is to:

- Understand the detailed processes involved with the material response, so that we can.
- Develop realistic material models that can be used in a hydrodynamics/multiphysics code to model real systems.

The new material models will provide a more realistic description of the explosive system during the most critical period of ignition and initiation.

The focus of this work is to use the results of such simulations to develop an advanced macroscopic reactive flow model that is consistent with our understanding of the grain scale details, and can incorporate such information quantitatively.

VIEWS

VU-0.1 FY2000 Q1 review completed January 10, 2000

Prototype system that allows weapons analysts to see and understand results from three-dimensional prototype primary-burn simulations

The ASCI burn code milepost depends upon critical STS PSE and technologies for success. The focus of this milepost is on delivering data management, data delivery and data visualization services for end-user weapons designers that allow them to see and understand the multiterabyte datasets produced by the ASCI simulation codes.

Weapons designers must be able to:

- Efficiently store and access multiterabyte ASCI simulation results.
- Organize and manage these datasets.
- See and understand complex simulation results via graphical visualization and analysis tools.
- Share results with other weapons designers and code developers.

VU-4.1 FY2004 Q4

Ability to do real-time analysis on an ASCI dataset

The focus of this milestone is on delivering Data and Visualization Corridors that allow weapons designers to do real-time analysis of FY2004 ASCI simulation datasets to enable them to see and understand the simulation results. It is expected that the FY2004 ASCI simulation datasets will be as large as 200 terabytes. One often thinks of the storage and I/O systems of supercomputers, and the graphics workstations attached to them, as a thin pipe through which the data must be pumped. The idea of a "Corridor" is meant to suggest the opposite metaphor, a wide path through which massive quantities of data can easily flow, and through which scientists and engineers can explore data and collaborate. Thus, the Corridor is precisely the kind of infrastructure needed to fully support the ASCI "see and understand" mission.

A robust and efficient data handling system will be required that will allow FY2004 ASCI simulation datasets to be stored and accessed effectively and manipulated, compressed, filtered and subsetted down to a smaller size that can be efficiently handled by visualization and analysis tools at interactive rates. Subset operations may be in the form of one timeslice; selected variables across some set of timeslices, spatially cropped data, and sliced data (reduced dimensionality). Manipulations will include data resampling, derivations, multiresolution processing, and geometry extraction. Based on the ASCI curves, it is expected that the data will need to be reduced to 2.0TB to allow real-time interaction.

Key technologies required to meet this milestone include:

- High bandwidth interconnects connecting the simulation platform, hierarchical storage management, data engines and visualization engines within a laboratory and between laboratories.
- A robust set of data services that enable efficient manipulation and subsetting of data for subsequent real-time analysis.
- Data discovery and multiresolution analysis preprocessing systems that allow extraction of key user defined features of the datasets.
- High performance browsing tools that allow high-speed interaction with the preprocessed condensed data and allow selection of smaller subsets for further detailed analysis.
- Detailed visualization and analysis tools that can be applied to subsets of the original data sets.

PSE

PS-1.1 FY2001 Q1 review completed April 10–13, 2001

Initial software development environment extended to the 10-teraOPS system

The definition of the ASCI Problem Solving Environment (PSE) PS-1.1 milepost is to demonstrate that the software environment needed for development of the ASCI simulation codes is available and functional at the scale used for application mileposts. This allows the ASCI code developers to focus on application development. This milepost represents a partnership of the Tri-Lab ASCI PSE team working with the ASCI code teams, with IBM as the platform partner, and with third-party software developers to provide the needed environment.

This PSE milepost is the second of a series of ASCI *WHITE* mileposts:

- PP-0.1 Q3, FY2000 (Platforms).
- ASCI *White* final system delivery and checkout.
- PS-1.1 Q1, FY2001 (PSE).
- Initial simulation development environment extended to the ASCI *White* system.
- DC 1.1 Q2, FY2001 (DisCom^2).
- Distance-computing environment available for use on the ASCI *White* system.

The following broad-based functionality areas will demonstrate that the basic ASCI *WHITE* software environment system is ready for code development and execution. The full *WHITE* system is not necessary for this portion of the milepost; consequently these demonstrations will take place on the unclassified *SNOW* system with 128 P3 CPUs. *SNOW* is an unclassified Lawrence Livermore test system featuring the same environment as the *WHITE* system.

