DOE Research and Development Portfolio

National Security

Volume 3 of 4 / February 2000

U.S. Department of Energy

Department of Energy
Washington, DC 20585

Maintaining a safe, secure nuclear deterrent while reducing the global danger posed by weapons of mass destruction is one of the most important elements in our country's national security strategy. Since its inception, the Department of Energy (and its predecessor agencies) has been a leading agency responsible for our nation's efforts in this area. The Department is making significant progress toward meeting its national security mission responsibilities. To ensure continued progress with U.S. national security goals, the Department will maintain and invest in an aggressive and balanced research and development program.

The Department of Energy (DOE) has undertaken a major effort to ensure that its national security research and development (R&D) programs and Federal R&D investments are balanced, focused on mission, and appropriately coordinated with other agencies in the Federal Government. To do this, DOE has instituted a portfolio approach for managing its R&D activities. One step in this approach entails developing a document that provides, in one place, a clear description of the entire $7.65 billion DOE R&D Portfolio. DOE's four-volume R&D Portfolio includes one volume for each of DOE's four major business lines, Energy Resources, Environmental Quality, National Security, and Science, plus an Overview. Volume 3 describes DOE's *National Security R&D Portfolio*, which will total $3.2 billion in FY 2001.

The *National Security R&D Portfolio* focuses on the FY 1999-2001 time frame. Its purpose is to 1) describe current National Security R&D activities, and showcase recent accomplishments, 2) evaluate whether the Portfolio is balanced appropriately to meet DOE's long-term strategic goals, 3) align technology investments with broader national policy goals, and 4) plan for future investments through technology roadmapping.

The investments presented in the *National Security R&D Portfolio* are important steps toward bringing forth the knowledge, innovation, technologies, and partnerships required to meet the challenges of the next century. Building on last year's R&D Portfolio, it is the hope that this document will provide a means for illuminating investments for FY 2001 and beyond, and serve as a useful framework and resource for further analysis and dialogue among interested parties.

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Foreword

National security is a critical part of the Department of Energy's mission, accounting for $6.6B of DOE's $18.9B budget in FY 2000. The Department is making significant progress in meeting it national security responsibilities of reducing the global danger posed by weapons of mass destruction while maintaining a safe and secure nuclear deterrent. An aggressive research and development (R&D) component is an important element of the Department's strategy for making further progress. These activities are primarily conducted by DOE laboratories and facilities while taking advantage of basic research contributions of leading universities and private sector companies.

In FY 2001, this National Security Research and Development Portfolio will require investments of $2.6B in science and technology to help maintain the nuclear deterrent, monitor nuclear treaties and agreements, prevent proliferation, develop proliferation detection technologies, and to counter weapons of mass destruction terrorism. This volume examines the Department's investments from 1999 through the year 2001. It describes the major national security technical challenges that our nation faces and the specific Department of Energy research and development activities being undertaken to address these challenges.

- **Chapter 2** provides a ***Portfolio Analysis*** of the National Security R&D Portfolio, including discussions of uncertainties and external factors affecting research and development, the distribution of investments by investment areas, and trends in funding levels.

- **Chapter 3** describes R&D activities related to ***Maintaining the Nuclear Deterrent*** in the absence of underground testing with a science-based Stockpile Stewardship Program (SSP) to ensure the safety, security, and reliability of the stockpile.

- **Chapter 4** describes R&D activities related to ***Monitoring Nuclear Treaties and Agreements*** to enhance confidence in nuclear explosion monitoring and ensure compliance with nuclear nonproliferation and arms control treaties and agreements.

- **Chapter 5** describes R&D activities related to ***Preventing Proliferation*** by developing and adapting technologies that convert U.S. weapons-usable plutonium to a form that will prohibit the plutonium from ever being used for nuclear weapons, assisting Russia in the demonstration of plutonium disposition technologies, developing technologies to increase the security of U.S. assets and developing information protection technology to prevent unauthorized access to data and prevent the disruption of classified or sensitive information systems.

- **Chapter 6** describes R&D activities related to ***Detecting Proliferation*** by developing technologies to facilitate early intercession to prevent the spread of weapons of mass destruction and identify problems before they become crises.

- **Chapter 7** describes R&D activities related to ***Countering Weapons of Mass Destruction Terrorism*** by developing technologies and methods to detect, deter or counter terrorism involving weapons of mass destruction (focused primarily on supporting domestic first responders).

The description of the National Security R&D Portfolio and its relevance to national interests is an important step in portfolio development and analysis, but is only the beginning. This document demonstrates that the DOE portfolio meets multiple objectives with the robustness required for an uncertain future, but continued and expanded planning and analysis is needed to ensure appropriate prioritization and efficient utilization of taxpayer funds applied to these efforts.

Future changes to portions of the portfolio will occur because of new opportunities, technological developments, and requirements from unfolding national and international events. Strategic planning, portfolio analysis, and technology roadmapping will provide the framework to keep pace with demanding national security needs.

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Executive Summary

The post Cold War national security environment is increasingly complex. At least 20 countries are known to be or are suspected of developing weapons of mass destruction (WMD), as underscored by the underground nuclear tests of India and Pakistan in May 1998. The fragmentation of the former Soviet Union has led to concerns about the accountability, control, and disposition of weapons, components, materials, and information. The threat that nuclear weapons or materials could fall into the wrong hands through theft or diversion is a clear and present danger. Increased activity and technical sophistication of non-state-supported terrorists are further concerns.

The DOE national security mission is driven by policies that have developed in response to this environment, and the fact that nuclear weapons continue to be the cornerstone of U.S. deterrence. Key policies from the perspective of reducing the global nuclear threat are support of the Strategic Arms Reduction Treaties (START I, II, and planning for III), the nuclear-testing moratorium, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), and Presidential Decision Directives (PDDs) on the Nonproliferation of Weapons of Mass Destruction, and Countering Terrorism. From the perspective of maintaining the U.S. nuclear deterrence, key policies are defined in Public Law and PDDs that require DOE to develop, plan, and execute a science-based Stockpile Stewardship Program (SSP) to maintain confidence in the nuclear stockpile, and to preserve the human, scientific, and physical infrastructure necessary to support the stockpile into the indefinite future. These policies require:

- A science-based stockpile stewardship program to assess and certify the safety, security, and reliability of the stockpile without nuclear testing.
- Preservation of the capability to design, develop, produce nuclear weapons, and to resume underground tests of nuclear weapons, if required.
- An effective nuclear explosion monitoring research and development program.
- A robust proliferation detection technologies research and development program to reduce the nuclear danger by identifying problems before they become crises.
- A proliferation prevention program to ensure that nuclear weapons useable materials are dispositioned subject to the highest standards of safety, security, and international accountability.
- A counter terrorism program focused primarily on supporting domestic first responders.

Prior to 1992, underground nuclear testing was the principal means of assuring the performance of nuclear weapon systems. Data gathered from these tests helped benchmark computer codes that were used to design new weapons and to assess weapon safety, security, and reliability in the existing stockpile. Since the 1992 testing moratorium, DOE has shifted from test-based to science-based methods to perform these assessments, relying on a science-based approach that used nonnuclear-yield experimentation and high-fidelity simulations that are based on scientific concepts, research, experimentation and archived nuclear test data. Similarly, science and simulation-based methodologies are being developed to assess the impact of aging, manufacturing defects, and process changes on weapons materials and components. Extrapolating weapon system performance from underlying physical models and data depends on the fidelity and efficiency of the numeric simulation.

Uncertainties exist regarding detection sensitivities for sensing in monitoring activities and the ability of countries to evade detection of their proliferation activities. The ability to monitor the activities of concern is often confounded by the proliferant nation's efforts to conceal them. Primary challenges facing the developers of new systems include: designing a system that will help overcome deception and denial efforts, improved measurement accuracy, and finding new detection techniques that existing state-of-the-art sensors do not have.

Nuclear materials such as plutonium and highly enriched uranium are highly valued by potential proliferators. This situation is made more complicated by the dissolution of the Soviet Union, and the political and economic turmoil currently affecting Russia. The development of technologies and systems to monitor, protect, and account for nuclear fissile materials must keep pace with the increasingly sophisticated efforts of smugglers to move such material, or thieves to remove them from safe keeping in sites throughout Russia and other countries. The U.S. will also strive to eliminate, where possible, accumulation of stockpiles of fissile materials through disposition and assist Russia in the demonstration of plutonium disposition technologies.

Responding to the threat of weapons of mass destruction terrorism is an extremely complex problem. The current world political and economic situation may make access to weapons of mass destruction technology more readily available. Nuclear smuggling is an acknowledged threat and detection of chemical and biological agents is constrained by the current state of technology. DOE's approach for these activities will leverage its science and technology expertise and prior R&D investment to support cooperative developments that serve the interest of the U.S. Government to address this difficult problem.

Four principal organizations manage DOE's National Security R&D Portfolio to support its national security mission. These include the Office of Defense Programs, the Office of Nonproliferation and National Security, the Office of Fissile Materials Disposition, and Office of Security and Emergency Operations. Their mission objectives are to:

- Maintain the U.S. nuclear weapon stockpile and the capability to design, produce and test nuclear weapons.

- Prevent the spread of WMD materials, technology and expertise.

- Secure nuclear weapon materials.

- Verify compliance with WMD treaties and agreements.

- Reverse the proliferation of nuclear weapons capabilities.
- Respond to emergencies.

Federal Role and Linkage to DOE Strategic Goals

DOE has the sole legislated responsibility for maintaining the viability of the nuclear weapon stockpile, overseeing the protection of all classified nuclear weapons technical information, and producing and handling of nuclear weapons components and special nuclear materials. To meet its nuclear weapons mandate, DOE owns and operates, through contractors, the Defense Programs national laboratories and the production plants. The Department is also responsible for the management, storage, and disposition of fissile materials from weapons and weapon systems that are excess to U.S. national security needs. Because of its historic expertise in nuclear weapons technology, DOE has been assigned principal R&D responsibilities in nuclear nonproliferation, arms control, and countering WMD terrorism.

To fulfill its responsibilities and to meet the strategic goals in the national security mission area, DOE maintains a robust portfolio of research and development that is centered on solving the following problems:

Maintaining the Nuclear Deterrent

- Provide a scientific basis for assessing the safety, security, and reliability of the stockpile with no underground nuclear testing. Major objectives to accomplish this include the development of:
  - Capabilities to conduct experiments in physical regimes important for understanding nuclear weapons performance.
  - Understanding of the effects of aging on nuclear weapons materials and components.
  - Experimentally-validated computational methods for simulating nuclear weapons performance.
  - New technologies to improve weapon surety, certification, and surveillance.
  - New technologies for the production of special nuclear materials (e.g. tritium) and weapon components that reduce cost and time, and that minimize environmental impact, and improve component and overall system reliability.

Monitoring Nuclear Treaties and Agreements

- Develop technologies to enable nuclear explosion monitoring and to ensure compliance with nuclear nonproliferation and arms control treaties and agreements .

Preventing Proliferation

- Develop and adapt technologies that convert U.S. weapons-usable plutonium to a form that will prohibit the plutonium from ever being used for nuclear weapons.

- Assist Russia in the demonstration of plutonium disposition technologies.

- Develop core security technologies that can be deployed to increase the security of U.S. facilities and to decrease program costs, including:
  - Nuclear materials measurement, accountability, and surveillance technologies to increase the accuracy of nuclear materials accounts, prevent and detect diversion of nuclear materials from their authorized locations, and reduce employee exposure to radiation.
  - Physical security of the DOE complex.
  - Information protection technology to prevent unauthorized access to data and to prevent disruption of classified or sensitive information systems.

- Develop proliferation resistant requirements and design modifications to existing Russian systems and develop new concepts for next-generation proliferation resistant reactor systems with improved safety.

Detecting Proliferation

- Develop monitoring technologies to reveal proliferation or spread of weapons of mass destruction.

Countering Weapons of Mass Destruction Terrorism

- Develop technologies and methods to detect, deter or counter terrorism involving weapons of mass destruction.

Investment Trends

Maintaining the Nuclear Deterrent Through Science-Based Stockpile Stewardship

The Office of Defense Programs (DP) has undertaken a major shift in program management strategy during the last year, resulting in the adoption of a business model for R&D management. This has resulted in significant changes to the organizational structure of the Stockpile Stewardship Program (SSP) relative to previous years. As a result, the SSP is organized into three focus areas: 1) Directed Stockpile Work (DSW), designed to ensure that stockpiled weapons meet military requirements, 2) Campaigns, designed to provide the science and engineering capabilities needed to meet ongoing and evolving DSW requirements, and 3) Infrastructure that is required for stockpile work and computational and experimental facilities at the DP laboratories and the Nevada Test Site. Within these three areas, R&D primarily is focused in DSW and Campaigns, which are multiyear research intensive initiatives that are designed to resolve DP's highest priority stockpile related scientific issues.

During FY 2000 and 2001, the SSP will significantly enhance experimental and computational facilities needed for assessing and certifying the stockpile's safety, security, and reliability in the absence of nuclear testing. These enhancements target improved scientific understanding and new scientific and computational facilities in six areas in FY 2001:

1. Assessment and certification of nuclear weapon primaries.
2. Assessment and certification of nuclear weapon secondaries.
3. Advanced radiographic facilities.
4. Inertial confinement fusion.
5. Defense applications and modeling.
6. Enhanced surveillance of the enduring stockpile.

Monitoring Nuclear Treaties and Agreements Through Enhanced System Development

- **Ground-based Monitoring Technologies** include the development of sensors and systems to enable effective U.S. monitoring with or without the Comprehensive Nuclear-Test-Ban Treaty (CTBT).
- **Improved Satellite Sensors** include the development of next-generation sensors to detect nuclear detonations in the atmosphere and in space.
- **Improved Radiation Detection Sensors** include the development of sensors to permit monitoring of warhead dismantlement and storage of nuclear weapons and materials for arms reduction treaties and agreements.

Preventing Proliferation Through Weapon Materials Disposition and Protection

The strategy for the disposition of surplus U.S. weapons-usable plutonium is to immobilize some of it in a ceramic form surrounded by high-level waste, and to burn the rest as mixed-oxide (MOX) fuel in existing, domestic reactors. The strategy to assist Russia in the disposition of Russian surplus plutonium is to conduct small-case tests and demonstration of disposition technologies jointly with Russia and initiate procurement for a pilot-scale system in Russia to convert weapons plutonium to forms suitable for disposition and international inspection. The research and development program to support this strategy involves:

- The development, testing, and demonstration of a technology for the disassembly and conversion of nuclear weapons components to a plutonium oxide form that can be used as feed in either disposition technology.

- The development, testing, and demonstration of a technology to immobilize plutonium in a ceramic and incasing the plutonium in high-level waste glass.

- Tests and demonstrations associated with assessing the performance of MOX fuel fabricated from weapons plutonium.

- Assisting Russia with tests and demonstrations of technologies for the disposition of Russian plutonium.

In the near future, warhead pits of different types will be disassembled and converted to an oxide to establish operating parameters for a pit disassembly and conversion facility. In the immobilization activity, demonstrations will commence to provide data for facility design and to finalize the technical baseline for ceramic immobilization. For the reactor option, work will continue on examining the performance of MOX fuel fabricated with weapons plutonium and depleted uranium and initiating a MOX lead test assembly program. In Russia, small-scale tests involving burning plutonium in reactors and immobilization of plutonium in glass and ceramic matrices will continue.

Technologies to control and protect nuclear materials must remain state-of-the-art to ensure these materials do not fall into the hands of increasingly sophisticated terrorists. Detection technologies must accurately gauge and quantify mixed-matrix and shielded nuclear materials, while reducing worker exposures. Intrusion detection, barrier and vault systems, as well as countermeasures, must remain effective against continuously emerging threats. Research in the Nuclear Materials Protection area also includes systems for protecting information and information systems that exist within the defense nuclear complex, a challenging task that continues to expand in scope and complexity.

Both the U.S. and Russia have interests in and responsibilities for reducing the risk of nuclear proliferation from civilian nuclear power, and both are pursuing technology development programs to accomplish that goal. Continuing interactions with Russian officials on this topic will lead to the identification of many areas where the U.S. and Russian philosophies and technologies contributing to the development of proliferation-resistant nuclear systems will overlap. The Department of Energy intends to accelerate development of proliferation-resistant nuclear systems by implementing a new research initiative (the Proliferation Resistant Reactors and Fuels Research Program) during FY 2001.

Proliferation Detection Technologies for Improved Sensor Development

- **Effluent Detection** includes the development and demonstration of sensor systems for detection of chemical signatures indicative of nuclear proliferation non-compliance.

- **Physical Detection** includes the development and demonstration of sensor systems for detection of physical signatures that indicate nuclear proliferation non-compliance.

Countering Weapons of Mass Destruction Terrorism

- **Nuclear Materials Detection** include the development and demonstration of nuclear radiation detection sensor systems to deter nuclear smuggling activities as well as to enhance nuclear material accountability and control.

- **Chemical/Biological Detection** include the development and demonstration of capabilities to detect the presence of chemical and biological materials and agents, to enhance biologic forensics tools and understanding, and to counter or remediate the presence of such weapons.

The Chemical/Biological portion of the countering terrorism R&D research area, that is developing technologies to deter, detect, and effectively respond to the use of chemical and biological weapons, will receive a modest increase in fiscal year 2001, growing from approximately $40M to over $42M, with more growth anticipated in the out years. This program builds upon ongoing activities in other agencies, and addresses specific scientific and technical areas in which DOE has unique expertise. The development of proliferation detection sensors will continue to be a top priority, so that timely information can be provided to policy makers with sufficient notification to allow the U.S. to intercede early in the proliferation cycle, before national security is significantly compromised.

Key Accomplishments

- Successfully completed fourth Annual Stockpile Certification process without resource to underground nuclear testing.

- Successfully completed the first hydrodynamic test using the first axis of the Dual-Axis Radiographic Hydrodynamic Test Facility. The improved radiographic performance offered by this facility will be crucial to developing the needed resolution for benchmarking primary code calculations and assessing system performance re-certification of the existing stockpile or future remanufactured weapons.

- Sustained the worldwide record for high-performance computing, with the operation of three computers in the 3 to 4 teraOPS capability class.

- Won the 1999 Gordon Bell Prize in computing by performing high-resolution, 3-dimensional simulations of the Richtmyer-Meshkov instability and associated fluid mixing.

- Partially certified the MC4380 neutron generator to hostile-environment specifications using simulations and aboveground, nonnuclear tests on the Z and Saturn pulsed-power facilities.

- Determined plutonium high-pressure thermodynamic properties by first-principles methods, illustrating fundamental advances in the ability to predict the properties of actinides, under conditions relevant to stockpile performance.

- Implemented a new technique on pulsed-power facilities that uses magnetic compression to produce continuous, shockless loading of multiple flat samples. The method can be used to determine material properties of weapon-primary surrogates.

- Developed and delivered an increased capability x-ray instrument that will enable detection of the evasive testing in space of primitive nuclear weapons. This instrument will be flown on the latest models of the Global Positioning System satellites.

- Utilized the DOE Fast On-orbit Recording of Transient Events (FORTÉ) small research satellite, launched in August 1997, to successfully demonstrate the next generation autonomous electromagnetic pulse sensor technologies for monitoring nuclear test ban treaties. FORTÉ is also providing scientists information on lightning and the structure of the ionosphere for possible use in weather forecasting and understanding the relationship of the ionosphere to environmental phenomena affecting the Earth.

- Delivered Release 3 of the ground-based nuclear explosion monitoring "Knowledge Base" to the U. S. National Data Center, providing a near-operational structure for managing large data bases pertaining to multiple technologies and regional geophysical and geologic information.

- Demonstrated a unique magnetic separation method for removing micron-size particles of SNM from large samples prior to analysis.

- Developed a solid state fiber optic neutron and gamma ray detector that won an R&D 100 award and was successfully transferred to the commercial sector resulting in a Federal Laboratory Consortium Award. The detector technology is currently being deployed on the Austrian-Hungarian border.

- Developed the Lab-on-a-Chip. The miniaturized system for performing wet chemistry operations has demonstrated separation of compounds faster than full-size laboratory instruments. This technology has been licensed to industry and has been declared by R&D Magazine to be one of the 40 most significant technological achievements since the magazine began their R&D 100 Awards program in 1963.