Code Capability Demonstration: Representative ASCI-related codes from all three labs will be built and will be run to show that all necessary components are functional:

- The compilers work for the standard language.
- The libraries are in place.
- The link-load can handle the application.
- The run-time system is operable.

These will be short code runs to produce output files for the I/O Capability Demonstration (see below). The codes are chosen to cover important aspects of the development environment, including languages (Fortran, C, and C++), mixed languages, parallel models (OpenMP and MPI), and key math libraries needed for the major ASCI applications.

I/O System Capability Demonstration: For codes utilized in the Code Capability Demonstration, the ability of the platform I/O and file system infrastructure to manage the capture and movement of simulation restart dumps and visualization files for subsequent analysis will be demonstrated:

- Demonstrate I/O from ASCI applications to the IBM general parallel file system (GPFS) disk. (The applications I/O may utilize intermediate I/O interfaces, or may perform GPFS calls directly.)
- Demonstrate I/O from GPFS disk to the HPSS archive disk using the transfer tools NFT/Endeavor or FTP/PFTP.
- Run the Lawrence Livermore I/O test suite to document the aggregate I/O throughput, tests for reliability (service and data integrity), and the interface functionality tests for GPFS, HDF5, MPI I/O, and HPSS on I/O patterns important to key ASCI applications. These tests demonstrate how we track quality and performance levels of these I/O resources.
- Support SIERRA code build on the ASCI *WHITE* system at Lawrence Livermore using DCE/DFS software to access the DFS code repository at Sandia.

Code Debugging and Tuning Demonstration: For selected codes in the Code Capability Demonstration, the availability and usability of tools for the common code development debug and run-time tuning functions will be demonstrated. All of the Lawrence Livermore codes will be used, and one code each from Los Alamos and Sandia will be used. Specifically, provide reports, screen dumps, and/or live demonstration of the following tool functionality:

- *Totalview debugger:* Demonstrate the features designed specifically for ASCI-type problems: mixed languages and mixed parallel models; data verification and anomaly detection; the command-line interface (CLI); and the filtering and measurement features aimed at increased scalability (e.g. window elimination and collapse).
- *Execution profiling:* Collect a performance profile for the application run—giving information about the percentage of time various code components use, and the relative load-balance across the tasks.
- *Performance tuning tools:* Exhibit output from tools for analysis of task/thread-level (e.g. hardware counter) performance and intertask communication characteristics.
- *MPI—OpenMP—pthreads:* Run the set of PSE tests for performance and functionality. These runtime products are commercially supplied products and the tests track quality of the products.
- *Memory usage debug/performance:* Demonstrate that memory-related tools (e.g. memory leak detection) are available.

Most ASCI code development activities take place at small numbers of processors to create and verify correct code, but there is also a nontrivial code development requirement that requires much larger-scale code runs. In particular, the PSE Milepost will repeat a subset of the tests defined above at scale at least to the CY00 Application Milepost requirements of 1500 processors. This can be achieved on the classified ASCI *WHITE* system. These at-scale demonstrations are described next.

Code Capability Demonstration at Scale: At least one ASCI-related code from each laboratory will be built and run at scale sufficient to meet the CY00 (NA-2.1 and NN-1.1) milepost requirement of 1500 processors. The purpose of this demonstration is to show the run-time system is operable at scale. These will be short code runs to produce output files for the I/O Capability Demonstration at scale.

I/O / File Capability Demonstration at Scale: For codes run in the Code Capability Demonstration at Scale, the ability of the I/O and file system infrastructure to manage the capture and movement of "milepost-scale" simulation restart dumps and full-resolution visualization files for subsequent analysis will be demonstrated.

- Demonstrate I/O at milepost scale from ASCI applications to GPFS disk. (The applications I/O may utilize intermediate I/O interfaces, or may perform GPFS calls directly.)
- Demonstrate I/O at milepost scale from GPFS disk to HPSS disk at varying file sizes, concurrency, and parallelism, using NFT/Endeavor or FTP/PFTP. This includes demonstration of an improved FTP interface that transparently invokes PFTP as required for higher data transfer rates on files larger than 1 gigabyte.
- Repeat the Lawrence Livermore I/O test suite to show aggregate I/O throughput, and tests for reliability (service and data integrity) for GPFS, HDF5, MPI I/O, and HPSS using the I/O configurations of milepost scale on I/O patterns important to key ASCI applications. These tests demonstrate how we track quality and performance levels of these I/O resources.

Code Development Debugging and Tuning Demonstration at Scale: For the codes in the Code Capability Demonstration at Scale, the basic debug and run-time tuning tools available for use at the 1500 processor milepost scale will be demonstrated. Specifically, provide reports, screen dumps, and/or live demonstrations of the following tool functionality:

- *Debugging:* Show the stack trace from a crashed code (examining a light weight core file) and the ability to examine a subset of processes, which are mixed language and mixed parallel models performing data verification and anomaly detection.
- *Execution profiling:* Collect a performance profile for the application run—giving information about the percentage of time various code components are using, and the relative load-balance across the tasks.

- *Performance tuning tools:* Run tools for analysis of task/thread-level (e.g. hardware counter) performance and cross-task communication statistics.
- MPI: Run the performance tests for analysis of scaling characteristics of important MPI functions for ASCI applications.

Selected Glossary Terms:

DCE:	Distributed Computing Environment—standard software for distributed computing.
DFS:	Distributed File System—part of DCE.
FTP/PFTP:	File transfer utilities, including parallel versions.
GPFS:	IBM's general parallel file system.
HDF5:	Hierarchical Data Format—standard file format used for ASCI parallel files usage.
HPSS:	High Performance Storage System—archive file system in use at ASCI sites.
MPI:	Standard Message Passing Interface.
NFT/Endeavor:	Lawrence Livermore persistent file transfer utilities.
OpenMP:	Standard set of directives for use with shared memory programming.
PSE:	Problem Solving Environment.
Pthreads:	Posix standard for thread programming.

DisCom^2

DC-1.1 FY2001 Q2 review completed April 10–13, 2001

Distance computing environment available for use on the 10-teraOPS ASCI system

The Distance Computing element of DisCom^2 extends the functionality and capability of ASCI resources to remote users. The environment will integrate the user environment components with secure, reliable, parallel data communications to meet the bandwidth requirements to provide 10 TOPS of remote computational capabilities.

Based on an analysis of the ASCI applications, 10 Gigabits/Second of network bandwidth will be made available to utilize 10 TOPS of computational resources. The requisite NSA approved type1 will be made available. The filters and gateways that limit the effective bandwidth between the ASCI resources will be eliminated in accordance with an approved security plan.

The DisCom^2 project has developed several data movement applications that can effectively utilize a parallel network. These applications are based on the standard tools that users are currently utilizing. (e.g. HPSS, SCP, FTP) Initial implementations of these applications are available today. Production releases of these applications will be delivered by Q2 FY2001.

There will be significant additional support requirements for both the remote user environment and the distance bandwidth. All of these areas will be in production operation by Q2 FY2001.

The DisCom^2 will synchronize the features within the distance computing environment to provide new capability in a stable environment to the user community. The environment addresses the user needs in the areas of problem setup, compilation, execution, visualization, as well as the I/O required. A system design activity will provide the interface for the DisCom^2 projects, operational & support projects, as well as other ASCI projects to provide the communication necessary for a tri-lab integrated release. For example, the synchronization will ensure that the parallel file I/O capability/feature and the parallel network capability/feature will be integrated appropriately for the user needs in the areas specified above.

(A more detailed description of this milestone is available on request from the DP Office of Advanced Simulation and Modeling.)

DC-3.1 FY2003 Q4

Complex-wide infrastructure that integrates all ASCI resources

By Q4 FY2003, DisCom^2 will develop and deploy infrastructure that integrates all of the ASCI computing resources into a flexible and adaptable distributed computing environment. The system will support a wide spectrum of the high-end modeling and simulation needs for design, analysis, manufacturing, and certification of nuclear weapons. The computing system spans high-end applications, resource management, ultracomputers, parallel wide-area and system-area networks, capacity clusters, visualization, and data services required by weapons simulations.

Meeting this milestone requires:

- Deployment of a secure production high-performance parallel wide-area network that interconnects the system-area networks in the machine rooms of the laboratories.
- Deployment of a robust distributed resource management system that brokers all of the required computing services.
- Deployment and integration of capacity clusters that complement the ultracomputers by providing simulation, visualization, and data services.
- An integrated approach to configuring the environments and to managing the allocation of the system's resources.

Each of these elements is described below.

By Q4 FY2003, a wide-area parallel network will be deployed with over 30 gigabit-per-second aggregate bandwidth among the three laboratories. This bandwidth will be aggregated from multiple lower bandwidth channels running in parallel. The parallel network architecture is composed of multiple simultaneous channels in parallel, low-cost high-performance network interface cards, OS bypass mechanisms, and wave division multiplexing in the wide area. Interim milestones in DisCom^2 provide for the development and integration of these capabilities into a manageable network that extends the high-end secure system-area networks for the ASCI machines across the wide area.