- Demonstrated the feasibility of a fully solid state, low power, no moving parts cryogenic cooling system that will enable the fielding of advanced cryogenically cooled sensor systems. This system was successfully transferred to industry and is being evaluated for use by the IAEA.

- Developed and tested major components of the technology to disassemble and convert nuclear weapon pits to a plutonium oxide form. The components have been integrated into a system, and a demonstration of the system has been initiated.

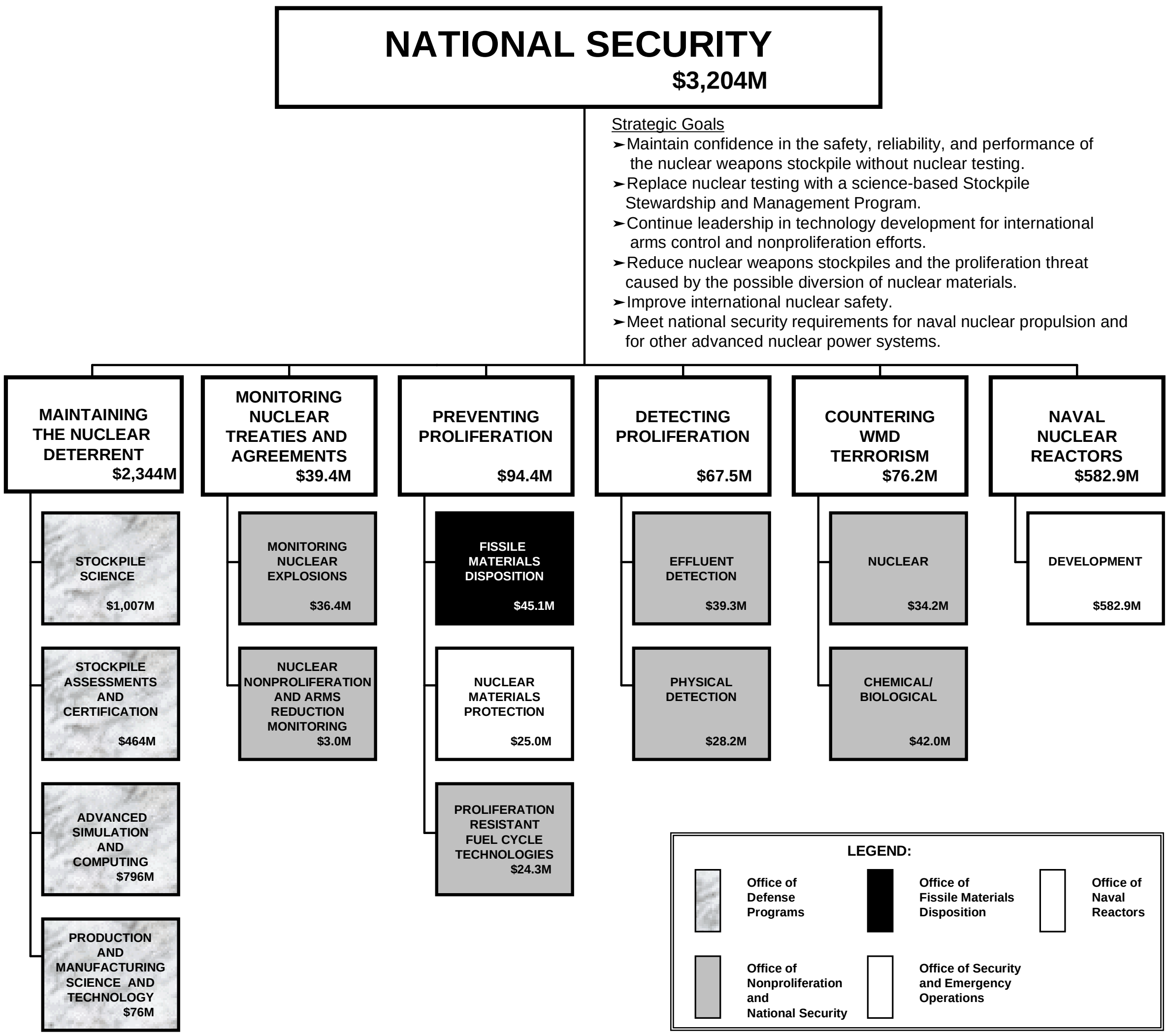
- Selected the baseline ceramic formulation for immobilizing plutonium. The process concept has been defined, and feasibility demonstrations of several key processes have been completed.

- Fabricated, irradiated and examined MOX fuel samples to study the effects of gallium on the performance of MOX fuel. Basic research was completed on the interaction of gallium with fuel clad materials.

- Initiated studies, tests and demonstrations in Russia to assist in selecting a process to convert plutonium from Russian weapons to an oxide form suitable for fabrication into a MOX fuel. Tests and demonstrations of immobilization of plutonium in glass and ceramics were initiated as well.

- Completed the DNA sequencing of the virulence plasmids in two key biological threat pathogens, *B. anthracis* (anthrax) and *Y. pestis* (plague) to enable detection and attribution technologies.

Chapter 1
Introduction



Chapter 1

Introduction

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Background

As the civilian steward of the U.S. nuclear weapons stockpile, the DOE is responsible for maintaining the safety, security, and reliability of that stockpile. Additionally, as an integral member of the U.S. national security community, the DOE plays an essential role in providing unique technical expertise in support of the Department of Defense, the Department of State, and other agencies focused on reducing the global danger from nuclear weapons and other weapons of mass destruction.

The post Cold War national security environment is dangerous and increasingly complex. U.S. national security continues to require the maintenance of a safe, secure, and reliable stockpile of nuclear weapons. For more than 50 years this has been, and continues to be, one of the core missions of the Department of Energy. The maintenance of the nuclear weapon stockpile is a primary deterrent to threats to the national interest.

> *"As a part of our national security strategy, the United States must and will retain strategic nuclear forces sufficient to deter any future hostile foreign leadership with access to strategic nuclear forces from acting against our vital interests and to convince it that seeking a nuclear advantage would be futile. In this regard, I consider the maintenance of a safe and reliable nuclear weapon stockpile to be a supreme national interest of the United States."*
>
> — President William J. Clinton

The DOE is responsible for the safeguarding and security of U.S. nuclear weapons information, expertise, technologies, and material. In pursuit of its responsibility to safeguard U.S. nuclear materials, DOE is reducing the number of sites where surplus weapons plutonium is stored and is disposing of surplus highly enriched uranium and plutonium, that are excess to national security requirements.

Concerns over the proliferation of weapons of mass destruction have grown considerably in recent years. At least 20 countries are known to be or are suspected of developing weapons of mass destruction (WMD). This concern was underscored by the recent underground nuclear tests of India and Pakistan in May 1998. The fragmentation of the Soviet Union has led to concerns about the accountability, control, and disposition of weapons, components, materials, and information. The threat that nuclear weapons or materials could fall into the wrong hands through theft or diversion is a clear and present danger. The increased activity and technical sophistication of non-state actors is a further concern.

The U.S. national security leadership has clearly stated that there is a close relationship between maintaining our national security and controlling the spread of weapons of mass destruction.

> *"The dangers we face are unprecedented in their complexity. Ethnic conflict and outlaw states threaten regional stability. Terrorism, drugs, organized crime, and proliferation of weapons of mass destruction are global concerns that transcend national boundaries and undermine economic stability in many countries."*
>
> —President William J. Clinton

> *"As the new millennium approaches, the United States faces a heightened prospect that regional aggressors, third-rate armies, terrorist cells, and even religious cults will wield disproportionate power by using – or even threatening to use – nuclear, biological, or chemical weapons against our troops in the field and our people at home."*
>
> —Secretary of Defense William S. Cohen

> *Those out to do us harm are no longer just political zealots with a few sticks of dynamite. These are determined operatives, with access to very sophisticated information and technology. Unable to confront or compete with the United States militarily, they try to achieve their policy objectives by exploiting small groups to do the dirty work for them.*
>
> —General John M. Shalikashvili, USA
> Chairman, Joint Chiefs of Staff

The DOE has shifted its priorities over the past several years to reflect the new and evolving geopolitical military realities of the post Cold War world. To deal with the change, DOE has enhanced activities that advance U.S. nonproliferation policy while maintaining the viability of deterrence with a smaller, more cost-effective, secure nuclear weapons complex.

Continual improvements to monitoring and verification capabilities to ensure treaty compliance, while protecting the nuclear information security interests of all parties are required. Verifiable treaties result in a reduction of the global stockpiles of nuclear weapons and materials, thereby reducing the danger for all States, both nuclear and non-nuclear. This encourages worldwide interest in, and incentives for, furthering nonproliferation goals.

In addition to its role in monitoring nuclear explosions and verifying nuclear treaties, DOE has a major role in research and development to prevent the spread of nuclear weapons in other countries. DOE and its national laboratories are involved in providing international safeguards for foreign nuclear facilities, in supporting the entire range of International Atomic Energy Agency (IAEA) activities, and in making sure that technologies related to nuclear materials and weapons are not deliberately or inadvertently transferred to countries of proliferation concern.

Monitoring technologies are an integral part of the U.S. national security strategy. Monitoring arms control treaties provides assurance that existing military threats will be reduced and that new threats will not arise. This is an essential complement to the nation's military programs, who can respond to foreign weapons only after they threaten the United States. Verifiable arms control treaties allow the U.S. to maintain greater security at lower cost, while improved monitoring technologies enable focus to be placed on problems before they become crises.

The DOE's national security area sponsors, and is responsible for, an extensive R&D program, most of which is carried out at the DOE national laboratories. DOE-sponsored R&D activities are focused on applied research, but include some basic research as well.

The DOE Research and Development Portfolio

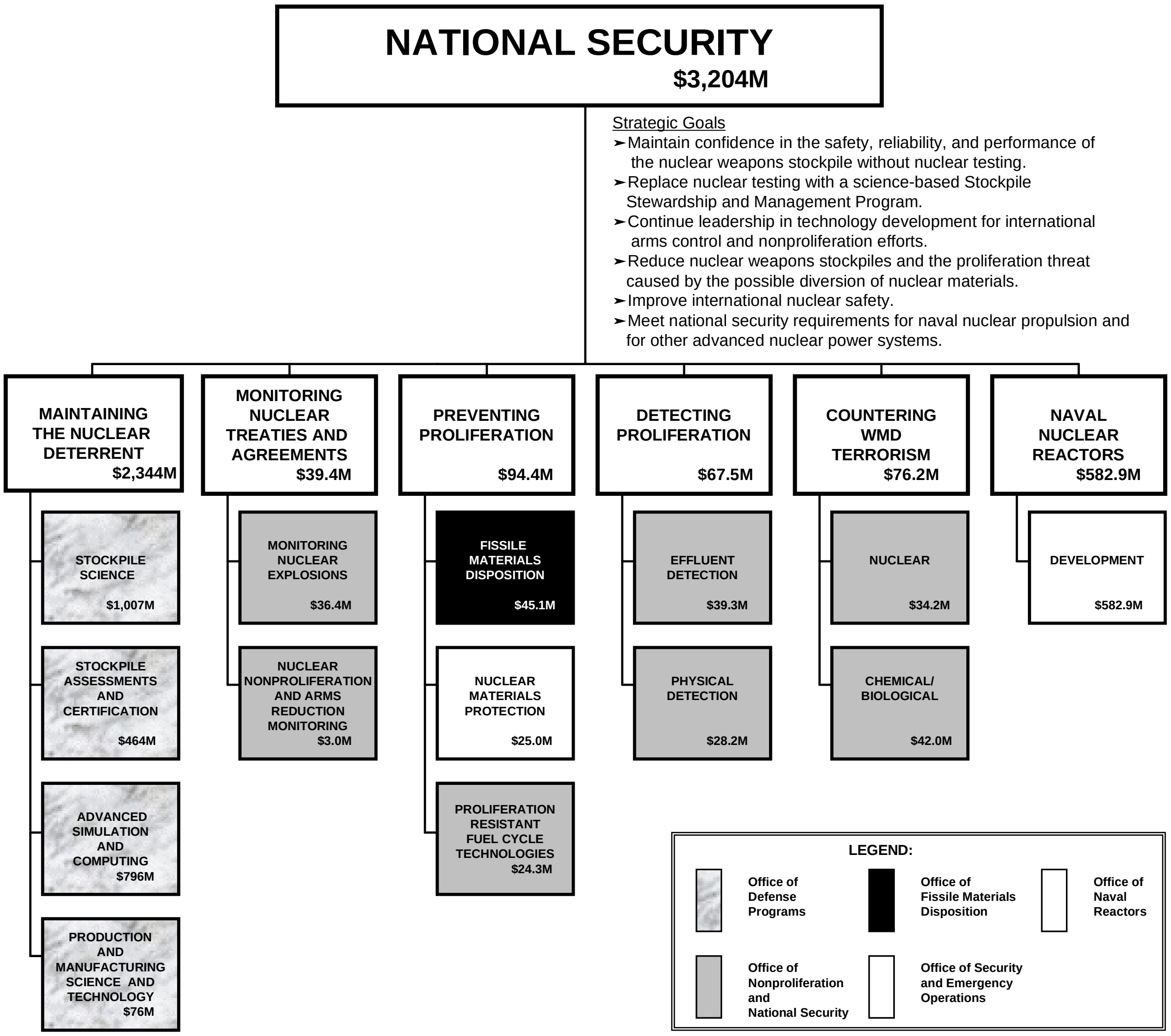
The DOE assembled its National Security R&D Portfolio recognizing the complexity of the U.S. national security challenge, and the requisite continuity implicit in DOE's current research activities. These activities reflect past and present Congressional and Executive guidance and intent. In assembling the Portfolio, DOE also acknowledged that the complexity and inter-relatedness of the U.S. Government national security establishment means research in any particular scientific or technological area may have direct or indirect effects on setting appropriate objectives for the National Security R&D Portfolio.

The DOE National Security R&D Portfolio has been structured into five primary activity areas that respond to DOE objectives:

- Maintaining the Nuclear Deterrent.
- Monitoring Nuclear Treaties and Agreements.
- Preventing Proliferation.
- Detecting Proliferation.
- Countering Weapons of Mass Destruction Terrorism.

The structure of the DOE National Security R&D Portfolio and organizational responsibilities is shown on the following page.

National Security Research and Development



Maintaining the Nuclear Deterrent

The Department of Defense (DoD) shares responsibility with DOE for maintaining the nuclear weapons stockpile. The requirements for the stockpile are stated in the Nuclear Weapons Stockpile Plan, which is developed annually by DOE and DoD and is approved by the President. The DoD sets military requirements, jointly manages with DOE the flight tests of weapons systems, participates in planning for surveillance of the stockpile, and participates in refurbishment activities. The DoD relies on DOE capabilities, including the Nevada Test Site (NTS), and provides personnel resources to DOE for planning and management.

Prior to 1992, underground nuclear testing was the principal means of assuring the safety, security, and reliability of nuclear weapon systems. Test results were also used to benchmark codes used to design new weapons and to assess weapon safety, security, and reliability. In 1993, the President challenged the Department of Energy and the Department of Defense “to explore other means of maintaining our confidence in the safety, reliability, and performance of our weapons." In the 1994 National Defense Authorization Act, Congress directed the Secretary of Energy "to establish a stewardship program to ensure the preservation of the core intellectual and technical competencies of the United States in nuclear weapons." In 1995, the President issued a statement of nuclear safeguards, further emphasizing the importance of stockpile stewardship.

Three particular stewardship challenges must be met:

- Maintain and refurbish nuclear weapons to sustain indefinitely the confidence in their safety, security, and reliability, without conduction nuclear testing.
- Achieve a robust and vital scientific, engineering, and manufacturing capability to enable present and future assessment and certification of the enduring stockpile, and develop the ability to design and manufacture nuclear components without conducting nuclear testing.
- Ensure the vitality of DOE's science, engineering and production enterprise required for nuclear stewardship.

Presently, DP's three R&D laboratories maintain confidence in the stockpile by using state-of-the-art scientific and engineering tools. To continue to meet this challenge in the future, new facilities are being established at the national laboratories. These new facilities are vital to increasing our fundamental understanding of the science and engineering behind weapons design, refurbishments, and manufacture. These facilities will allow stockpile stewardship scientists to push the bounds of knowledge in fields as diverse as plasma physics, materials science, and aging effects.

The evolving stockpile stewardship program is increasingly reliant on computer simulations to predict at complete end-to-end performance of nuclear weapons and to design and interpret experiments that reveal the behavior of selected phenomena. The extent to which simulations can be relied upon to extrapolate system performance from underlying physical models and data is an open scientific question and a principal question to be addressed by the DOE's R&D. Methodologies must be developed to assess the impact of aging and manufacturing defects and changes, among other scientific and engineering challenges.

Monitoring Nuclear Treaties and Agreements

The goal of monitoring nuclear explosions research and engineering program area is to develop technologies and systems, and the attendant scientific basis thereof, to enable detection, characterization, and attribution of nuclear explosions with sufficient timeliness and confidence to permit effective national and international treaty verification. The current focus is largely on development of a robust capability to monitor the Comprehensive Nuclear-Test-Ban Treaty (CTBT), when it enters into force. However, the underlying conditions that shape U.S. monitoring requirements will remain in effect, whether or not official entry into force of CTBT ever occurs.

The nuclear nonproliferation and arms reduction monitoring program area focuses on developing suitable technologies to support and validate treaty-specified U.S. and Russian initial declarations of nuclear warheads, monitor the dismantlement, and provide for long-term monitoring and periodic reporting of material inventories. Detection technologies must be able to verify that materials actually came from nuclear weapons, and at the same time, they must also provide barriers to protect weapon design information.

Preventing Proliferation

United States policy seeks to eliminate, where possible, accumulation of stockpiles of highly enriched uranium and plutonium, and to ensure that where these materials already exist they are subject to the highest standards of safety, security, and international accountability. DOE is committed to safely dispose of the nuclear material made surplus by the downsizing of the nuclear arsenal in conformance with arms control and nonproliferation treaty requirements. Disposition strategies include immobilizing plutonium in a ceramic matrix and surrounding it by high-level waste and ‘burning’ plutonium as mixed-oxide (MOX) fuel in commercial U.S. reactors. The research and development portfolio in the area of preventing proliferation addresses completing the necessary process development and technology tests that will provide the design and operational basis for facilities that can disposition surplus plutonium.

The threat that nuclear weapons or materials could fall into the wrong hands through theft or diversion is a clear and present danger. Nuclear materials such as plutonium and highly enriched uranium are highly valued by potential proliferators. The danger exists not only in the potential for proliferation of nuclear weapons, but also in the potential for environmental, safety, and health consequences, if surplus fissile materials are not properly managed. This situation is made more complicated by the dissolution of the Soviet Union, and the political and economic turmoil currently affecting Russia. The development of technologies and systems to monitor, protect, and account for nuclear materials must keep pace with the increasingly sophisticated efforts of smugglers to move such material, or thieves to remove them from safe keeping in sites throughout Russia and other countries.

To reduce the danger of nuclear weapons proliferation, the Department of Energy supports the Reduced Enrichment for Research and Test Reactors (RERTR) program. One of RERTR's most important and successful activities has been the development of low enriched uranium (LEU) fuels to permit conversion of research reactors from high enriched uranium (HEU) fuel to LEU.

Both the U.S. and Russia have interests in and responsibilities for reducing the risk of nuclear proliferation from civilian nuclear power, and both are pursuing technology development programs to accomplish that goal. Continuing interactions with Russian officials on this topic will lead to the identification of many areas where the U.S. and Russian philosophies and technologies contributing to the development of proliferation-resistant nuclear systems will overlap. Successful collaboration between the United States and Russia will identify areas of mutual interest. The Department of Energy intends to accelerate development of proliferation-resistant nuclear systems by implementing a new research initiative (the Proliferation Resistant Reactors and Fuels Research Program) during FY 2001.

Detecting Proliferation

Proliferating nations go to great lengths to conceal their proliferation activities and take other actions to prevent their detection. We are constantly faced with new and demanding technical problems that need to be solved. Efforts to stem proliferation activity rely upon remote sensing and other technologies, for which numerous technical challenges remain. Primary challenges facing the developers of new systems include: designing a system that will overcome deception and denial efforts, will be capable of all weather and day/night operation, will improve measurement accuracy, and will provide new detection techniques not possible with existing state-of-the-art sensors. The development of verification technologies sensors will continue to be a top priority, so that timely information can be provided to policy makers with sufficient notification to allow the U.S. to intercede early in the proliferation cycle before national security is significantly compromised.

Countering Weapons of Mass Destruction Terrorism

While deterring terrorism is not new to DOE (which sustains a modest Nuclear Emergency Search Team program within its Stockpile Stewardship and Management Program), the breadth of the WMD terrorism problem and its overlap with nonproliferation programs is much greater than before the dissolution of the Soviet Union. This program builds upon ongoing activities in other agencies, and addresses specific scientific and technical areas in which DOE has unique expertise. There are two primary activity areas: nuclear material detection, including the development and demonstration of nuclear radiation detection sensor systems to deter nuclear smuggling activities as well as to enhance nuclear material accountability and control; and chemical/biological detection, including the development and demonstration of capabilities to detect the presence of chemical and biological materials and agents, to enhance biologic forensics tools and understanding, and to counter or remediate the presence of such weapons.

Role and Relationship with Technology Partners

Because of an increased reliance on science in maintaining our nuclear deterrent, the contribution of the nation’s science infrastructure is of increasing value. Studies and work in atomic physics, nuclear physics, plasma physics, chemistry, engineering science, materials science, and other scientific disciplines that can be applied to stockpile stewardship are supported by other components of DOE and by other agencies, as well as by industry and universities. The weapons laboratories conduct stockpile-related research and development that applies all of these sciences. In their efforts, they contribute to the scientific infrastructure and increasingly engage with the larger national community of science and technology developers. DP funds more than $75 million of research grants annually at universities. The weapons laboratories may also engage in cooperative research and development with industry where DOE’s capabilities can contribute to national interests. In addition, the university partnerships are an important investment. They provide the laboratories with both unclassified R&D and academic instruction to students capable of potentially contributing to the National Security programs as future DP laboratory scientists and engineers

DOE or its predecessor agencies have been charged with providing the technologies and systems needed for the United States to monitor the compliance with nuclear test treaties for over 35 years. Requirements to enable treaty monitoring as established by the Department of Defense (DoD) and the Intelligence Community (IC) drive the development of sensor technology for detecting nuclear explosions conducted underground, underwater, in the atmosphere, and in space. They also specify the needs for data management and analysis tools to process and correlate the enormous amounts of data produced by these sensor systems.

DOD requirements for sensor and data systems to support their nuclear warfighting mission (specifically Nuclear Force Management and Integrated Tactical Warning and Attack Assessment) significantly overlap atmospheric and space treaty monitoring requirements. Accordingly, our satellite-based sensor systems are designed to address both missions. DoD provides the funding for the deployment and operation of these systems.

Congress directed that the Department be responsible for all activities relating to the management, storage, and disposition of fissile materials from weapons and weapons systems that are surplus to the national security needs of the United States. DOE executes R&D activities associated with the disposition of surplus plutonium through the expertise and facilities provided by the national laboratories, universities, and, in some instances, industry.

Success in developing new capabilities to detect proliferation will require an end-to-end approach, with detailed attention to the range of alternative proliferation paths, the phenomenology of the collection technology, and the interplay of potential new forms of technical data with other existing sources of information in assessing a target activity. In partnership with the Intelligence Community and the Department of Defense, DOE provides end-to-end system concepts for new technical approaches which can augment our national capabilities, along with technical risk mitigation through the development and field demonstration of prototype systems. DOE's partnerships with these agencies are facilitated through Memoranda of Agreement (MOA).

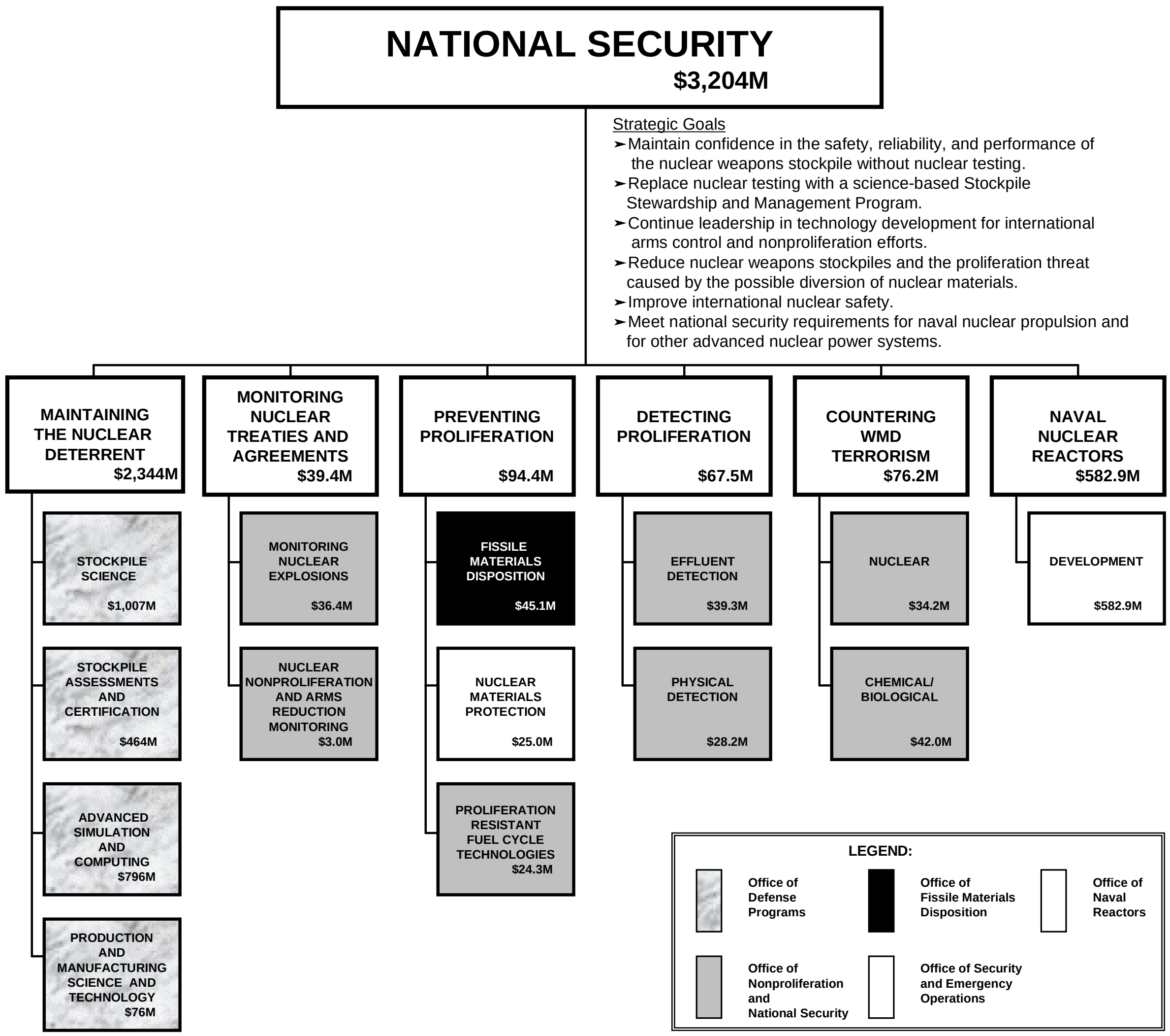
The Department of Energy has unique roles because of its nuclear weapon responsibilities, and the DOE laboratories are uniquely qualified to meet these national challenges. The production of weapons-quality fissile material is the greatest challenge faced by a would-be nuclear state. In many instances technologies developed to remotely monitor the proliferation of weapons of mass destruction also are well suited to support other important national needs. DOE's national laboratories feature unique assets in sensor technology development. Furthermore, efforts that address the detection of biological and chemical agents for counterproliferation, force protection, and anti-terrorist applications can be spun off and will be supported.

Presidential Decision Directives have established a role for the Department of Energy in addressing nuclear terrorism. This is an element of the total WMD terrorism picture and complements the responsibilities of other agencies. The DOE and its Laboratories have a history of working with others to address this problem in a structured way so that national technology investments will yield the greatest result.

Deterring and responding to chemical and biological terrorism presents formidable technological challenges. The chemical and biological nonproliferation R&D capitalizes on an annual DOE R&D investment of over $1B in relevant chemical and biological sciences. Through close coordination with other agencies, the Department provides applications-oriented direction to the Laboratories performing R&D in areas such as detection, modeling and prediction, decontamination, and biological forensics. The Laboratories' efforts are coordinated with each other and with R&D programs supported by other agencies.

The R&D in its early phases is generally executed at the DOE national laboratories. DOE is sensitive not only to requirements from those agencies which must use its technology but also to the opportunities to partner with companies which ultimately produce much of the equipment DOE develops.

Chapter 2
Portfolio Analysis



Chapter 2
Portfolio Analysis

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The Context for the National Security Research and Development Portfolio

The Department of Energy's national security research and development responsibilities have traditionally focused on matters regarding nuclear weapons, special nuclear materials, nuclear security and safety, arms control, and nonproliferation. DOE is an integral part of the U. S. national security community. DOE maintains an essential role in the provision of unique technical expertise in support of the Departments of Defense and State, and other agencies by focusing on reducing the global danger from nuclear weapons or other weapons of mass destruction.

Over the past several years, the United States national security policies have undergone profound change to reflect the new and evolving geopolitical and military realities of the post Cold War world. Reflecting these changes, DOE has enhanced the Nation's nonproliferation and international nuclear safety policies. At the same time, DOE has worked towards maintaining the viability of deterrence with a smaller, cost effective, secure nuclear weapons complex without underground testing.

Program Performance Measures

DOE is committed to a science-based program in order to maintain confidence in the nuclear weapons stockpile without testing, as required by Presidential directive. In addition, DOE is committed to safely disposing the nuclear fissile materials made surplus by the downsizing of the nuclear arsenal in conformance with arms control and nonproliferation treaty requirements, countering the proliferation of weapons of mass destruction, and furthering international safeguards. The Department foresees a future national security environment with continued uncertainty and risks of international terrorism from weapons of mass destruction.

The Strategic Objectives, Strategies, and Performance Measures in development for the current update of the Department of Energy Strategic Plan are the basis for this portfolio presentation. The first three nuclear stewardship strategic objectives will be accomplished as a result of carrying out the supporting activities detailed in this R&D portfolio description. The remaining goals are reflected in the additional national security objectives:

- **Objective 1—** Maintain and refurbish nuclear weapons to sustain indefinitely the confidence in their safety, security, and reliability, without conducting nuclear testing.

- **Objective 2—** Achieve a robust and vital scientific, engineering, and manufacturing capability to enable present and future assessment and certification of the enduring stockpile, and develop the ability to design and manufacture nuclear components without conducting nuclear testing.

- **Objective 3—**Ensure the vitality of DOE's science, engineering and production enterprise required for nuclear stewardship.

- **Objective 4**—Reduce nuclear weapons stockpiles and the proliferation threat caused by the possible diversion of nuclear materials.

- **Objective 5—**Continue to provide leadership in policy support and technology development for international arms control and nonproliferation efforts.

- **Objective 6—**Meet national security requirements for naval propulsion and for other advanced nuclear power systems.

- **Objective 7—**Improve international nuclear safety.

The R&D activities described in the following chapters demonstrate both significant activity changes since the end of the Cold War and how DOE is investing its resources to solve current critical national security issues.

The National Security R&D Portfolio

National security is the constitutional mandate of the Federal Government, and has no commercial/industrial analogue. Resource allocations and funding are entirely driven by the need to maintain the country's national security in a rapidly changing post-Cold War world facing a less defined, more diffuse threat. While details of many of DOE's national security activities are not widely publicized, the Department is acutely aware of the need to uphold the public's trust by fulfilling its important national security mission.

The DOE National Security R&D Portfolio has been structured to address the following five major activity areas:

- Maintaining the Nuclear Deterrent.

- Monitoring Nuclear Treaties and Agreements.

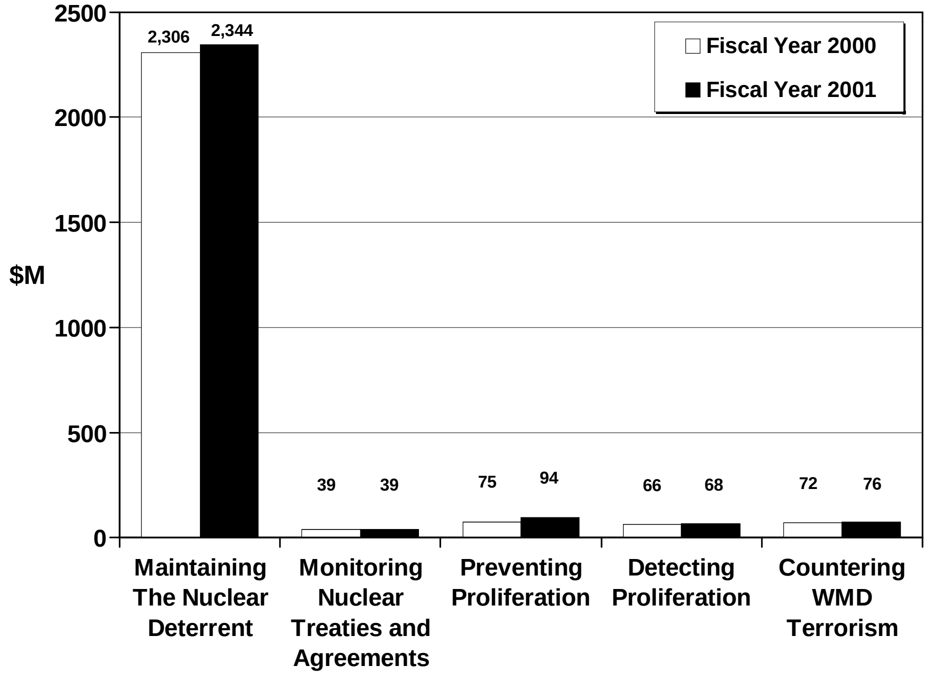
- Preventing Proliferation.

- Detecting Proliferation.

- Countering Weapons of Mass Destruction Terrorism.

The distribution of the Portfolio's resources to address these issues is shown in the figure on the following page.

National Security Portfolio Resources



The National Security R&D Portfolio's resources have been balanced in accordance with DOE's strategic plan along with numerous factors related to national needs. Maintaining the nation's nuclear deterrent in the absence of underground nuclear testing is a resource-intensive challenge. The Department's goal of implementing a science-based stockpile stewardship approach requires a large investment in new technology and research to develop and validate science-based methods to ensure the safety and reliability of the nuclear deterrent.

The nuclear weapons R&D activities generally are considered to be "applied research." Some of the research is quite basic in nature and is pursued in this Portfolio because of its value to specific applied problems encountered in maintaining the stockpile. Defense Programs (DP) has undertaken a major shift in program management strategy during the last year, resulting in the adoption of a business model for R&D management. This has resulted in significant changes to the organizational structure of the Stockpile Stewardship Program (SSP) relative to previous years. As a result, the SSP is organized into three focus areas: 1) Directed Stockpile Work (DSW), designed to ensure that stockpiled weapons meet military requirements, 2) Campaigns, designed to provide the science and engineering capabilities needed to meet ongoing and evolving DSW requirements, and 3) Infrastructure that is required for stockpile work and computational and experimental facilities at the DP laboratories and the Nevada Test Site. Within these three areas, R&D primarily is focused in DSW and Campaigns, which are multiyear research intensive initiatives that are designed to resolve DP's highest priority stockpile related scientific issues.

During FY 2000 and 2001, the SSP will significantly enhance experimental and computational facilities needed for assessing and certifying the stockpile's safety, security, and reliability in the sabsence of nuclear testing. These enhancements target improved scientific understanding and new scientific and computational facilities in six areas in FY 2001:

1. Assessment and certification of nuclear weapon primaries.
2. Assessment and certification of nuclear weapon secondaries.
3. Advanced radiography facilities.
4. Inertial confinement fusion.
5. Defense applications and modeling.
6. Enhanced surveillance of the enduring stockpile.

Although at a lower level of funding, the Department of Energy's other national security research and development programs are making considerable progress in meeting their important objectives. The Department of Energy continues its long history of developing technology to monitor nuclear treaties and agreements. In response to profound world-wide political changes, during the last decade, the Department has increased its activities in the areas of developing technology to detect and prevent proliferation. DOE's investments in preventing proliferation are 'opportunity driven' and we expect that changes in DOE's level of investment will be closely correlated with these new opportunities.

Preventing proliferation is an area of critical importance to U.S. national security and a high-interest research area for the Department of Energy. The U.S. and Russia have similar interests in and responsibilities for reducing the risk of nuclear proliferation from civilian nuclear power, and both are pursuing technology development programs to accomplish that goal. Continuing interactions with Russian officials on this topic will lead to the identification of many areas where the U.S. and Russian philosophies and technologies contributing to the development of proliferation-resistant nuclear systems will overlap. The Department of Energy intends to accelerate development of proliferation-resistant nuclear systems by implementing a new research initiative (the Proliferation Resistant Reactors and Fuels Research Program) during FY 2001.

While research and development in countering weapons of mass destruction terrorism is not new to the Department of Energy, changing world events have clearly demonstrated that terrorism is rapidly becoming a primary threat to national security. The Department recognizes that its existing expertise in nuclear weapons is a valuable asset to meet the challenges of terrorism and is leveraging the DOE Laboratories' large investment in chemical and biological sciences to support the national effort.

DOE places a high priority on its R&D so that essential long-term goals are not sacrificed to address current problems. Solving challenging problems often involves long-term, long lead time research. Within the R&D planning process, decisions are continually being made in the planning-programming-budgeting process in order to keep the priorities in rank order. At the same time, however, it must be recognized that R&D, which is one of the most important DOE functions, cannot remain healthy and vibrant within a rapidly varying funding environment.

Next Steps

The portion of this R&D Portfolio titled "Maintaining the Nuclear Deterrent" summarizes unclassified R&D activities conducted by DP. A comprehensive and classified description of the DP's Stockpile Stewardship Program can be found in the "FY 2001 Stockpile Stewardship Plan" also known as the "Greenbook." This plan is prepared annually, and is submitted by the Secretary of Energy to Congress by March 15 of each year, as mandated by the FY 1988 National Defense Authorization Act (P.L. 105-85).

Formulation of the National Security R&D Portfolio makes use of extensive scientific and programmatic reviews to help delineate the path forward. These reviews, a primary source of feedback, are used to establish baselines, to gauge and track progress, and to tune and balance R&D programs. Many of these reviews are science-focused, including JASON, the National Academy of Sciences, *ad hoc* program review groups, and laboratory-specific reviews. It is anticipated that the SSP and its constitutive elements will continue to be the subject of multiple external reviews each year. During FY 2000, for example, it is anticipated that several of the Campaigns will be reviewed by JASON.

A comprehensive review of DOE's SSP, as directed by Secretary of Energy Richardson, was recently conducted by Under Secretary Moniz. The review concludes that the SSP is "on track," but is stretched thin in many areas. A fifteen-point action plan was developed in response to the Review's recommendations, and steps to implement the action plan will be completed during FY 2000. A report that summarizes the results of the review is available at http://www.dp.doe.gov/dp_web/doc/CONRAD.PDF.