By Q4 FY2003, distributed resource management (DRM) will be deployed among the three laboratories that simplifies the way users interact with simulation and supporting resources. DRM will provide the resource management infrastructure complex-wide for the discovery, reservation, allocation, monitoring, and control of geographically distributed resources. The resources comprising the complex-wide secure intranet include heterogeneous computing, communication, storage, visualization, data, and software resources. Users must receive consistent, fair, and responsive access to resources regardless of location. DRM must achieve high utilization of all resources. This service may be limited due to enhanced security requirements and new policy limitations.

By Q4 FY2003, a robust and broad set of simulation services will be deployed in commodity clusters. Clusters at both Sandia sites will be tightly integrated together and have an aggregate computing capacity of over 3000 nodes. Commodity web and computing technologies will be configured to utilize the clusters to provide integration of many product and process design tools. This will enable delivering the capabilities of the interconnected design tools and data to the designer's desktops in both classified and unclassified network environments. Bringing together simulation, product design data, and computational services will help to reduce product cycle time, cost, and defects. Collectively, these resources provide an "information and simulation nuclear weapons complex intranet".

By Q4 FY2003, DisCom^2 will coordinate an integrated approach to configuration management and system allocation. At a minimum, the features supported by the system will be documented to provide understanding to the user community of what is available and additionally will provide a mechanism for reporting and tracking bugs. A tri-lab configuration management process will be coordinated to ensure technical integration of the resources.

Physical Infrastructure and Platforms

PP-0.1 FY2000 Q3 completed September 2000

10-teraOPS system (*White*), final delivery and checkout

The ASCI *White* MuSST SMP cluster (multiple sustained stewardship teraOPS, symmetric multiprocessor) cluster forms the third major step along the ASCI Platforms curve. Developed by IBM and being sited at Lawrence Livermore, the MuSST PERF system will enjoy in excess of 10.2 teraOPS of computing capability, 4.0 TB of memory and 150 TB global disk to ASCI classified ultrascale code development and programmatic activities.

Installation of ASCI *White* will proceed in a phased manner for both hardware and software. During the second quarter of FY2000, the vendor will demonstrate the operation of the MuSST system, with 4.0 TB of SDRAM memory, meeting the requirements with a laboratory-supplied benchmark. The demonstration milepost represents an early exhibition of system capability. In the following quarter, checkout and testing will occur using compact applications run in parallel on the entire system, and the system will be exercised with selected nuclear weapons application(s) and selected verification problem(s).

PP-2.1 FY2002 Q1

30-teraOPS system (*Q*), final delivery and checkout

The delivery and installation of the 30-teraOPS system to Los Alamos National Laboratory is the fourth important milestone in the implementation of ASCI's platform strategy. The 30-teraOPS system will be delivered and installed at Los Alamos during the first quarter of FY2002. Once installed, the system will be tested and demonstrated in two important ways.

First, a set of compact applications will be run in parallel on the entire installed system. This initial test will serve as a test of the operational status of the full system.

Second, the system will be exercised with selected nuclear weapons application(s) and selected verification problem(s). These tests will serve as an initial check of system functionality.

It should be noted that this milestone assumes a specific contract delivery date and corresponding peak performance rate. Options exist for later delivery with corresponding higher performance. If one of these options is selected, the specifics of this milestone will be modified.

PP-3.1 FY2003 Q4

20-teraOPS system (*Red Storm*), final delivery and checkout

ASCI *Red Storm*, a 20-teraOPS system, will be delivered and installed at Sandia by FY2003, a significant upgrade to the computing resources at Sandia. Once installed, the system will be tested and demonstrated in two important ways.

First, a set of compact applications will be run in parallel on the entire installed system. This initial test will serve as a test of the operational status of the full system.

Second, the system will be exercised with selected nuclear weapons application(s) and selected verification problem(s). These tests will serve as an initial check of system functionality.

It should be noted that this milestone assumes a specific contract delivery date and corresponding peak performance rate. System delivery dates are expected to differ between various potential vendor partners, depending on the individual vendor's business plans. The performance and delivery dates noted here is a nominal strategy. Exact dates and performance values will be obtained in the procurement process, and later deliveries are anticipated to result in higher performance numbers.