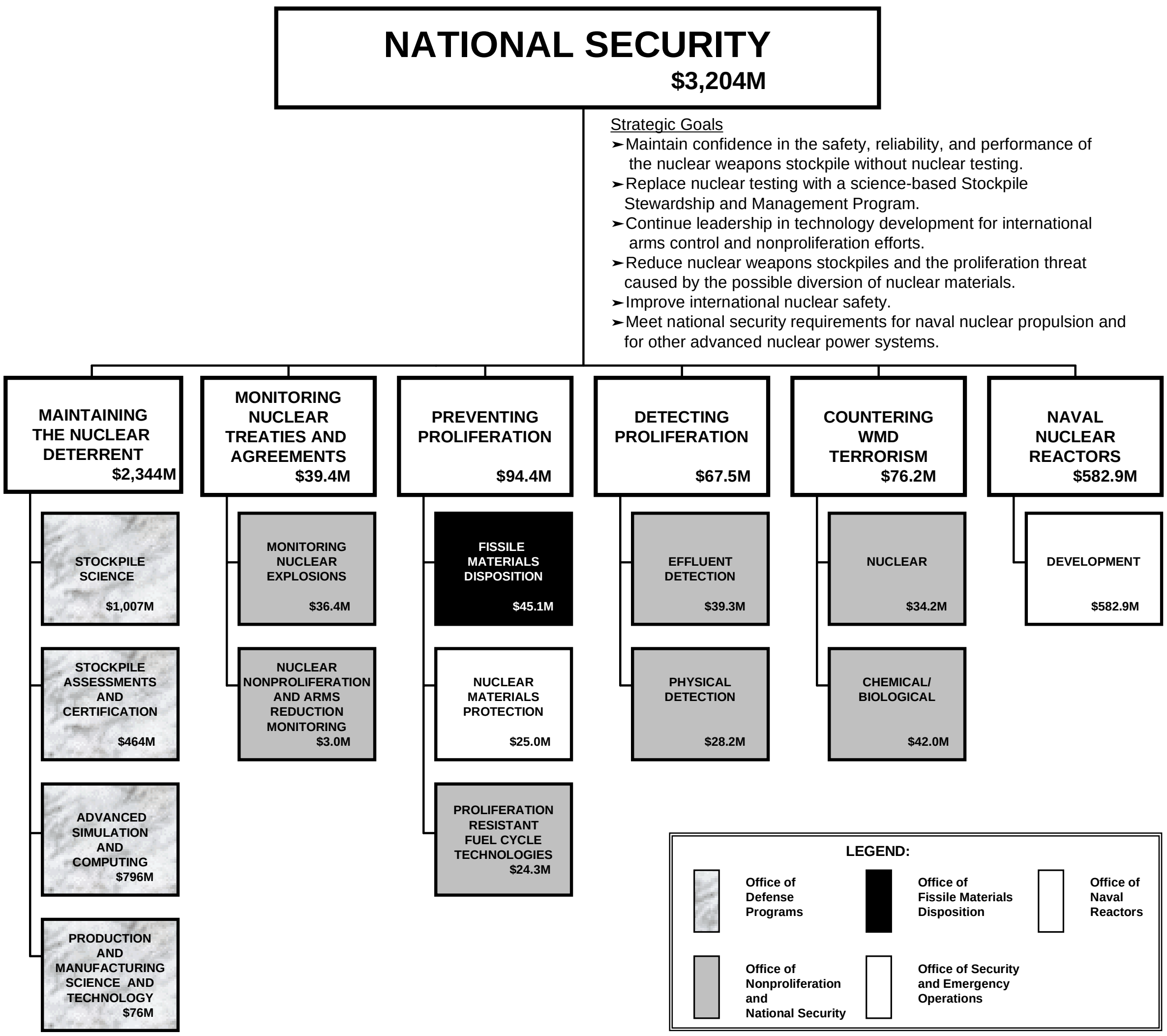
The quality of the work conducted within the National Security R&D Portfolio is directly related to, and dependent upon, the quality, capability, and motivation of the researchers themselves. Maintaining the science, engineering, and production facilities from a human resources perspective is one of the most important challenges DP faces, and one that will continue to grow as the private-sector demand for top talent increases. To understand comprehensively the issues surrounding this challenge, Congress directed in Public Law 104-201 the establishment of the Commission on Maintaining U.S. Nuclear Weapons Expertise. This Commission, chaired by Admiral H. G. Chiles, Jr., reported its findings and recommendations (Summarized in Appendix C) to Congress on March 1, 1999. One of the most important recommendations calls for the development of work force plans for each DP facility that address the human resource needs of the laboratories and production plants over the next decade. These plans will ensure that the weapon complex has in place qualified scientists, engineers and technical experts who can ensure the safety and reliability of the enduring stockpile.

The chapters on "Monitoring Nuclear Treaties and Agreements," "Preventing Proliferation," and "Countering Weapons of Mass Destruction Terrorism" provide comprehensive descriptions of DOE's contributions to national security R&D (due to classification issues, Chapter 6 of the National Security R&D Portfolio, "Detecting Proliferation," is a separate supplement). This presentation and description of the Portfolio and its relevance to national interests is an important first step in portfolio development and analysis. This document demonstrates that the Portfolio meets multiple objectives, with the robustness required for an uncertain future. Continued and expanded planning and analysis is needed to ensure appropriate prioritization and efficient utilization of taxpayer funds applied to these efforts. Future steps should include expansion of current technology and program roadmapping.

The Department of Energy has established the Nonproliferation and National Security Advisory Committee in accordance with Section 9 of the Federal Advisory Committee Act, Pub. L,. No. 92-463, and Executive Order 12838. The Advisory Committee will provide an external review of research and development activity within the Office of Nonproliferation and National Security (NN). A review and analysis of research and development activity of the Office of Nonproliferation Research and Engineering (NN-20) programs was completed in FY 2000.

Future changes to portions of the Portfolio will occur as new opportunities, technological developments, and requirements arise from evolving national and international events. Strategic planning, portfolio analysis, and technology roadmapping will provide the framework to keep pace with demanding national security needs.

Chapter 3
Maintaining The Nuclear Deterrent



Chapter 3
Maintaining the Nuclear Deterrent

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Overview

Definition of Focus Area

The Stockpile Stewardship Program is responsible for maintaining the safety, security, and reliability of the nation's nuclear weapons stockpile, while maintaining an effective nuclear deterrent under a policy of not conducting nuclear testing of weapons.

National Context and Drivers

The Stockpile Stewardship Program (SSP) was established in response to the FY 1994 National Defense Authorization Act (P.L. 103-160), which called upon the Secretary of Energy to "establish a stewardship program to ensure the preservation of the core intellectual and technical competencies of the United States in nuclear weapons." In the absence of nuclear testing, the SSP must now, and in the future: 1) support a focused, multifaceted program to increase the understanding of the enduring stockpile, 2) predict, detect, and evaluate potential problems due to the aging of the stockpile, 3) refurbish and remanufacture weapons and components, as required, and 4) maintain the science and engineering institutions needed to support the nation's nuclear deterrent. Each year, the details of the SSP are communicated to Congress through the Stockpile Stewardship Plan, which responds to direction of the National Defense Authorization Act for FY 1998 (P.L. 105-85). This chapter is, in part, derived from the November 15, 1999, draft of the FY 2001 Stockpile Stewardship Plan.

The post-Cold War national security environment is increasingly complex. Nuclear weapons and delivery systems still exist. In fact, the dissolution of the Soviet Union has led to concerns about the accountability, control, and disposition of weapons, as well as weapons components, materials, and information. Seven countries are known to possess nuclear weapons, and many others have weapons of mass destruction (WMD). Concerns in this area are underscored by underground nuclear testing conducted by India and Pakistan in May, 1998.

As the civilian steward of the nation's nuclear weapons complex, the Department of Energy (DOE) is responsible to the nation for the safety, security, and reliability of the nuclear arsenal. The Department of Defense (DoD) is the military customer for the nuclear stockpile and partners with DOE in setting requirements and establishing production goals. The Secretary of Energy represents and is obligated to the U.S. public to ensure that the nuclear arsenal remains safe, secure, and reliable. A key challenge of the SSP is to balance military weapon performance goals against civilian and military surety (safety, security, and reliability) concerns.

A significant number of the nation's nuclear weapon systems are scheduled to undergo refurbishment, the process of replacing aging components, starting in the current decade. Additional systems will simultaneously undergo engineering and manufacturing development in preparation for refurbishment. The DOE must be able to remanufacture weapon components and continue to "qualify" them as safe, secure, and reliable against future threats. A top priority of a science-based SSP includes assuring the availability of the tools, technologies, and people skills required to support these activities. The cost and schedule of developing these tools and technologies, as well as the availability of skilled personnel must be factored into the planning of life extensions of stockpiled weapons.

The DOE national security mission is driven by national security policies developed in this post-Cold War environment. On August 11, 1995, President Clinton announced the decision to maintain a strong nuclear deterrent, while seeking a Comprehensive Test Ban Treaty (CTBT). On October 13, 1999, the Senate voted not to ratify the CTBT. However, it remains national policy not to conduct nuclear testing, but instead to ensure confidence in the nuclear deterrent through the SSP. The establishment of a science-based stockpile stewardship program to maintain the stockpile without nuclear testing is a fundamental change from how stockpile confidence was previously assured. In the past, weapons systems were replaced by new systems that had been certified through underground nuclear testing, before aging effects became an issue.

Linkage to Goals and Objectives

Research in the portion of the National Security R&D Portfolio that focuses on maintaining nuclear deterrence is aligned with the following national security objectives of the draft FY 2001 DOE Strategic Plan:

- Maintain and refurbish nuclear weapons in accordance with directed schedules to sustain confidence in their safety, security, and reliability, indefinitely, under the nuclear testing moratorium and arms reduction treaties.

- Achieve a robust and vital scientific, engineering, and manufacturing capability for the future certification of the enduring stockpile, and the manufacture of nuclear weapons components under the nuclear testing moratorium.

- Ensure the vitality and readiness of DOE’s nuclear security enterprise.

To support these national security objectives, the SSP maintains five principal capabilities:

1. **Assessment and Certification—**The scientific and technical expertise to determine, annually, whether a return to nuclear testing is required to maintain confidence in the nuclear stockpile’s safety, security, reliability, and ability to meet military requirements.

2. **Design—**The scientific and engineering expertise and facilities to design new weapons, if required.

3. **Production—**The ability to produce the components, subsystems, and subassemblies necessary to support an aging stockpile and to manufacture new nuclear weapons in the future as a hedge against strategic uncertainty.

4. **Stockpile Support—**The ability to provide nuclear weapons maintenance and training support for military personnel with operational responsibilities.

5. **Nuclear Test Readiness—**The ability to resume nuclear testing, if directed by the President.

Uncertainties

The scope of the Defense Programs R&D Portfolio is governed by a consensus among nuclear weapons complex experts with regard to the contribution of the R&D to assessing and addressing risks to nuclear deterrence. These risks include: 1) risks associated with aging weapons, 2) risks associated with production capabilities and capacities, 3) risks resulting from unanticipated design issues, 4) risks associated with losing designers who have significant underground test and weapon development experience before that experience can be passed on to the next generation of stockpile stewards and before new facilities are calibrated and incorporated into assessment processes, 5) risks associated with recruiting, training, and retaining people with the dedication and education to use that expertise in the furtherance of stockpile stewardship, and 6) risks that result from an evolving international strategic environment that can cause changes in military requirements. The premise of stockpile stewardship is that technical risk in the nuclear weapons program can be understood and mitigated through a science-based approach without nuclear testing. Maintaining the ability to produce new weapon designs, to resume underground nuclear testing, and to fabricate new weapons is a hedge, to be used should the efforts of stockpile stewardship be deemed inadequate to maintain confidence in the nuclear deterrent at some future time.

Various approaches can be taken to assess and mitigate risk. Although it is a deliberate national security policy to classify nuclear weapons information, one principle of deterrence is that a potential adversary should remain deterred even if it were to possess complete knowledge of U.S. designs and operating procedures. This principal justifies a stockpile stewardship program that actively pursues a scientific understanding of the state of our weapons in each stage of their life cycle.

Although there are presently no plans to introduce new weapon types into the stockpile, the stockpile is not static. Changes occur in the state of the stockpile, and thus ongoing assessments of its condition are essential to ensure confidence in deterrence. Anticipated factors include:

- The continuing aging of weapon components and the discovery of latent design and manufacturing defects.

- The inability to produce replacement parts for weapon refurbishments because some technologies are no longer available.

- Adjusting military requirements as the international strategic environment evolves.

- The continuing improvement of the safety, security, and reliability of nuclear weapons, as improved technologies become available.

- Small intentional or unintentional changes in operations or manufacturing processes that produce unanticipated problems.

DOE's plan is to indefinitely maintain confidence in the stockpile by using nonnuclear testing and experimentation, modeling and simulation, and surveillance and selective refurbishment. This is a radical break from how confidence was assured from the Manhattan Project into the early 1990s. During that period, each new weapon type that was introduced into the stockpile was proven via underground nuclear testing at the conclusion of its development.

Because of the grave importance of maintaining the nation's nuclear deterrence, the SSP has been reviewed extensively since its inception in 1994. All of these reviews have concluded that the current SSP is the correct approach. However, indefinite maintenance of the stockpile through the SSP will remain an open scientific question for the foreseeable future.

Program Organization

The Defense Programs R&D Portfolio has been organized into four major technical areas: 1) Stockpile Science, 2) Advanced Simulation and Computing, 3) Stockpile Assessments and Certification, and 4) Production and Manufacturing Science and Technology.

Stockpile Science includes R&D into the physical phenomena that underlie the operation and performance of nuclear weapons and research in the core sciences that has promise to advance stockpile stewardship. This includes significant R&D in materials properties, advanced radiography, and inertial confinement fusion.

Advanced Simulation and Computing involves the development of terascale massively parallel computers, the hardware and software infrastructure to enable their use, and high-fidelity 3-dimensional simulation software to model weapon features and performance.

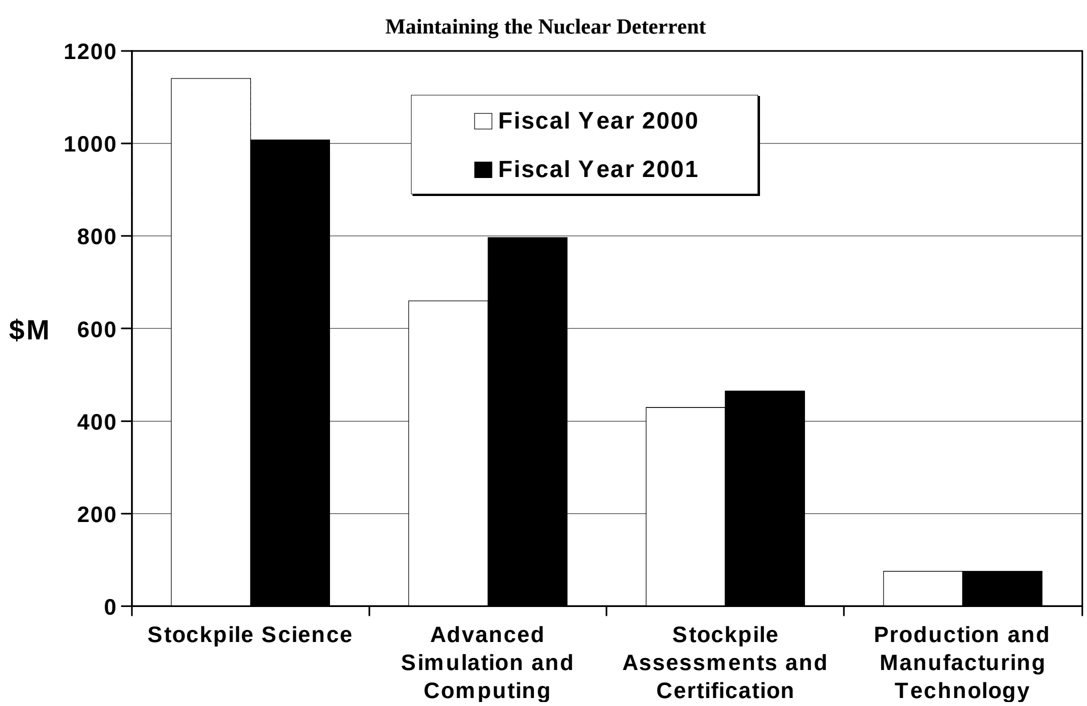
Stockpile Assessments and Certification includes development of tools for, and understanding of, weapons surveillance and certification, improved technologies for weapon engineering, improved options for weapon surety (safety, security, and reliability), and tools to certify weapon survivability in harsh radiation environments that may be encountered.

Production and Manufacturing Science and Technology includes activities that improve the ability to expeditiously design and fabricate defect-free systems, by using modern, data-intensive, computer-networked design and production technologies.

The budget numbers associated with these four technical areas reflect the entire budget for the DP Office of Research, Development and Simulation and the R&D budget from the DP Office of Stockpile Management (excluding Program Direction funds). This total represents the fully loaded costs of the DP nuclear weapons R&D enterprise which supports the SSP and deterrence.

Business Model

DP has undertaken a major shift in program management strategy during the last year, resulting in the adoption of a new business model for R&D management. This reflects significant changes to the organizational structure of the SSP relative to previous years. As a result, the SSP is organized into three focus areas: 1) Directed Stockpile Work (DSW), designed to ensure that stockpiled weapons meet military requirements, 2) Campaigns, designed to provide the science and engineering capabilities needed to meet ongoing and evolving DSW requirements, and 3) Infrastructure that is required for stockpile stewardship work, including computational and experimental facilities at the DP laboratories and the Nevada Test Site (NTS). Within these three areas, R&D is focused primarily in DSW and Campaigns, which are multi-year, research–intensive initiatives designed to resolve DP's highest priority stockpile– related scientific issues.



During FY 2000 and 2001, the SSP will enhance the experimental and computational facilities needed for assessing and certifying the stockpile's safety, security, and reliability in the absence of nuclear testing. These enhancements target improved scientific understanding through new scientific and computational facilities in six areas in FY 2001:

1. Assessment and certification of nuclear weapon primaries.
2. Assessment and certification of nuclear weapon secondaries.
3. Advanced radiography.
4. Inertial confinement fusion.
5. Defense applications and modeling.
6. Enhanced surveillance of the enduring stockpile.

Directed Stockpile Work. Directed Stockpile Work (DSW) encompasses all activities that directly support specific weapons in the nuclear stockpile. These activities include current maintenance and day-to-day care, as well as planned refurbishments outlined by the Stockpile Life Extension Process (SLEP). Additionally, DSW includes research, development, engineering, and certification activities in direct support of each weapon, both in the present and future. DSW is executed through an integrated system of plans that draw upon the entire nuclear weapons complex, including DP Headquarters, national laboratories, production plants, and other DP facilities. DSW represents a robust program that will ensure the future viability of the stockpile by maintaining a balanced effort of both near-term weapon activities and long-term future R&D.

DSW is executed through several subordinate activities, including Stockpile Research and Development, Stockpile Maintenance, Stockpile Evaluation, Dismantlement/Disposal, Production Support, and Field Engineering, Training, and Manuals. The only one of these that has significant R&D activities is Stockpile Research and Development, which involves the pursuit of the scientific understanding and engineering development capabilities necessary to support near-term and long-term requirements of the nuclear stockpile. This includes, if needed, development of all new weapon designs, pre-production design and engineering activities, design and development of weapon modifications, technical aspects of the laboratory surveillance and flight test program, safety studies and assessments, and the technical analysis needed to dismantle and safely store weapons being removed from the stockpile.

Campaigns. A significant portion of the Defense Programs R&D Portfolio is organized into Campaigns. Campaigns are technically challenging, integrated, multi-year, multi-functional initiatives managed and conducted across the DP laboratories, production plants, and the NTS. They are designed to develop specific critical tools needed to sustain the nation's nuclear deterrent. Campaigns will provide the capabilities needed to address current and future stockpile issues by employing world-class scientists and engineers and utilizing the most advanced scientific and engineering infrastructure possible. Campaigns have specific goals designed to focus efforts in science and computing, applied science and engineering, and production readiness through well-defined deliverables. Currently, there are 17 Campaigns. It is anticipated that as these Campaigns mature, and as milestones are achieved, new Campaigns will be identified and implemented. The Campaigns are listed below.

Stockpile Science Campaigns:

- Primary Certification.
- Dynamic Materials Properties.
- Advanced Radiography.
- Secondary Certification and Nuclear-Systems Margins.
- Inertial Confinement Fusion (ICF) Ignition.
- Certification in Hostile Environments.

Advanced Simulation & Computing Campaign:

- Defense Applications and Modeling.

Stockpile Assessments & Certification Campaign:

- Weapon System Engineering Certification.

The enormity of developing a comprehensive scientific understanding of all aspects of nuclear weapons has led DOE and its laboratories to evaluate existing facilities within the nuclear weapons complex and in the U.S. academic/scientific community. DOE is looking to upgrade some of its existing assets and develop a number of new facilities that are unique.

Facilities presently under construction include the following:

- **Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility** at the Los Alamos National Laboratory (LANL) has improved radiographic performance that will be crucial to developing the needed resolution for benchmarking primary code calculations and assessing system performance re-certification of the existing stockpile or future remanufactured weapons.

- **National Ignition Facility (NIF)** at the Lawrence Livermore National Laboratory (LLNL) will achieve fusion ignition and target gain in the laboratory allowing the study of fusion and high energy density conditions for national security, scientific, and energy missions.

Facilities under consideration for construction include the following:

- **Advanced Hydrodynamics Facility (AHF)** at LANL will enable high-resolution, multiple-axis proton radiography.

- **Microsystems and Engineering Sciences Applications (MESA)** facility at Sandia National Laboratories (SNL) will provide research, design, and production capabilities necessary to meet postulated microsystem-based weapon surety improvements.

Existing, highly-capable experimental resources include the following:

- **Flash X-Ray (FXR)** machine at LLNL and the **Pulsed High-Energy Machine Emitting X-Rays (PHERMEX)** at LANL provide radiographic capabilities (DARHT and AHF facilities are natural follow-ons to their capabilities).

- **Z machine** at Sandia is a pulsed power accelerator capable of a 50-trillion-watt, 18 million-amp pulse that can create a collapsing plasma known as a "z-pinch" resulting in intense x-radiation.

- **Nova** at LLNL was the world's largest and most powerful laser, used to study inertial confinement fusion (shut down in FY1999 to support construction of NIF).

- **Trident** at LANL, **Saturn** at Sandia, and **Nike** at the Naval Research Laboratory are all high-power, short-pulsed laser systems.

- **Omega,** at the University of Rochester, is the nation's principal direct-drive laser fusion research facility (also used to study inertial confinement fusion).

- **Pegasus—**This microsecond pulsed-power facility used for hydrodynamics experiments was shut-down at the end of FY1999.

Experimental Facilities/Test Readiness. Activities are conducted at the NTS to preserve the skills and facilities required to resume testing within 24 to 36 months, if directed by the President. Key positions are identified for the technical areas required to safely execute a nuclear test. Overall readiness is supported by experimental programs conducted at the test site, in particular Campaigns and laboratory-based experiments.

Experimental Facilities/Simulation and Computing. Simulation science plays a prominent, underpinning role in the SSP. A significant portion of the SSP focuses on providing the infrastructure necessary at each of the sites to support the Accelerated Strategic Computing Initiative (ASCI). Major activities include:

- Acquisition of terascale computer systems.

- Development of problem solving environment software to enable effective use of massively parallel computers.

- Development of distance- and distributed-computing software, tools, and systems.
- Development of extremely high-bandwidth data visualization capabilities.
- Partnerships with universities in unclassified computing endeavors of similar complexity to those in SSP.
- "Path forward" activities through which the SSP is collaborating with computer vendors in development of next-generation computer systems.

To prepare for the large computer systems necessary to meet the SSP's simulation objectives, new computer support facilities are under construction at both LLNL and LANL.

Federal Role

In response to Public Laws and Presidential Decision Directives, DOE is responsible for:

- Establishing and executing the SSP.
- Maintaining the capability to design, fabricate, and certify new weapons.
- Developing a stockpile surveillance engineering base.
- Demonstrating a capability to re-fabricate and certify weapon types in the existing stockpile.
- Maintaining a nuclear weapons science and engineering base.
- Ensuring the availability of tritium.
- Preserving the ability to resume underground nuclear testing, if ordered by the President.
- Formulating and executing activities to extend the effective life of stockpiled weapons.
- Ensuring that the best available surety technologies are incorporated into stockpiled weapons.

By law, DOE has responsibility for design and testing of nuclear weapons, sole responsibility for the production of nuclear weapons, weapons components, and special nuclear materials, and sole oversight of all classified nuclear weapons technical information. DOE oversight is conducted through Federal personnel at Headquarters and supported by the DOE Operations Offices. DOE owns and operates, through its contractors, the nuclear weapons complex made up of national laboratories (Lawrence Livermore National Laboratory, Livermore, California; the Los Alamos National Laboratory, the Sandia National Laboratories,), the production plants (Pantex Plant; the Kansas City Plant; the Y-12 Plant; and the Savannah River Site), and other facilities (the Nevada Test Site).

Key Accomplishments

Key accomplishments for the SSP during the past year include performing extensive activities to maintain the nuclear deterrent with a safe, secure, and reliable stockpile. For example, SSP:

- Completed the fourth annual certification of the stockpile without the need for underground testing.
- Successfully completed the inaugural hydrodynamic test using the first axis of the Dual-Axis Radiographic Hydrodynamic Test facility.
- Sustained the worldwide record for high-performance computing, with the operation of three computers in the 3 to 4 trillion floating point operations per second (teraOPS) capability class.
- Won the 1999 Gordon Bell Prize in computing by performing high-resolution, 3-dimensional simulations of the Richtmyer-Meshkov instability and associated fluid mixing.
- Partially certified the MC4380 neutron generator to hostile-environment specifications using simulations and aboveground, nonnuclear tests at the Z and Saturn pulsed-power facilities.
- Determined plutonium high-pressure thermodynamic properties by first-principles methods, illustrating advances in the ability to predict the properties of actinides under conditions relevant to stockpile performance.
- Implemented a new technique at pulsed-power facilities that uses magnetic compression to produce continuous, shockless loading of multiple flat samples which can be used to determine material properties of weapon-primary surrogates.

Stockpile Science

Budget: FY99-$1,208.2M, FY00-$1,140.4M, FY01-1$1,007.4M

The Stockpile Science portion of the Defense Programs R&D Portfolio is structured to provide comprehensive scientific understanding of all aspects of the operation of nuclear weapons to support the SSP's strategy of assuring confidence in stockpiled weapons, without nuclear testing.

The operation of a nuclear weapon consists of a sequence of precisely timed events. This includes detonation of a high-explosive charge that renders a quantity of fissile material, called the primary (sometimes referred to as a "pit"), into a supercritical state. The "pit" then undergoes nuclear detonation. Present-day nuclear weapons can use tritium and deuterium to intensify or "boost" the energy output of the primary detonation. The energy released by detonation of the primary then contributes to the detonation of another nuclear explosive, referred to as the secondary. Most of the energy output of a nuclear weapon is produced by detonation of the secondary. It is this spectrum of processes, occurring at relevant time scales, pressures, and temperatures, for which the Stockpile Science R&D strives to provide comprehensive scientific understanding.

The scientific approach used to develop this comprehensive understanding relies heavily on theory, simulation, and the development and use of specialized high-velocity launchers and laser-based and pulsed-power-based experimental facilities that can replicate the relevant time scales, pressures, and temperatures that occur during a nuclear explosion. Significant emphasis is placed on experimental facilities, called radiographic facilities, capable of precise diagnosis of the mechanics of rendering fissile material supercritical. Similar emphasis is placed on understanding the physical, mechanical, and radiological properties of weapon fissile materials and tritium, and their interactions with other materials. To understand the operation of weapon secondaries, critical research is planned on the transport of radiation and its interactions with matter. Finally, because weapons can be exposed to high doses of radiation, major research is scheduled on the interaction of radiation with nonnuclear weapon components. The remainder of this section summarizes the highlights of this portion of the Defense Programs R&D Portfolio, along the lines of the Campaigns introduced in the previous section.

Primary Certification

The *Primary Certification Campaign* includes experimental skills and facilities which help develop and implement capabilities to certify rebuilt and aged primaries within stated margins without nuclear testing. Activities include hydrodynamic experiments, subcritical experiments to validate simulation and modeling conclusions and other aboveground experiments, including experiments at the NIF, and more detailedanalysis of past underground nuclear test results. This Campaign will integrate improved computational capabilities developed under the *Defense Applications and Modeling Campaign*. Capabilities developed under the *Dynamic Materials Properties Campaign* will support directed stockpile activities for life extension efforts for the B61, W80, and W76 and certification of the rebuilt W88 pits. Certification of the performance and safety of any newly fabricated replacement or aged primary based on hydrodynamics and generalized materials descriptions is the goal of the Primary Certification Campaign.

Principal concerns are the changes in materials properties and response with aging, especially fissile material and high explosives. Long-term materials compatibility issues associated with engineering features in the weapon are important. As weapons are remanufactured, differences in the details of fabrication processes may change the properties of high explosives or fissile materials, altering the implosion process, and consequently, the performance of the primary. The effect of such changes on the initial stages of the compression can be understood through nonnuclear experiments conducted in support of this Campaign.

Boost Physics. Uncertainties in the understanding of boost physics have the greatest impact upon the ability to assess nuclear performance margins. Certain aspects of the primary system detonation process leading to boost are studied in subcritical experiments. Boost physics questions usually relate to high energy density physics issues that can be studied by using ignition and non-ignition experiments.

Dynamic Materials Properties

The *Dynamic Materials Properties Campaign* includes efforts to provide stockpile stewards with physics-based, experimentally validated physical data and models of all stockpile materials in regimes of relevance to stockpile safety, security, and reliability. In the past, dynamic materials properties of significance to the nuclear weapons program were often inferred from, and normalized to, underground test data on a descriptive and empirical basis. Without the ability to conduct such underground tests, there is a high premium on the development of advanced capabilities–experimental, theoretical, and computational–to predict materials properties and response under the broad range of dynamic conditions found in nuclear explosions. The goal for this Campaign is to provide complete, accurate, and experimentally validated models that describe the state and evolution of material properties in imploding primaries, with special emphasis on plutonium.

The physics-based materials models to be developed by this Campaign are essential to establishing predictive relationships between materials properties and stockpile safety, security, and reliability. This Campaign provides physics-based, experimentally validated data and models of all materials in stockpiled weapons at a level of accuracy commensurate with primary and secondary certification. This requires understanding materials properties under relevant pressure and temperature regimes that are often not readily achieved experimentally, but where underlying chemical complexity, constitutive properties, and microstructure evolution are still very important.

The *Dynamic Materials Properties Campaign* will provide materials data and predictive models of actinide thermodynamic properties (with an emphasis on plutonium equation-of-state and complete phase diagram) to directly support refurbishment and additional pit surveillance of various weapons systems. Moreover, this Campaign will provide physics-based, experimentally validated models of all relevant dynamic mechanical constitutive properties of stockpile materials, including failure, spall, and ejecta.

Implementing an overarching strategy to link all length scales between atomistic and continuum descriptions, the integration of laboratory experiments, theoretical models, and high-performance simulations will provide the basis for the development of predictive models and validated data of stockpile materials. Initially, the Campaign will focus on stockpile materials with the highest leverage and greatest uncertainties, including actinides, surrogate metals, boost gas, high explosives, organic chemicals, and foams. Other materials will be studied as appropriate to the development and validation of models.

Plutonium. Plutonium exhibits a unique and unusual set of materials properties. Fundamental understanding of these properties in weapons-relevant regimes is essential to assess the safety, security, and reliability of the stockpile in the absence of nuclear testing. Of particular interest are the properties and dynamic response of plutonium in high-pressure and high-temperature regimes characterizing nuclear explosions. Several experimental methods and facilities are able to produce static and dynamic high-pressure/temperature conditions that can serve as the basis for the validation of materials physical data and models. These include, but are not limited to the following:

- Diamond-Anvil Cell (DAC) apparatus which can generate static multi-megabar (Mbar) pressures in micron-sized samples of metals, gas, or high explosives. Laser- and resistive-heating techniques provide the ability to reach conditions of high-pressure and temperature in DAC-encapsulated materials.

- Gas-guns which are able to create mechanically-driven dynamic high-pressure conditions through the production of carefully controlled shock waves generated in a target made of a solid, fluid, gas, or high explosive. A plutonium shock physics facility–the Joint Actinides Shock Physics Experimental Research (JASPER) facility–is planned for construction at the NTS.

- Large-scale, high-energy lasers, such as NIF, enable the investigation of the dynamic response of materials under ultra-high-pressure conditions of shock loading, for beyond what is achievable with gas-guns.

- Pulsed-power facilities, such as the Z facility, are capable of shock and isentropic compression measurements to pressures exceeding that afforded by gas-guns. For example, the Z facility is capable of producing smoothly increasing compression to pressures in the Mbar regime over time scales of 100 to 200 nanoseconds and for measuring the resulting isentropic compression waves with time-resolved velocity instrumentation.

- Kolsky-Hopkinson apparatus which enables measurements for the determination of stress/strain behavior over low to moderate strain, and yield stress.

- Taylor cylinder impact tests allow quantification of large-strain dynamic response of weapon application materials, and serve as input to verify/validate constitutive models of weapons materials.

- Tensile split-Hopkinson pressure bar studies provide measurements of crystallographic texture, strain rate, and microstructure of materials for weapons application.

In this Campaign, several static and dynamic high-pressure experiments are planned to investigate the properties and response of plutonium and other materials, including:

- The determination of the high-pressure crystal structure and phase diagram of plutonium, using static compression in a DAC. This effort will require completion of a dedicated high-pressure beamline at a national synchrotron-radiation facility.

- The determination of the pressure-temperature dependence of volume collapse transitions in plutonium, up to the melt curve, at high pressures using static compression in a DAC.

- The investigation of the dynamic response of shock-loaded plutonium in a dedicated gas-gun facility, the JASPER facility, at the NTS.

- The quantification of the influence of crystallographic grain orientation (using the Los Alamos Neutron Science Center and x-rays) and damage evolution in plutonium and other weapons materials.

- Static neutron diffraction experiments at the Los Alamos Neutron Science Center (LANSCE), in a high-pressure cell at pressures up to 30 GPa (100 GPa = 1 Mbar) and temperatures up to 1000 K.

- Measurements of the distribution of crystal grain orientations in materials to guide more accurate modeling of strength.

- Plutonium phonon spectroscopy to validate first-principles electronic structure calculations for the development of equation-of-state models based on fundamental properties.

- Three-dimensional mapping of internal strain fields in weapon components to benchmark finite element structural models of welds and joints for remanufacturing process design and for prediction of distortion, cracking, and lifetime of pits and gas reservoirs.

- Shock Hugoniot and sound speed measurements on actinides, as required, using existing gas-gun techniques.

- Neutron Resonance Spectroscopy dynamic measurements to determine temperatures of shock compressed plutonium, for use as inputs to model development.

- Melting experiments on explosive pulsed-power systems at NTS, where controlled compression in convergent geometry potentially drives the sample through solid phases into the liquid state.

- Gas-gun "soft" recovery experiments to quantify the influence of shock hardening on the post-shock constitutive behavior and damage evolution/failure of relevant weapon materials.

Equation-of-State and Thermal Properties. The equation-of-state (EOS) of a material is a mathematical relationship between its density, temperature, and pressure. Knowledge of EOS is critical in determining how materials respond to a wide range of physical environments. The accurate hydrodynamic description of an event or system that addresses heating, phase changes, ionization, compression, and expansion, depends on accurate EOS data for the materials involved. Thus, improved EOS information is essential to providing a reliable predictive capability for weapon performance.

DP has long carried out a program of EOS measurements using a comprehensive suite of facilities, including gas-guns, DACs, lasers, and pulsed-power devices. This work has been visible in the external scientific community. An example of this visibility is the measurement of the EOS of deuterium near 1 Mbar using the Nova laser. This work, which received "The Excellence in Plasma Physics Award" from the American Physical Society in 1998, has implications for weapons research, as well as for astrophysics and planetary physics.

The next generation of stewardship facilities relevant to this problem (NIF, pulsed-power facilities with longer pulses, and high-velocity launchers) will enhance capabilities significantly, and extend access to higher pressures. For instance, with its higher energy, NIF will enable EOS measurements at pressures up to 10 Gbar. At lower pressures, NIF will carry out experiments with larger samples than previously available. The use of larger samples will help reduce experimental error and lead to improved EOS measurements. With increased energy and corresponding larger samples, the Z and Pegasus facilities are already providing an improved capability for EOS-related measurements.

Mechanical and Constitutive Properties and Response. The mechanical properties of stockpile materials include yield strength and plastic flow (both before and after melt and rapid resolidification) and failure through spallation and ejecta from shocked surfaces. Weapons simulation codes require complete mechanical properties information in the form of constitutive materials models to accurately simulate material shape changes and energy loss resulting from mechanical work. The ultimate task for the "dynamics of metals component" of this project is to develop predictive models of mechanical properties, dictated by requirements of the physics and engineering Campaigns. Unlike thermodynamic properties, however, mechanical (constitutive) properties are determined from phenomena occurring at multiple length scales, ranging from atomistic to continuum. Dynamic evolution across several time scales is also a significant issue. As a result, the theoretical treatment and experimental validation of dynamical processes, such as rapid resolidification, plastic flow and strength, and failure, are at a less advanced stage than the prediction and validation of the thermodynamic properties (EOS, melt, etc.) of materials.

In the short-term, the strategy is to improve existing phenomenological constitutive models through the use of new experimental data, *ab initio* theoretical analyses and computational simulation results, as they become available. In the long-term, the strategy is to develop rigorous multi-scale theoretical and experimental approaches to rapid resolidification, plastic flow and strength, and failure with full predictive power and extensive experimental validation.

For the *Dynamic Materials Properties Campaign* to fully support the SSP, close coordination with the Defense Applications and Modeling Campaign and with associated validation and verification efforts must be established to define insertion paths into simulation capabilities for improved materials models. This is necessary to translate the milestones and deliverables of the *Dynamic Materials Properties Campaign* into increased confidence in the ability to certify the aging stockpile. The long-standing insertion path for thermodynamics properties of materials has been the formatted EOS tables, which can be directly accessed by full-system, multi-physics weapons simulation codes. The insertion path for dynamical constitutive mechanical properties of materials requires further development.

Advanced Radiography

The *Advanced Radiography Campaign* will develop technologies for multi-view, multi-time imagery of imploding surrogate primaries, with sufficient temporal and spatial resolution to resolve uncertainties in primary performance. This work will include developing advanced multi-time, multi-view, x-ray diagnostic techniques at DARHT and further developing and evaluating proton radiography techniques. The capabilities provided by this Campaign will enable designers to infer experimentally the integral primary performance parameters. This Campaign will provide technical requirements and demonstrate required technologies for upgrading national hydrodynamics experimental capabilities that will provide the radiographic imaging needed for long-term assessment and certification of the stockpile. The goal for this Campaign is to provide accurate imagery of imploding surrogate primaries by FY 2005.

One of the most critical needs for understanding the implosion process is the ability to image the details of the compression of a pit during primary detonation. Hydrodynamic radiographic facilities presently are used for this purpose, but better spatial resolution and time-sequenced images are needed. The DARHT facility, which is based on x-ray imagery, is an example of a new capability under construction and initial testing. Development of an advanced hydrographic facility that would utilize proton radiography with adequate resolution and time-sequenced images is a goal of this Campaign.

The Flash X-Ray (FXR) machine at LLNL's Site 300 and the Pulsed High-Energy Radiographic Machine Emitting X-Rays (PHERMEX) at LANL use x-ray radiography to view and otherwise diagnose the implosion of primaries. The PHERMEX facility has undergone improvements to increase the radiographic dose available (from 250 to 350 roentgens at 1 meter) and to incorporate a double-pulse capability for producing two sequential radiographic images of about 125 roentgens each. The double-pulse capability includes a new large format, two frame gamma-ray camera. This double-pulse capability has been successfully used on several hydro-tests. DOE is building newer facilities to improve these capabilities, the DARHT facility, the first axis of which became operational in November, 1999. Enhancements to FXR will increase the resolution and increase the sensitivity for measuring thicker metal shells, allow two sequential pulses to record dynamic changes in a primary assembly, and add containment space for hazardous materials (Contained Firing Facility).

These facilities improve our understanding of how various alterations to the primary system, due to aging or fabrication processes, change its configuration during implosion and they also provide important data for bounding and validation of computational models. These tests use a surrogate for the fissile material, and therefore do not replicate the nuclear behavior or its impact on materials exactly. Consequently, the performance of the weapon, subsequent to formation of a critical mass, must be extrapolated from radiographic tests and other sources of information, including computer simulations and data from past tests.

Sub-Critical Experiments. Sub-critical experiments are performed in the Underground Experimental Complex (U1a) at the NTS using special nuclear materials, but in quantities and configurations such that critical mass cannot be reached. These experiments provide vital data on materials properties, validate modeling, and provide realistic assessments of data collection under the challenging conditions of underground experiments. In addition to providing important physical data, these experiments exercise NTS readiness to resume nuclear testing in accordance with national policy.