PP-4.1 FY2004 Q1

60-teraOPS system (Lawrence Livermore), final delivery and checkout

A 60-teraOPS system will be delivered and installed at Lawrence Livermore by FY2004. Once installed, the system will be tested and demonstrated in two important ways.

First, a set of compact applications will be run in parallel on the entire installed system. This initial test will serve as a test of the operational status of the full system.

Second, the system will be exercised with selected nuclear weapons application(s) and selected verification problem(s). These tests will serve as an initial check of system functionality.

It should be noted that this milestone assumes a specific contract delivery date and corresponding peak performance rate. System delivery dates are expected to differ between various potential vendor partners, depending on the individual vendor's business plans. The performance and delivery dates noted here is a nominal strategy. Exact dates and performance values will be obtained in the procurement process, and later deliveries are anticipated to result in higher performance numbers.

PP-5.1 FY2005 Q2

100-teraOPS system (Los Alamos), final delivery and checkout

The delivery and installation of the 100-teraOPS system by FY2005 is the milestone that completes the ASCI platform goal of implementing a 100-teraOPS computing platform. Once installed, the system will be tested and demonstrated in two important ways.

First, a set of compact applications will be run in parallel on the entire installed system. This initial test will serve as a test of the operational status of the full system.

Second, the system will be exercised with selected nuclear weapons application(s) and selected verification problem(s). These tests will serve as an initial check of system functionality.

It should be noted that this milestone assumes a specific contract delivery date and corresponding peak performance rate. System delivery dates are expected to differ between various potential vendor partners, depending on the individual vendor's business plans. The performance and delivery dates noted here is a nominal strategy. Exact dates and performance values will be obtained in the procurement process, and later deliveries are anticipated to result in higher performance numbers.

Appendix B: Glossary

Advanced Architectures—an ASCI program element that is focused on development of more effective architectures for high-end simulation and computing.

ASAP—Academic Strategic Alliances Program, a program element within the University Partnerships category of ASCI.

ASC—Advanced Simulation and Computing. ASC is the program element of the Stockpile Stewardship Program that is developing the advanced simulation capabilities needed to analyze and predict the performance, safety, and reliability of nuclear weapons and certify their functionality. For historical reasons, ASC is more commonly know as ASCI.

ASCI—Accelerated Strategic Computing Initiative. ASCI is the name initially given to the Stockpile Stewardship Program element that is now called ASC.

ASCI *Blue Mountain*—A Silicon Graphics Cray system located at Los Alamos National Laboratory. In 1998, ASCI *Blue Mountain* was installed as a 3.072-teraOPS computer system.

ASCI *Blue Pacific*—An IBM system located at Lawrence Livermore National Laboratory. In 1998, ASCI *Blue Pacific* was installed as a 3.89-teraOPS computer system.

ASCI *Heartland*—An SGI system located at the Kansas City Plant. *Heartland* is currently operating at about 0.1 teraOPS and will be upgraded to about 0.2 teraOPS.

ASCI *Manhattan*—An SGI system located at Y-12. *Manhattan* is currently operating at about 0.1 teraOPS.

ASCI *Red*—An INTEL system located at Sandia National Laboratory. ASCI *Red* was the first teraOPS platform in the world when it was installed in 1998 (1.872 teraOPS). Processor and memory upgrades in 1999 converted ASCI *Red* to a 3.15-teraOPS platform.

ASCI *Red Storm*—A 20-teraOPS system to be located at Sandia National Laboratory, scheduled for delivery in Q4 FY2003.

ASCI Q—A Compaq system that will be located at Los Alamos National Laboratory. ASCI Q is designed to be a 30-teraOPS-computer system and is scheduled for delivery in 2002.

ASCI *White*—An IBM system located at Lawrence Livermore National Laboratory. In 2000, ASCI *White* was installed as a 12.3-teraOPS supercomputer system.

burn code—a computer code used to simulate the behavior of a weapon that involves significant energy released by thermonuclear reactions.

Campaigns—an organization of the SSP activities that are focused on the scientific and engineering aspects that address critical capabilities, tools, computations, and experiments needed to achieve weapons stockpile certification, manufacturing, and refurbishment now and in the future, in the absence of nuclear testing.

Cplant™—The Computational Plant project at Sandia National Laboratories is developing a large-scale, massively parallel computing resource from a cluster of commodity computing and networking components.