The 1998 Cimarron experiment measured the properties of two separate plutonium and high-explosive packages. Leading up to this experiment, LANL conducted 28 smaller scale tests without plutonium in the development of diagnostics which included:

- Holography, to measure particle distribution.
- X-ray shadowgraphy, to provide a 2-dimensional measurement of mass density.
- Specialized measurements to provide localized mass measurements.

- Pyrometry, to measure surface temperatures.

- Electrical contact pins and VISAR (laser-based interferometry measurement system) experiments, to characterize the front-surface velocity.

- Microwave interferometry and electrical contact pins to characterize high-explosive burn.

Los Alamos Neutron Science Center. LANSCE is a proton linear accelerator with a storage ring and neutron spallation source. It provides the capability for proton and neutron radiography and for a wide variety of proton and neutron scattering experiments relevant to weapons physics for fundamental measurements of actinide material properties and nuclear cross-sections. DP shares funding of the LANSCE facility operations with the DOE Office of Science.

The use of high-energy protons (>10 GeV) for radiography is a new application based on using magnets to refocus protons scattered deep inside a sample material, just as a camera focuses light scattered off of an opaque surface. Protons have the distinct advantage of very high penetrating power and low induced image background, attributes that may more than compensate for lower inherent material contrast. Proton radiography has illuminated the behavior of high explosives and may have application to primary hydrodynamics. The primary proton beam from the linear accelerator has been used to produce multiple time-sequenced radiographic images in detonated samples of high explosives. These experiments were used to calibrate reactive burn models of high explosives and were critical for the certification of the B61-11 primary.

Neutron radiography can be used to examine weapon components statically and is a potential resource for information on weapon components on dynamic materials behavior. Neutron resonance spectroscopy provides dynamic temperature measurements of burning high explosives. Low energy neutrons have wavelengths comparable to atomic dimensions. Thus, neutron scattering experiments provide information about the structure of materials at atomic scales. In addition, neutron scattering has a direct application to plutonium EOS studies.

Several projects are underway or proposed to enhance the capabilities of LANSCE. The first project will increase the neutron source intensity at LANSCE by delivering more proton beam power, and will be completed in FY 2000. The second project, to be completed in FY 2001, will increase the technical capability of LANSCE by adding five additional spectrometers to the existing suite of seven, for use in studying material stress and strain relationships at different temperatures.

Set up of the LANSCE Dynamic Experiments Laboratory will establish a dedicated firing site for dynamic experiments to take full advantage of the LANSCE's peak, single pulse capability. Key applications will allow the study of weapons hydrodynamics phenomena and high-explosive performance, and the development of dynamic proton radiography techniques as part of technology R&D for an Advanced Hydrographic Facility. Possible future capabilities might include a long pulse spallation neutron source to provide advanced capabilities for neutron scattering using cold neutrons, a field of research that underpins many of today's advanced technologies in areas such as polymers and ceramics.

Secondary Certification and Nuclear-Systems Margins

The *Secondary Certification and Nuclear-Systems Margins Campaign* includes experimental and computational activities to determine the minimum primary factors necessary to produce a militarily effective weapon. In the past, incomplete understanding of energy flow required underground nuclear tests to establish performance "margins." In the absence of underground nuclear testing, aging and remanufacturing issues require a predictive capability. The activities in this Campaign will develop a validated, predictive computational capability for each weapon type in the stockpile, determine the primary radiation emission and energy flow, and determine the performance of nominal, aged, and rebuilt secondaries. The goal of this Campaign is to determine margins and weapon-primary factors necessary to produce weapons that fundamentally fulfill the military's stated requirements.

Assessing the expected yield of the secondary is essential to ensure that a weapon will perform as specified. Predicting secondary yield requires detailed knowledge of radiation flow, atomic physics, properties of materials, and hydrodynamics. Properties of materials must be understood during processes which occur at temperatures over 100 million degrees Fahrenheit and at pressures over 10 million atmospheres, and which involve material velocities of more than one million miles per hour and time spans of billionths of a second.

Understanding how to extrapolate from theory, experimental data at much smaller scales in aboveground facilities, and code predictions of the full secondary system is much of the focus of research in this area. Secondary design efforts rely heavily on code predictions, with validation being accomplished through the program's experimental facilities, as well as archived nuclear test data.

Radiation Transport and Radiation Hydrodynamics. The transfer of heat and radiation is critical to understanding inertial fusion target performance. Radiation transport occurs through streaming, scattering, absorption, and remission of photons, and is dependent upon the physical geometry of materials. Advanced simulation codes must be able to handle radiation transport under conditions where the radiation travels either a long or short distance between interactions within the surrounding medium. These two extremes, streaming and diffusion, require different software treatments and present a difficult computational challenge.

Radiation transport experiments have been carried out primarily at Inertial Confinement Fusion Program facilities such as Omega and Z and were carried out at Nova before its operation ended in FY 1999. Looking ahead, the higher temperatures and longer pulse duration that will become available when NIF is completed will be valuable in expanding the study of radiation transport.

Facilities with high energy and/or high radiation temperature capabilities are required for such experiments. A companion program to develop new radiation transport computational capabilities is underway as part of the Defense Applications and Modeling (DAM) Campaign to develop next generation software tools for weapon calculations and simulation of inertial fusion targets.

Radiation transport experiments can be 1-, 2-, or 3-dimensional. In 1-dimensional experiments, radiation interacts with planar foil or other similar targets. These experiments address basic physics of the interaction of radiation with a given inertial fusion target material, including issues such as how the material absorbs radiation (known as opacity) and ablation. Two- and 3-dimensional experiments focus on issues specific to producing symmetric radiation to drive an inertial fusion capsule. Such 3-dimensional radiation flow experiments often serve as excellent "integrated" test beds for simulation codes.

Experimentation in all three dimensions described above have already been carried out, primarily using Z and Nova. Looking ahead, the higher temperatures and longer pulse duration that will be available at NIF will significantly expand capabilities to study radiation transport.

Opacity and Radiation Transport. Opacity, the ability of matter to absorb radiation, is fundamental to radiation transport research. The opacity of a given material depends on the degree of ionization of the material. This ionization is a function of the plasma temperature and density and of the properties of the surrounding radiation field. A thorough understanding of the electronic structure of the material (energy levels, spectral lineshapes, etc.) is also required. The plasma environment may affect the electronic properties of a given material. The development of an opacity model involves atomic physics, spectroscopy, the physics of dense plasmas, and related areas, such as molecular dynamics simulation.

Because of the enormous amount of atomic data required and the complex nature of quantum mechanical many-body problems, current opacity models rely on simplifying assumptions and the use of approximations. Increased confidence in calculated opacities is essential to full-physics simulation.

During the last ten years, a sophisticated capability to conduct opacity experiments has been developed using lasers facilities (e.g., Nova, Omega) and sub-microsecond pulsed-power facilities (e.g., the Z facility). These experiments are among the most sophisticated in the world in the area of plasma opacity. The ability to diagnose plasma temperature and density independently has been important in this effort, and many broadly applicable innovative diagnostic techniques, such as x-ray laser interferometry, have been developed in the course of this research. Much of this work has been published in scientific literature, and has had a significant impact in the astrophysical community, as well as in the nuclear weapons program. Opacity has long been of interest in the astrophysical community, as it is a major factor in understanding energy transport in stars. As an example, a series of opacity experiments, carried

out first at Nova for low-atomic-number materials and later at Z for iron, helped resolve some long-standing anomalies related to the light variability of a particular class of stars.
Under this Campaign, the opacity experimental database will be significantly expanded via future Omega, Z, and NIF experiments. The utility of NIF in this area will be its enhanced energy over Nova and Omega, which will allow access to higher temperatures.

Finally, a particular area where improvements will be pursued is in the area of ICF-based non-equilibrium opacities. In the equilibrium case, the spectral shape of the opacity is a function simply of plasma conditions. In the non-equilibrium case, collision and radiative processes affecting each of the potentially millions of excited states present must be tracked to calculate excited state populations and produce a correct frequency-dependent opacity. Detailed calculations of millions of excited states within hydrodynamics simulation codes is not practical. A major goal is to derive simplified opacity models appropriate for use in the non-equilibrium regime.

Inertial Confinement Fusion Ignition

The *Inertial Confinement Fusion (ICF) Ignition Campaign* includes those activities needed to achieve fusion ignition and enhance experimental capabilities for stewardship. Material conditions that will be reachable at NIF, through ignition of isotopes of hydrogen, together with the diagnostics available, will provide an augmented experimental capability approaching those for weapon primary assessment, certification, and weapons-relevant materials dynamics measurements. Ignition at NIF will provide a unique test bed for radiation-hydrodynamic codes, including burn propagation and hydrodynamic mixing. Achievement of ignition will be preceded by developing the ignition targets and target diagnostics, and by experiments that verify conditions produced by the laser pulses necessary for ignition. Ignited targets and other special targets will provide additional high x-ray and neutron fluxes for hostile environment assessment and certification of weapons subsystems.

The mission of the *ICF Ignition Campaign* is: 1) to address high energy density physics issues for the SSP, and 2) to develop a laboratory-scale micro-fusion capability for defense and energy applications. DOE has, for the past two decades, viewed ICF as a principal means by which to preserve nuclear weapons design competencies under a test moratorium. Although the smaller scales of ICF experiments cannot directly replicate nuclear weapons configurations, these experiments share similar design methodologies and underlying physics. Furthermore, laser and pulsed-power facilities operated primarily for the *ICF Ignition Campaign* are the only avenue, in the absence of underground testing, to reach physical conditions approaching those found in a nuclear detonation. ICF is a crosscutting area of research. The facilities are relevant to studying issues related both to primaries and secondaries with a particular role in testing and validating computer codes. Pulsed-power ICF facilities will continue to be used as sources to study the effects of hostile environments on nuclear weapons systems.

Experiments using ICF facilities provide integrated tests of computer simulations that can be scaled to conditions relevant to weapons performance. Simulation tools developed to model ICF targets include many of the same physical models (e.g., hydrodynamics, radiation transport, atomic physics, material behavior, etc.) required to simulate and predict weapon performance. In this context, ICF experiments provide an opportunity for model validation which, in turn, increases confidence in predicting weapon performance.

High-Energy-Density Physics. The study of material brought to extreme conditions in temperature and density is referred to as high-energy-density physics. Development of an understanding of materials under such conditions requires information about the intrinsic state of the material itself (atomic physics, opacity, material properties, and EOS), as well as an understanding of the evolution of the material under external forces (hydrodynamics and radiation transport). In general, high-energy-density physics problems are particularly complex because a system can often evolve to a turbulent, non-linear state in which all correlations to initial conditions and driving forces are lost. Activities in specific areas of high-energy-density physics are discussed below.

An important spin-off of the laser-based work is the use of large lasers for “laboratory astrophysics.” A group of national laboratory and university researchers have actively collaborated during the past few years on studies of fundamental nonlinear hydrodynamics common to both supernovae and nuclear weapons. This highly visible work has invigorated the stewardship program scientifically and has resulted in productive scientific interaction between the DP laboratories and the scientific community external to DOE.

The restricted energy and pulse duration capabilities of current laser and pulsed-power facilities have limited the ability to study hydrodynamics in weapons-relevant regimes. New facilities under construction as part of the stewardship program, such as NIF and a proposed extension of the pulse duration capabilities at Z, will enhance the ICF Campaign’s ability to study hydrodynamics in several major ways:

- Larger target samples may be accommodated in experiments at newer facilities. For a given diagnostic resolution, larger samples will allow more detail to be observed and thus allow more accurate comparison of data and simulation. This is especially important in the non-linear regime where precise comparison between subtle features of data and calculation is necessary to ensure proper code validation. As an example, the ability of NIF to irradiate larger samples will allow the capability to study 3-dimensional flow effects.

- Samples may be accelerated for longer periods of time, which will allow studies to proceed farther into the regime of non-linear, turbulent behavior. This is critical for validating DAM codes. Present day aboveground experiments cannot begin to explore adequately the regime characteristic of weapons.

- Stronger shocks may be generated over larger samples. This provides access to a greater regime of parameter space relevant to weapons than can be accomplished with current facilities. As an example, with the NIF it will be possible to study systems driven by multiple shocks.

Hydrodynamics. The physics of hydrodynamic flows and instabilities is important in understanding the operation of imploding primaries and inertial fusion targets. Hydrodynamic instabilities are coupled and it is necessary to calculate them well into the non-linear regime. Indeed, nonlinear hydrodynamics is a "grand challenge" scientific problem important in a number of other fields, including astrophysics, fluid flow, and aircraft design. Subtleties peculiar to defense interests, such as strongly-coupled plasma conditions, high-Z materials, and thermonuclear burn make the problem even more difficult. Fundamental nonlinear hydrodynamic phenomena of interest include Rayleigh-Taylor and Richtmyer-Meshkov instabilities, high-mach-number flows, high-vorticity flows, and compressible turbulent flows in solid, gaseous, and plasma matter. A fundamental understanding of these topics and the ability to test that understanding in relevant regimes are important in carrying out the stewardship program.

The experimental capabilities developed by DP over the past two decades make it possible to conduct experiments that address these hydrodynamics issues in aboveground experiments and in scaled experiments at temperatures and pressures of relevance to weapon applications. The suite of facilities used in this work includes facilities in the *Inertial Confinement Fusion Ignition Campaign* (Nova, Omega, Z, Nike, and Trident), as well as gas guns, shock tubes, and microsecond pulsed-power facilities (Pegasus).

Hydrodynamic experiments are being designed and analyzed by using large-scale hydrodynamics codes that provide the integration of physical processes to model many of the compound phenomena in the experiments in much the same manner that compound phenomena are modeled in weapons. The 3-dimensional codes developed under the ASCI Program are crucial to this effort. Benchmarking of the hydrodynamics simulation software via experiments is essential to the development of a predictive capability for weapons.

There already is a strong history of successful laboratory-scale measurements of hydrodynamic behavior within the DP laboratories. Rayleigh-Taylor and Richtmyer-Meshkov instability growth rates were measured successfully in a variety of configurations by using high power laser facilities, primarily Nova. This work has been communicated to the larger scientific community via publications and has received numerous awards. In addition, studies of complex features have been carried out at microsecond pulsed-power facilities. In doing these experiments DP has built up diagnostic capabilities that are used broadly throughout the program and will be applied immediately as new facilities become operational.

Fusion Ignition Experiments. Demonstration of ignition in the laboratory has long been identified as a "grand challenge" science problem, and is a major goal of the NIF. Ignition is the production of more energy from the thermonuclear reaction of the deuterium and tritium than that produced by lasers and subsequently absorbed by the target. In ICF, the fuel is contained in a spherical capsule that is compressed and heated to temperatures and densities necessary for thermonuclear combustion. For indirect drive ICF, the capsule is placed inside a hollow cylinder made of a high atomic number (high-Z) material, usually gold, known as a hohlraum, and the laser heats the hohlraum producing x-rays that compress and heat the capsule. For direct drive ICF, the laser irradiates the capsule directly compressing and heating it. A National Ignition Plan has been formulated which lays out the program of work for indirect and direct drive ignition at NIF. The plan specifies that ignition experiments would begin at NIF in FY 2006. However, this date is being revised pending completion of a new NIF baseline.

The demonstration of ignition is an important milestone for the SSP for a variety of reasons. One factor to consider is that ignition provides a means to study the physics of burning plasmas. Ignition capsules will be used in experiments aimed at understanding burn in primaries and secondaries. Certain experiments in the areas of the hydrodynamic mixing of materials, radiochemistry, and weapons effects will require ignition experiments. Another factor is that ignition is a stringent integrated test of computational modeling capability, and thus provides an important demonstration of the next generation of weapon simulation codes. In the larger view, proof of ignition will represent a major step forward in DP ICF capability.

ICF Facilities. Laser and pulsed-power devices/facilities provide complementary capabilities to perform experiments appropriate to both primary and secondary physics at energy densities that are not accessible through other kinds of laboratory experiments. The laser and pulsed-power facilities within this Campaign constitute the most advanced set of high-energy-density physics research facilities in the world.

Laser facilities within the ICF Program are:

- **National Ignition Facility**—A 192 beam laser facility that can deliver 1.8 megajoules of 0.35 micron photons to implosion targets is under construction. Early limited operations could start at the beginning of FY 2002 and full power ignition experiments will begin towards the end of FY 2006, depending on revised project scheduling. Once completed, the NIF will be the principal facility for high-energy-density weapons-physics research within the nuclear weapons complex.

- **Nova Laser at LLNL**—This 10 beam, 30 kilojoule laser facility was shut down in May 1999 to support NIF construction.

- **Omega Laser Facility at the University of Rochester—**This 60 beam 30 kilojoule laser facility will be the principal focus of laser ICF experiments until start-up of experiments at the NIF and will continue to develop techniques for application at NIF.

- **Nike Laser at the Naval Research Laboratory—**This facility provides up to 4 kilojoules of laser energy with exceptionally smooth beam uniformity. Nike is used to test the physics concepts underlying direct drive ignition and to carry out other high-energy-density physics experiments requiring high beam uniformity.

- **Trident laser at LANL—**Trident is dedicated to conducting experiments requiring high-energy laser-light pulses.

Pulsed-power programs are listed below:

- **Pegasus—**will extend experiments performed at LANL to regimes of higher energy density and partial material ionization.

- **Z—**Z is a large, sub-microsecond-scale pulsed power machine that produces z-pinch implosions, is located at Sandia. In 1997, Z achieved record x-ray output power (>200 Terawatts) and energy (almost 2 Megajoules). Z is used for weapons physics and radiation effects experiments, and to assess the feasibility of producing high-fusion yield from a z-pinch implosion.

- **Saturn—**Saturn is a lower-energy version of the Z pulsed-power device at Sandia that produces approximately 1/4 the energy in x-rays that is produced by Z.

Diagnostics. Diagnostic techniques for ICF experiments use x-ray or neutron measurement techniques that are often derived from diagnostics used for underground tests, which require larger size, higher fluxes, and longer time scales. ICF experiments serve to maintain diagnostic capabilities that are essential to test readiness. A set of diagnostics is available for weapons physics and ICF experiments at current laser and pulsed-power facilities. Goals for diagnostic development include: x-ray framing cameras with enhanced time resolution, better reflective optics and multilayer coatings for x-ray imaging, and more sensitive x-ray detectors with better spatial resolution. The high levels of x-ray fluence anticipated from future targets will force sophisticated shielding techniques. New diagnostics for ignition experiments at NIF will have to be developed, and prototypes are being tested at existing facilities (Omega, Z, Trident). Neutron fluxes will be orders of magnitude higher for ignition experiments than for sub-ignition experiments. Development will be undertaken to extend the dynamic range of current approaches and to develop new techniques to accommodate the higher fluxes. Some of these new techniques may be adaptations of nuclear test diagnostics to the smaller size, lower fluxes, and shorter time scales of NIF. An appropriate suite of calibration facilities required to support these diagnostics will be identified and developed as needed. In FY 2001, a kilojoule-class laser, Z/Beamlet, will be available as part of the diagnostics suite at the Z facility to assess symmetry and energetics issues applicable to stockpile stewardship. The Beamlet laser originally was the single-beam prototype for the NIF.

Target Fabrication. The *ICF Ignition Campaign* has a significant development activity in place on a schedule consistent with completion of NIF to manufacture cryogenic fuel capsules with the required smoothness. Numerous non-cryogenic targets also will be developed in support of the experimental program. Research into target development techniques involves work in a broad variety of fields related to chemistry and materials and is an essential component of the high-energy-density physics experimental program.

Certification in Hostile Environments

The *Certification in Hostile Environments Campaign* will develop and improve certification tools and microsystems technologies required in the absence of nuclear testing. This Campaign will develop validated computational tools for certification, reevaluate nuclear weapon hostile environments, improve radiation-hardened technologies, and demonstrate certification technologies in weapon life extension activities. The goal for this Campaign is to develop the tools and technologies required to ensure that refurbished weapons meet Stockpile-to-Target Sequence (STS) hostile environment requirements.

Hostile environments, such as those produced by a nuclear detonation, can threaten the functioning of a nuclear weapon in its STS sequence. The primary effects of a nuclear detonation are blast, radiation, and heat. U.S. strategic weapons must be designed, if possible, to survive these effects, which can compromise the physical integrity of a weapon and destroy or isrupt the operation of weapon electronic subsystems, or can disrupt their operation at key times, thereby precluding proper operation.

There are five major considerations with respect to radiation environments: 1) exposure to nuclear weapon-induced radiation while in the stockpile or on alert status, 2) exposure to radiation from anti-ballistic missile threats, 3) fratricide resulting from strategies that assign multiple warheads or bombs to a single target, 4) exposure to space radiation environments while in flight, and 5) weapon electronics exposure to radiation during their life cycle; for example, radiography required for assembly and surveillance and any other form of radiation.

To respond to this concern, the DoD includes specific radiation hardness requirements in each weapon’s STS document. These requirements are continuously examined and adjusted, as needed, to reflect understanding of current threat scenarios.

This Campaign responds to these issues by investing in modeling and simulation capabilities, aboveground testing of electronics and materials, and producing improved radiation-hardened microelectronics. These capabilities must be rigorously validated with appropriate experiments. The radiation-hardened microelectronics development and backup production capability is provided by Sandia. Related simulation studies are performed at all three DP laboratories. Aboveground experiments are performed principally at Sandia, LANL, and NTS using pulsed-power and explosively driven systems.

Radiation Hardness. In the past, nuclear systems were certified for radiation hardness by using underground nuclear tests. Aboveground facilities, including electromagnetic pulse sources, pulsed-power x-ray sources, and nuclear reactors have been used to simulate various portions of the threat spectrum. Computational simulation will play an increasing role in this area. The continuing requirement to assess and certify the performance of individual components and the entire weapon system to hostile radiation (x-ray) environments in the absence of underground nuclear testing motivates research that supports the development of simulation capabilities that can confidently predict electronic upset, thermal-mechanical shock, and thermal-structural response.

Work also is aimed at improving experimental facilities for radiation testing, both for pulsed-power and laser systems. Specific tests, in conjunction with improvements to computational simulation of radiation effects, will continue to be important to certify radiation hardness of weapon systems without nuclear testing.

As an example, a replacement neutron generator was partially certified in FY 1999, the first time a modern generator has been certified without nuclear testing. The new certification methodology relies on small-scale materials-characterization experiments at the Z facility and computer simulations using experimentally validated codes. Future projects include shields for replacement arming, fuzing and firing subsystems, and a replacement neutron generator. Improved physics understanding and new codes will form the basis for this new modeling certification methodology.

Electronics Radiation Effects. One cannot use microelectronics original design in future stockpile replacement hardware because the parts are no longer manufactured. R&D provides an understanding of the evolving radiation hardness vulnerabilities. Current research provides aging and radiation models for use in integrated circuit simulation software. These models include the effects of x-rays, gamma rays, cosmic rays, and neutrons. This understanding is expected to dramatically reduce the time and cost to develop the new electronic and optical devices required for future weapon upgrades, by assuring radiation resistance in advance, and by shortening the expensive design-build-test-fix cycle. Currently, this project is providing validation of a 3-dimensional charge-transport-device computer code.

Advanced Simulation & Computing

Budget: FY99-$483.7M, FY00-$660.5M, FY01-$796.2M

The Advanced Simulation and Computing portion of the Defense Programs R&D Portfolio (consisting of the Defense Applications and Modeling Campaign and associated infrastructure activities) subsumes all of the program elements originally contained within the Accelerated Strategic Computing Initiative (ASCI). ASCI was established to be the focus of DP's simulation and modeling efforts aimed at providing high-fidelity computer simulations of weapon systems that will enable scientists to make the necessary judgements to maintain the confidence of the nuclear deterrent. The FY 2004 to 2010 timeframe is the key target for having usable, working ASCI computer systems and codes available so that a smooth transition from test-based to simulation-based certification and assessment can be made. To achieve this goal, planning has been accomplished during the last year to link experimental data from aboveground test facilities, archived nuclear test data from fifty years of nuclear tests, and improved scientific understanding to provide high-confidence predictive simulation capabilities to support decisions regarding the enduring stockpile. Nearly all of the other Campaigns have linkages with and rely at ASCI capabilities. The use of simulation pervades the SSP.

The DP laboratories historically have been at the forefront of supercomputing. Atomic weapon calculations were among the first applications performed at the ENIAC (the Electronic Numerical Integrator and Computer), the first general-purpose digital computer. Developed jointly by the University of Pennsylvania's Moore School of Engineering and the U.S. Army's Ballistic Research Laboratory (BRL), ENIAC became operational at BRL in 1946. In the mid- to late-1950s, DP partnered with IBM in the development of the IBM "Stretch" computer, which became operational in 1959. In the 1960s and 1970s, computers designed by Seymour Cray (the Control Data Corporation (CDC) 6600 in 1964, the CDC 7600 in 1969, and the Cray-series of computers starting in 1976) became the mainstays of defense supercomputing until the late 1980s. During this period, the DP laboratories also recognized the importance of interactive computing, developing operating systems enabling that capability, first for the CDC 7600, and later for the Cray-series of computers.

Until the mid 1980s, national security applications accounted for the preponderance of supercomputing. After 1985, supercomputing became pervasive in a number of industrial applications (automobile crash simulations, pharmaceutical design, analysis of seismic data for petroleum exploration, etc.). National security uses represented only a small share of the supercomputer market. Correspondingly, DP's influence on supercomputer vendors diminished.

Following the cessation of nuclear testing in 1992, this situation reversed. Beginning around 1995, it became evident that the SSP's success relied on the achievement of computer performance significantly beyond Moore's Law (the empirical observation that computer speed increases by roughly a factor of two every one and one half years, because of decreasing feature size on microprocessor chips) before the end of the decade. As a result, DP developed ASCI, with the goal of accelerating the increase in performance beyond Moore's Law, by developing computers and associated simulation software that exploited massive parallelism (1,000s to ~10,000s processors). Because such computers were not part of the business plans of any computer vendors, DP entered into partnerships with these vendors to develop the needed capabilities. By December 1996, the DP-Intel partnership developed a massively parallel computer (9072 processors) that exceeded a trillion (1×10^{12}) operations. Today, as a result of that partnership and partnerships with IBM and SGI-Cray, massively parallel supercomputers that perform in excess of 3 teraOPS are in operation at each of the three DP laboratories.

In the absence of nuclear testing, quantifying the effects of aging and the changes introduced in nuclear weapons through refurbishment will require integrated high-fidelity simulations based on algorithms and models that accurately reflect the underlying processes in physical regimes analogous to those encountered during weapon detonation. The development of the software and computational platforms for these high-fidelity simulations is a principal product of ASCI. ASCI's goal is to deliver the required hardware and associated software by FY 2004, the time beyond which DOE is concerned that the availability of designer test experience could erode rapidly.

From an R&D portfolio perspective, ASCI is organized into five categories: Defense Applications and Modeling (the campaign for Advanced Simulation and Computing), Simulation and Computer Science, Integrated Computing Systems, University Partnerships, and Program Integration–each made up of one or more program elements. Each of these program elements is described below, along with the top-level strategies each element will use to contribute to overall ASCI goals.

Defense Applications and Modeling

Advanced Applications Development. ASCI is developing, on an accelerated schedule, the progressively higher performance applications software needed to implement virtual testing and prototyping. The key to reaching SSP objectives outlined for initial implementation by 2004 and full implementation by 2010 is the ability to achieve ASCI's critical simulation and applications code milestones in the intervening years. ASCI strives to provide simulations embodying the physical and chemical processes needed to predict the safety, reliability, and performance of weapon systems, as well as optimizing their manufacturability. It is a formidable challenge to refine or eliminate the empirical factors and adjustable parameters used in current calculations with predictive physical models. Meeting this challenge will require large, complex computer applications software that can utilize fully the scale of computing machinery and infrastructure. However, increased capability in computational machinery and infrastructure alone is insufficient. Much of the increased computational capability to be provided by ASCI will come from advances in the applications software. These applications will integrate 3-dimensional capability, finer spatial resolution, and more accurate and robust physics. Tightly integrated code teams—large interdisciplinary work groups whose objectives are to produce integrated software packages for efficient predictive simulations—will develop these codes.

Applications Objectives. Application objectives associated with Advanced Applications Development portion of ASCI include:

- Full system applications for 3-dimensional, complex-physics problems.

- Full-system component or scenario-driven (e.g., an accident scenario) simulations.
- Validation of simulations by rigorous correlation with constrained experiments and archival nuclear test data.
- Acceleration of code performance.

Verification and Validation. Verification is the process of assuring that the computational simulation accurately represents the conceptual model being used. It assesses what von Neumann called the mathematician's errors, and answers the question: "How accurately have we solved the problem?" Validation is the process of determining whether the conceptual model being used represents the real world. It assesses what von Neumann called the scientist's uncertainty, and answers the question: "Have we solved the right problem?" There are considerable benefits to addressing and reducing uncertainty and error beyond merely answering these questions. Analysis of sources of uncertainty and error can guide the construction of better models and the selection of the appropriate level of detail for each element of a complex modeling system. The verification and validation (V&V) process can be used to guide future research by identifying and quantifying the dominant sources of error or uncertainty in modeling.

The validation of nuclear weapon simulation software is a multi-faceted problem. The core capabilities can be analyzed by using a suite of test problems ranging from simple laboratory-scale experiments to very realistic weapon configurations. Additional experimental tests can be run to evaluate the models used by the simulation software. Validation of full-scale simulations of actual weapon systems requires data from representative underground nuclear tests. The validation suite must be sufficiently broad to fully exercise the software's physics models. Unfortunately, for realistic systems, the data that has been collected from underground tests is very limited in scope. For that reason, the methodology also needs to be tested against laboratory-scale experiments where a richer set of measurements are possible.

ASCI has placed special emphasis on V&V by establishing it as an independent program element. Because it not only extends traditional computer codes into new areas of 3-dimensional and complex physics simulations, this element bears the additional burden of doing so in the absence of underground nuclear tests. ASCI needs more systematic, rigorous V&V methodologies to establish the increased level of confidence that will be expected of weapon simulations. This element 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 then be supplemented by many Problem Solving Environment activities. These multiple interfaces present a significant management integration challenge for which ASCI applications and platforms can assist in the resolution of interest to weapons scientists. The link between V&V activities, the experimental program, and Campaigns is crucial to the success of this effort.

V&V Objectives. The following objectives are being pursued to verify and validate ASCI simulation software to:

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

- Provide the experimentation requirements to conditional validation efforts within the SSP.

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

- Evaluate current software engineering practices for application to ASCI-scale simulation software development and computing platforms and establish minimum requirements for the verification process to reduce uncertainties associated with computational implementations.

Materials and Physics Modeling. In the past, physical properties of matter that are significant to the nuclear weapons program were often inferred from underground test data. Because such underground tests are no longer performed, there is a high premium on the development of advanced capabilities (experimental, theoretical, and computational) to predict the physical properties of matter under conditions found in nuclear explosions.

At the heart of the development of these predictive capabilities is the determination of the physical properties of matter in regimes relevant to processes governing the performance, safety, and reliability of the nuclear stockpile. Of particular interest are the dynamic properties and response of materials under conditions of high strain and high-strain rates, impact, shock compression and quasi-isentropic loading. The dynamic response of materials is largely defined by the functional relationship between microstructure evolution, mesoscale properties, and macroscopic response. 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 and high-performance simulations will provide the basis for the development of predictive models and validated physical data of stockpile materials. Consequently, ultra-scale scientific computing platforms, multi-physics 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 elucidated and have led to the partial resolution of long-standing anomalies observed in some nuclear tests. This example illustrates the powerful synergy from combining high-performance scientific computing with advanced experimental facilities in the rigorous development of predictive models and validated materials properties data. Timely insertion of validated materials models and properties data into next-generation, full-physics, full-system weapons codes will provide the basis to ensure confidence in the stockpile without nuclear testing.

Rigorous linkages from the atomistic to the continuum scales will lead to the development of predictive simulation capabilities describing the properties and response of matter in regimes of significance to nuclear weapon operation. The recent first-principles determination of the high-pressure properties of actinide and hydrogen illustrate these advances. Key high-pressure actinide properties have been validated in the Mbar regime and have produced fundamental advances in this area.

Similarly, quantum-scale simulations and laser-driven shock compression experiments have validated the EOS of hydrogen up to several Mbars, providing valuable insight both into weapon performance and inertial confinement fusion.

Materials and Physics Modeling Objectives. The following objectives are used in modeling materials and physical properties:

- Determine from first-principles the global EOS for deuterium.
- Develop physics-based, multi-length scale constitutive models for the dynamic response of relevant metals.
- Develop predictive models of materials failure, spall, and ejecta.
- Develop predictive models of interfacial dynamics in materials used in primaries.
- Develop physics-based models for predicting the properties of plutonium due to aging and self-irradiation.
- Develop physics-based models of the thermal and mechanical properties of high explosives, including decomposition kinetics, detonation performance, properties of reaction products, and constitutive properties.
- Develop validated models for the dynamic response of foams, polymers, and other organic compounds.

Simulation and Computer Science

Problem-Solving Environment. ASCI's code-development effort will require robust computing and developing environments in which codes can be developed rapidly. Through the Problem-Solving Environment (PSE) program, ASCI will develop a computational infrastructure to allow applications software to execute efficiently on the ASCI computer platforms and allow accessibility from the desktops of scientists and engineers. This computational infrastructure will consist of local area networks, wide-area networks, advanced storage facilities, and software development and data visualization tools.

PSE Objectives. The goal of the PSE program element is to provide application developers and weapon scientists and engineers with the computational tools they need by:

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

- Producing an end-to-end high performance input/output (I/O) and storage infrastructure encompassing ASCI platforms, large-scale simulations, and data/visualization corridors, enabling improved terascale code execution and data exploration.

- Ensuring appropriate access to ASCI computers and other ASCI resources across the three weapons laboratories.

Visual Interactive Environment for Weapons Simulation. Visual Interactive Environment for Weapons Simulation (VIEWS) is a new ASCI program element focused on the problem of "seeing and understanding" the results of multi-teraOPS simulations, and comparing results across simulations and between simulations and experiments. VIEWS brings together ASCI-supported research, development, engineering, deployment, and applications support for visualization, data management, and data exploration. Through the creation of VIEWS, DP intends to focus increased attention on the problem of exploring and understanding multi-terabyte scientific datasets.

The goal of VIEWS is the creation of an infrastructure called a "Data and Visualization Corridor (DVC)." The storage and I/O systems of supercomputers, and the graphics workstations attached to them can be characterized 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 and rapidly 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.

The corridor concept was outlined through a collaboration of DOE scientists, researchers from academia and industry, and leaders of a number 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 capable of being produced from teraOPS scientific simulations was, from the beginning, the driving force. The VIEWS Program implements the DVC concept within the DP laboratories.

There are several steps involved in achieving successful DVCs. In many cases, needed hardware and software technologies do not exist or are not yet mature. 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 focuses on promising technologies that can have direct impacts on the ASCI program in a two- to four-year time frame. Once prototype technologies exist, they need to be "hardened," i.e., integrated, tested, and evaluated by a representative set of users. Finally, these technologies need to be deployed in a generally available, operationally reliable environment for direct day-to-day use by ASCI users and applications.

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

- Visual exploration and interactive manipulation of voluminous, complex data.
- Orchestrated, effective data management, extraction, and delivery.
- Efficient solutions for remote and collaborative scientific data exploration.
- Deployment of highest-performance DVCs.
- Partner with academia, industry, and Federal agency R&D.

Distance and Distributed Computing and Communications. Distance and Distributed Computing and Communications (DisCom^2) will assist in the development of an integrated information, simulation, and modeling capability to support the design, analysis, manufacturing, and certification functions of the DP complex through developments in two key strategic areas: distance computing, which extends the environments required to support high-end computing to remote sites, and distributed computing, which develops an enterprise-wide integrated supercomputing architecture that will support DOE's science and engineering requirements for stockpile stewardship.

DisCom^2 Objectives. DisCom^2 has three top-level objectives:

- Extend the environments required to support high-end computing by users located at remote sites.

- Develop and deploy an integrated distributed computing environment.

- Develop an enterprise-wide, integrated supercomputing architecture that will support DOE's science and engineering requirements for stockpile stewardship.

PathForward. ASCI's hardware and software strategy is to build future high-end computing systems by scaling commercially viable building blocks to a 100 plus teraOPS capability by 2004. The PathForward program consists of partnerships with multiple computer companies to develop and accelerate technologies that are expected to either not be in the current business plans of computer manufacturers, or to not be available in either the time frame or the scale required to support the SSP. ASCI is executing the PathForward program by entering into partnerships with U.S. industry to accelerate the development of balanced (i.e., balanced among processor speed, memory capacity, and disk-storage capacity) 30- to 100-plus teraOPS computer systems.

Currently, the PathForward program element invests in the development of technology in three critical areas: interconnect, storage, and software.

PathForward Objectives. PathForward uses the following top-level objectives to:

- Stimulate development of inter-processor interconnect technologies leading to a bandwidth of up to 0.1 teraOPS, while maintaining low mean-time between failures.

- Maximize performance factors of data density and steady-state data rate in development of advanced storage technologies.

- Stimulate development of software to accelerate runtime system technologies and third-party alternatives for use in 100-teraOPS computing environments.

Integrated Computing Systems

Physical Infrastructure and Platforms. The DOE weapon laboratories have a strong scientific computing capability, a continuing commitment to leading-edge hardware, and a tradition of developing large simulation codes. DOE's core-computing program maintains and improves the current design codes and adapts them to run on more capable machines as they become available.

More powerful computing platforms are needed to achieve the performance simulation and virtual prototyping applications that the SSP requires. ASCI is stimulating 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 would have resulted from past trends. ASCI will continue to partner with various U.S. computer manufacturers to accelerate the development of larger, faster computer systems and software that are required to run DP applications. ASCI partnerships have already brought about development and installation of the world's first teraOPS capable computer (the 1.8-teraOPS Intel machine at Sandia, recently upgraded to 3 teraOPS), and two three-plus teraOPS machines at LANL (in partnership with SGI) and LLNL (in partnership with IBM), respectively. An extension of the LLNL/IBM contract has set in motion the development of a 10-teraOPS machine to be installed at LLNL during 2000. The delivery and installation of a 30-teraOPS system by 2002 to LANL is the next important milestone in the implementation of the Platform program's strategy. Beyond the 30-teraOPS, the strategy calls for a 100-teraOPS system in 2004.

Integrated Computing Systems Objectives. To develop, procure, and make available next generation computing systems, the following objectives are used to:

- Accelerate the development of scalable architectures.

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

Operation of Facilities. The Operation of Facilities element is focused on making the computational resources needed to support stewardship available to the laboratories. While this element is structured differently at each of the laboratories, program-wide it is divided into three areas: Operations, Software, and R&D.

- **Operations—**The Operations effort is focused on the operation of the computer centers at the three DP laboratories. In general, this effort has two mission elements to: 1) provide ongoing stable production computing services to laboratory programs, and 2) foster the evolution of simulation capabilities towards a production terascale environment as ASCI computer platforms evolve towards the 100-teraOPS goal by the middle of the next decade. This effort consists of hardware platforms, software infrastructure, networks, data storage, and output systems.

- **Software—**The Software portion of the Operation of Facilities Software effort supports the evolution of existing weapon simulation capabilities and provides ongoing support for the physical databases used by both legacy codes and the advanced ASCI weapon simulation codes. These efforts are structured to coincide with the technical programs associated with each of the computer codes.

- **R&D—**The R&D effort of the Operation of Facilities element focuses on underlying R&D to provide a continuing stream of new information and simulation innovation for ASCI and the stewardship effort.

Operation of Facilities Objectives. The following objectives are used to ensure operational computer facilities:

- Operate and maintain laboratory computing centers.
- Maintain legacy production codes for near-term stockpile stewardship use.
- Use legacy input data and codes for benchmarking and V&V.
- Provide production simulation capabilities that support the enduring stockpile and serve as the foundation of future ASCI code development.
- Enable, preserve, and advance existing computational capabilities to meet stockpile requirements.
- 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.
- Conduct underlying R&D in computational sciences, networking, computational physics, and engineering sciences to support development of advanced ASCI codes.
- Conduct underlying R&D to support development and deployment of advanced physics and engineering simulation and information environments within ASCI programs.