DARHT—the Dual Axis Radiographic Hydrodynamic Test Facility will examine implosions from two different axes.

DisCom^2—Distance and Distributed Computing and Communication, a program element within ASCI focused on computing at a distant location, data communications between geographically distant locations, or geographically distributed computing.

DISL—the Distributed Information Systems Laboratory, a computing and communications facility scheduled for Sandia, Livermore.

DoD—U.S. Department of Defense.

DOE—U.S. Department of Energy.

DP—Defense Programs, one of the three major programmatic elements in NNSA.

DSW—Directed Stockpile Work, those SSP activities that directly support the day-to-day work associated with the refurbishment and certification of specific weapons in the nuclear stockpile.

DVC—data and visualization corridors provide the capabilities to allow visualization and manipulation of massive scientific datasets.

FY—fiscal year. The U.S. Government's fiscal year runs from October 1 through September 30.

JCEL—the Joint Computational Engineering Laboratory, a computing and communications facility scheduled for Sandia, Albuquerque.

Lawrence Livermore—Lawrence Livermore National Laboratory, a prime contractor for NNSA located in Livermore, California, and operated by the University of California.

Los Alamos—Los Alamos National Laboratory, a prime contractor for NNSA located in Los Alamos, New Mexico, and operated by the University of California.

MESA—the Microsystems and Engineering Sciences Application facility, scheduled for construction at Sandia New Mexico, will provide the design environment for nonnuclear components of a nuclear weapon.

NIF—the National Ignition Facility.

NNSA—National Nuclear Security Administration, a semi-autonomous agency within DOE.

NSA—the National Security Agency.

NSF—the National Science Foundation.

NTS—the Nevada Test Site, the primary site of past U.S. underground nuclear tests, and the site for ongoing subcritical and large-scale nonnuclear tests.

PathForward—ASCI program element that partners with industrial partners to accelerate the development of critical technology leading to commercial products needed by ASCI.

PSE—Problem-Solving Environments, an ASCI program element focused on the development of an infrastructure that provides effective software development tools, production computing environments, and archival storage.

Sandia—Sandia National Laboratories, a prime contractor for NNSA with locations primarily in Albuquerque, New Mexico, and Livermore, California, and operated by Lockheed Martin Corporation.

SCC—the Strategic Computing Complex, a combination computer facility and office complex under construction at Los Alamos.

science-based—indicates the effort to increase understanding of the basic phenomena associated with nuclear weapons, to provide better predictive understanding of the safety and reliability of weapons, and to ensure a strong scientific and technical basis for future United States nuclear weapons policy objectives—compare with "test-based".

SFI—Significant Finding Investigation. An SFI results from discovery of some apparent anomaly with the enduring stockpile. DSW Surveillance generally initiates an SFI. For complex SFI's, resolution comes from the Assessment & Certification element of DSW, often in partnership with ASCI capability.

SIERRA—a code development framework being developed by Sandia.

SLEP—the Stockpile Life Extension Program. SLEP is the Defense Programs element responsible for planning and execution of component and weapon refurbishments.

SSP—the Stockpile Stewardship Program, Defense Programs response to its responsibility to ensure the safety, performance, and reliability of the U.S. nuclear stockpile.

STS—Stockpile to Target Sequence, a complete description of the electrical, mechanical, and thermal environment in which a weapon must operate, from storage through delivery to a target.

terabyte—trillions of bytes, abbreviated TB, often used to designate the memory or disk capacity of ASCI supercomputers. A byte is eight bits (binary digit, 0 or 1) and holds one ASCII character. (ASCII—the American Standard Code for Information Interchange.) For comparison, the book collection of the Library of Congress has been estimated to contain about 20 terabytes of information.

teraOPS—trillions of floating-point operations per second. TeraOPS is one important measure of the performance of a computer.

test-based—the traditional approach used for the development of nuclear weapons based on full-scale nuclear tests—compare with "science-based".

Tri-Lab—Referencing Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Sandia National Laboratory.

TSF—the Terascale Simulation Facility, a computer and office facility scheduled for construction at Lawrence Livermore.

V&V—Verification and Validation. Verification is the process of confirming that a computer code correctly implements the algorithms that were intended. Validation is the process of confirming that the predictions of a code adequately represent measured physical phenomena.

VIEWS—Visual Interactive Environment for Weapons Simulation. VIEWS is the ASCI program element that provides the capability for scientists and engineers to "see and understand" the results of a simulation.

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

Sandia National Laboratories