University Partnerships

Academic Strategic Alliances Program. Historically, universities have always have had a close relationship with the DP laboratories. In fact, LANL and LLNL have been managed for the DOE by the University of California for many years. There have been times, however, when the missions of the universities and the DP laboratories have not been closely aligned. The mission of the DP laboratories is focused on nuclear weapons, which requires very tight control of scientific information. Universities, on the other hand, generally encourage the free and open exchange of ideas and scientific knowledge. While this difference in the approach to handling information has sometimes led to tensions, ASCI and universities share a new, common and critical interest. The success of ASCI depends on the ability to demonstrate that simulations can credibly be used as a means of ensuring stockpile confidence. Universities share this interest in proving that simulations can credibly reflect and predict physical reality. Simulation has already proven valuable in exploring 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 strategy.

The SSP requires the technical skills of the best scientists and engineers working in academia, industry, and other Federal 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 larger computing community to develop and apply commercially acceptable standards. Finally, 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. This is viewed as an important step toward developing the next generation of scientists needed for national security R&D at the DP laboratories.

Research projects in the University Partnerships part of ASCI are being implemented in three levels.

Level One Strategic Alliances have established five major centers that engage in long-term, large-scale, unclassified, integrated multi-disciplinary simulation and supporting science and computational mathematics representative of ASCI-class problems. The centers have a five-year funding commitment, each starting at about $3.7M per year with planned growth to about $5M per year and are subject to contract renewal in the third year. These centers will collectively have access to up to 10 percent of the ASCI-class computing resources at the DP national laboratories:

- 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.

Level Two Strategic Investigations have established smaller discipline-oriented projects working in computer science and computational mathematics areas identified as critical to ASCI success.

Level Three Individual Collaborations establish focused projects initiated by individual ASCI researchers working on near-term ASCI-related problems. Typically, these specific projects are in the $50K to $100K per year range, funded out of other ASCI program element budgets.

In addition to these three levels, ASCI is establishing the ASCI Institutes at the laboratories in FY 2000. The charter of the ASCI Institutes is to collaborate with academia on research topics in computer science, computational mathematics, and scientific computing that are relevant to the SSP. These collaborations will be conducted through a variety of mechanisms, ranging from one-day seminars to multi-month sabbatical leaves at the laboratories. The three Institutes will each have different topics of emphasis, depending on local needs; but they are expected to coordinate and leverage their activities to ensure maximum benefit to the program. 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.

University Partnerships Objectives. University partnership objectives are used to:

- Encourage strategic alliances and collaboration.
- Leverage other national initiatives.
- Collaborate with the best R&D programs of other DOE departmental offices, other agencies, universities, and industry.
- Attract top researchers in the 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.
- Include smaller scale collaborations with individual investigators and research groups to work on more narrowly focused problems, such as turbulence.
- Closely link task-oriented collaborations with specific ASCI deliverables.

Program Integration

One Program—Three Laboratories. The problems that ASCI will solve for the SSP span the activities and responsibilities of the three DP national laboratories. Cooperation among the DP laboratories is essential to solving these problems in an efficient and effective manner. In accordance with this cooperative philosophy, representatives of the laboratories have jointly developed the ASCI portion of the Defense Programs R&D Portfolio. The ASCI program is implemented by project leaders at each of the laboratories, guided by the Federal oversight of DOE's Office of Research, Development, and Simulation, under the Assistant Secretary for DP.

The DP laboratories share ASCI code development, computing, storage, visualization, and communication resources across laboratory boundaries in joint development efforts.

Integration Objectives. Integration objectives are used to:

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

Stockpile Assessments and Certification

Budget: FY99-$432.9M, FY00-$428.9M, FY01-$464.3M

The Stockpile Assessments and Certification portion of the Defense Programs R&D Portfolio is structured to provide the scientific and technological tools, data, and skills to assess and certify the safety, security, and reliability of the nuclear weapons in the stockpile in their normal day-to-day routine, and in normal and abnormal flight environments, such as fires and crashes. The Portfolio's activities provide tools and skills to survey stockpiled weapons for age- and possible latent-design-related problems, as well as the engineering skills to produce revised designs to overcome problems that are discovered. The activities also provide the comprehensive engineering skills to produce designs for weapon refurbishments that are anticipated to start during the next decade. Part of the Portfolio targets development of advanced technologies for improved weapon safety and security, potentially to be incorporated in these refurbishments.

As in the case of the Stockpile Science area, this domain relies heavily on a combined simulation and experimental approach. Because of the expense of flight tests and other nonnuclear system-level tests, there is a heavy reliance on providing data for use in validating the simulation techniques being developed in the Advanced Simulation and Modeling area. There is a similar dependence on simulations in understanding and predicting age-related problems before these problems can compromise the safety, security, or reliability of stockpiled weapons. The remainder of this section describes R&D highlights of the Stockpile Assessments and Certification area, first in terms of its Campaigns, followed by a brief description of non-Campaign research that focuses directly on immediate stockpile needs.

Weapon System Engineering and Certification

The *Weapon System Engineering and Certification Campaign* will establish science-based engineering methods to increase future certification confidence in weapons systems through validated simulation models and high-fidelity experimental test data within a limited test program. The goal is to conduct one half the number of tests while obtaining twice as much experimental data for system engineering certification. This Campaign will develop validated engineering computational models and a suite of tools to allow for science-based certification of the B61, W80, and W76 life extension programs. The goal of this Campaign is to establish a predictive capability integrated with fewer, but smarter, experiments to assess weapon performance with science-based certification.

System integration is the disciplined approach to assure that each subsystem will perform as expected in the presence of other subsystems, and that the entire system will perform as required when mated to the delivery system and subjected to normal and abnormal environments as specified in the STS sequence. System integration strongly motivates engineering research, particularly the development of validated simulation capabilities. System integration is essential to ensure that all DOE subsystems can be assembled with DoD supplied systems and components into a militarily effective weapon.

Thermal/Fluids engineering concentrates on energy and mass transport and the induced physical and chemical changes in systems. With fluid mechanics, research focuses on mass and energy transport in liquids and gases. Thermal science concentrates on energy transport in liquids, gases, solids, and their interfaces. Aeroscience applies thermal sciences, fluid mechanics, and reactive processes and a better understanding of vehicles and objects subjected to aerothermal environments. Reactive process research is concerned with the chemical and physical changes that result from energy and mass transfer.

Solid mechanics and structural dynamics research is focused on the behavior of structures in regimes of large deformation and failure, or in the case of structural dynamics in large jointed structures such as a reentry body. These disciplines are underpinned by material mechanics research, which seeks to develop engineering descriptions of material response primarily in regimes of nonlinear response.

As the scope and complexity of the engineering simulations that support system integration grows, it is becoming necessary to develop more formal methodologies for treating uncertainties. DP research in this area is providing national leadership in developing methods for uncertainty quantification. These methods will deliver the capability to enable quantitative characterization of the accuracy of calculations of nuclear weapon systems. In related disciplines, optimization methods are being developed that provide the capabilities to optimize engineering designs by using computational studies, determine the optimum paths for the manufacturing of systems and components, determine sensitivities to a multivariate parameter set, and generate solutions for other problem sets requiring optimization techniques.

Environmental Testing. Various facilities are used to simulate shock, vibration, acceleration, and the thermal environments to which a nuclear weapon may be exposed to in normal or abnormal environments. With the increasing emphasis on the use of simulation to certify the integrated nuclear weapon system, traditional environmental testing must support a dual role of confirmatory analysis in the certification process and verification in the process of model validation. This expanded role places greater emphasis on research in the area of improved diagnostics in exploring high shock, fire environments, large mechanical deformation and failure, and material response to radiation environments.

Enhanced Surety

The *Enhanced Surety Campaign* includes efforts to develop improved surety options to be incorporated in future weapon refurbishment. This Campaign will develop enhanced surety options for the B61, W80, and W76 weapon systems in concert with refurbishment schedules. It also will incorporate new computational capabilities in the component development process and support integration of microsystems components. This Campaign is needed to meet DOE's obligation to provide the most modern surety possible for nuclear weapons during the replacement, refurbishment, and/or upgrade of weapon components. This Campaign is enabled by the MESA complex, which will provide advanced microsystem technology options for weapons surety upgrades. The goal for this Campaign is to meet modern nuclear safety standards in time for scheduled weapon refurbishment.

The initiation scheme is an essential part of the nuclear safety system, and is the first step in reliable operation of a weapon in the STS. To assess the health of the current stockpile components and to design, manufacture, and certify replacement components, a strong R&D base is essential. The principal challenge for the initiation system is to maintain simultaneously the required system reliability coupled with extreme safety requirements (less than $1x10^{-9}$ probability of unintended detonation over the lifetime of the weapon in normal handling, and less than $1x10^{-6}$ in any possible accident scenario) to avoid accidental or unintended detonation over the lifetime of a weapon. By comparison, these requirements are 400,000 times more strict than those for a nuclear reactor, and place very high standards on individual component reliability. New challenges arise because some technologies used to produce many of the components in these systems are no longer available, and refurbished weapons must therefore use alternate technologies to produce new components. Contemporary technologies are being explored that have great potential to improve the safety, security, reliability, and maintainability of stockpiled weapons.

Developing improved arming, fuzing, and firing subsystems will remain an important aspect of weapon refurbishment during the coming decade. In the past, the arming system has relied upon complex electromechanical coded switches. These devices operate to arm the weapon when they receive the correct coded train of electrical pulses, otherwise they lock-up to prevent further arming action. Understanding how these components age and what technologies will replace them is a central part of the ongoing R&D effort. Modern initiation technologies that use microelectromechanical systems or electro-optical systems that have a great potential to improve safety, security, reliability, and maintainability.

The fuzing system (radar altimeters, contact fuzes, flight timers, etc.) determines the point at which the weapon should be detonated. Radar systems must operate in hostile environments and be compact enough to fit in the small volumes available in a reentry body. Contact fuzes must operate reliably on ground contact at the extreme velocities associated with reentry and be capable of detonating the warhead before the ground shock destroys the weapon system. Similarly, flight timers must be robust enough to survive intensely harsh conditions and function as designed.

The firing system must generate precisely timed high voltage signals. One of the aging issues faced in the stockpile results from the generation of this high voltage by explosive depolarization of a ferroelectric material. The capability of that ferroelectric material as it ages must be understood to guarantee proper and safe initiation of the weapon.

The underlying science base for microelectronics and microsystems provides a foundation for the incorporation of new technologies into weapon systems and stockpile stewardship operations. These technologies represent improved weapon control and operation, as well as introduction of intelligent systems that monitor and diagnose weapons condition with regard to aging, functional status, intrusion or tampering, and anticipated performance. Key elements of nanosciences (study of objects from two to hundreds of billionths of a meter in size) research include aging and analysis, self-aware sensors and systems, radiation environmental effects, advanced concepts for firing systems, arming and fuzing, telemetry instrumentation, and optical communications.

Nanoscience research relevant to primary initiation addresses two specific task areas—the science of semiconductor technologies and nanoscale materials. These areas augment and support complementary tasks in materials and electronics research.

The science of semiconductor technologies has as its objective the development of novel tailored semiconductor materials and structures for micro-optical and nanoelectronic devices and systems, and to investigate quantum transport in novel semiconductor structures to provide the basis for ultra-high-speed electronic and optical devices. Research is underway to explore the integration of semiconductor microcavity lasers with other material classes as the basis for novel sensing applications. In addition, advanced materials growth and fabrication techniques are being probed for use in multi-functional, monolithic semiconductor structures and systems.

The objective of nanoscale materials research is the understanding of atomic-level, nanostructured materials, of shock and radiation at the nanoscale, and development of a complementary diagnostic suite in order to create the scientific technology base needed by DP. Specific research activities underway on nanoscale materials include developing field-structured and nanocluster-assembled materials, as well as materials with mixed bonding configurations with tailorable properties and anisotropies. In addition, work is underway to understand surface modification and thin film deposition requirements to tailor surface hardness, wear, friction, adhesion, optical, and electrical properties. Further research concentrates on developing and determining the range of validity of first-principles computational methods to describe the defect properties and dynamic response of these materials.

In the area of mechanical shock and radiation effects on components, physics research is being conducted to develop continuum and atomic-level understanding, models of shock-induced phenomena, and complementary advanced diagnostic capabilities. Such research is necessary to improve our understanding, prediction, and proficiency of microelectronic and optical device performance in radiation environments.

Integrated microsystems exploit advances in modern microelectronics technology the processing of information performed by microprocessor chips. Integrated microsystems incorporate ultra-miniature sensors, actuators, and wireless (optical or radio-frequency) communication components, with the potential to replace hundreds of individual parts with a multi-functional piece of silicon, eliminating thousands of solder joints, (a frequent source of failure) through single-chip integration. This will reduce the cost of manufacturing functionally similar parts by using modern microelectronics batch fabrication methods and will provide components that can easily be replaced or upgraded in the future. Integrated microsystems for nuclear weapon applications must meet significantly more demanding requirements than commercial applications, while at the same time ensuring higher confidence and greater reliability.

Safety. Maintaining the safety and security of nuclear weapons and preventing their unauthorized use has always been of paramount concern because of the potential consequences. Although much of the issue of nuclear weapons safety and security is integral to other nuclear weapons design and assessment activities, the primacy of nuclear weapons safety in meeting national security goals requires that it be highlighted as a separate functional area. There are separate groups of researchers who are responsible for independent safety assessment. Even if relatively small in terms of overall effort, these efforts are essential to maintaining confidence in the safety of a nuclear weapons system.

Nuclear weapons safety research is focused on nuclear, conventional, and radiological safety. It is a combination of efforts in nuclear science, chemistry, materials science, and systems analysis. For nuclear safety, the issue lies in setting an upper bound on criticality levels in irregular geometries that result from fire and mechanical insults to a weapon. Safety analysis software emphasizes accurate modeling of materials strength properties. Safety studies take this information into account in assessing the likelihood that accident scenarios or unauthorized actions could compromise the security of a weapon.

Necessary refurbishment in stockpiled weapons expected over the next decade will provide opportunities for upgrading critical safety components. Two critical technologies that have the potential of improving weapon safety are MicroElectroMechanical Systems (MEMS) and direct optical initiation. A range of research activities to be carried out at the proposed MESA complex would support the development of these technologies into practical design options for future consideration.

The research effort in MEMS structures is focusing on improved fabrication technologies, and developing functional device and component prototypes. The attractiveness of MEMS technology stems from inherent characteristics of the candidate material, polycrystalline silicon. Its mechanical properties are excellent: it is stronger than steel (polysilicon has a strength of 2 to 3 GPa while steel has a strength of 200MPa to 1GPa), it is extremely flexible,and does not readily fatigue. Most importantly, polysilicon is directly compatible with modern integrated circuit fabrication processes. Batch fabrication in integrated circuit foundries makes it possible to produce MEMS in large volumes at extremely low cost.

Research is focused on increasing the complexity of the devices being created using polysilicon surface micromachining. The complexity is governed by the number of mechanical layers available in the fabrication process. For example, with a ground plane and one mechanical level, an actuating comb drive can be created. With two mechanical levels, it is possible to create mechanisms, such as a gear constrained to rotate on a hub, and various types of mirrors. Adding a third mechanical level enables the creation of linkages to connect actuators to mechanisms and opens up an entirely new range of design possibilities.

Two of the challenges associated with adding extra layers of polysilicon to a surface micromachining fabrication process are related to residual film stress and device topography. Recent research advances have allowed development of technologies focused on reducing polysilicon stress.

Other polysilicon research is aimed at improving the flexibility and applicability of the MEMS devices. The creation of microsystems, that sense, think, act, or communicate often requires electronic circuitry coupled with mechanical elements. The monolithic integration of electronic circuitry (such as CMOS) on the same chip as electromechanical devices has many advantages over approaches that involve complex multichip packaging schemes. Batch fabrication of "systems on a chip" enables very low cost production. In addition, by reducing the number of components in the system, significantly improved system reliability may be achieved. For example, reducing the chip count, eliminating the bond wires connecting electrical to mechanical circuits, and reducing the complexity of the packaging/assembly process all benefit reliability. Finally, monolithic integration enables overall system performance, particularly for microsensing systems, to be increased by many orders of magnitude by reducing electrical interconnect parasitics, such as capacitance (i.e., the ability to store electrical charge).

The obvious and overwhelming benefits of an integrated CMOS/MEMS technology have motivated the pursuit of numerous fabrication approaches by MEMS researchers. The Enhanced Surveillance Program is focusing on "Integrated Trench Technology" to realize the potential of integrated systems. Integrated Trench Technology forms the mechanical devices in a trench prior to the fabrication of the associated CMOS circuitry.

Direct-optical ignition refers to initiating the explosive charge that implodes the pit by using light energy (directly using photons). In principle, this can eliminate the need for conducting electrical wires in the immediate vicinity of the explosive, which could improve the safety of some weapon types. Research supporting direct optical initiation technology focuses on the development of physics-based models in lasers, optical parametric oscillators, and nonlinear optics and processes. Optical components, such as micro-optics and photosensitive materials, are under development. For all these technologies there is a concomitant requirement to understand how radiation affects these components, so companion research in this area is being conducted. Specific activities include developing an ultra compact optical source for direct optical initiation combining plasma and laser expertise to reliably trigger a sprytron using a laser signal with the goal of using the results of that research to develop a miniature laser and optical delivery system.

Enhanced Surveillance

Most weapons in the enduring stockpile were built for a defined lifetime. These weapons are approaching ages for which current scientists have little experience. Several cases of component aging and other issues that require either intensive analysis or component refurbishment have been experienced. While retired systems provide some experience base, most of the important materials and processes differ from those in the enduring stockpile. The goal for this Campaign is to preserve confidence in the stockpile by providing advance warning of defects to allow refurbishment before performance is affected.

The Stockpile Evaluation Program and this Campaign have been effective in the detection and disposition of defects but must be changed to meet the challenges of extended stockpile lives. It must be assured that components are virtually defect free and surprises must be prevented. Precursors to damage need to be identified and detected as a means of early warning. A means must be developed to focus attention on the most important components and to identify sub-populations that may be more susceptible to damage than others. Regions within components that may be more sensitive to damage than others must be identified. Non-destructive examination tools for in-depth and high resolution examinations are being pursued. It is essential to understand the complex materials, engineering, and physics phenomena that drive aging behavior and to make optimal use of limited resources. Substantial changes to the surveillance program are in progress. Issuance of the 21st Century Surveillance Plan is the first step. Changes to the statistical basis, frequency and intensity of primary, secondary, and nonnuclear component examinations are being considered. A new type of Joint Test Assemblies (JTA) is to be implemented.

This Campaign will provide validated lifetime assessments and the technical decision basis for future life extension programs. Quantitative determination of component life (up to 60 years) which will impact refurbishment decisions and certification for the enduring stockpile will be provided.

FY	Requirements
FY00	Begin lifetime assessment reports for the W76, W80, and B61-7/11.
FY03	Key diagnostics, complete performance predictions for highest risk nonnuclear components, and the decision basis for a decision on a new large capacity pit manufacturing facility.
FY04	Lifetime assessment for priority pit and canned subassembly (CSA) types.
FY05	Basis for certification of aged components and validated lifetimes for refurbishment decisions.

Work in the *Enhanced Surveillance Campaign* is divided into six major technical elements: Pits (primaries), CSAs (secondaries), High Explosives, Systems, Nonnuclear components, and Nonnuclear materials.

Pits—The approach to the work on pits is to use a design sensitivity study to determine if potential age-induced changes in plutonium properties or other changes affect performance. Old pits and accelerated aging alloys are being used to study materials properties, engineering properties, and physics properties, as well as to develop non-destructive examination tools. The results will be used in a design sensitivity study. There has already been evaluation of potential aging mechanisms, identification of the precursor of damage for the dominant mechanism and establishment of the means to detect it. Examination of old pits has so far not allowed identification of the precursor for the dominant aging mechanism for plutonium. Some materials and physics property data on these old pits have been obtained. There are special alloys of plutonium being made to study the effects of accelerated aging. Once validated, these accelerated aging alloys will be used to obtain data representative of extended age pits that can be used in the design sensitivity study. High-resolution x-ray tomography is being developed as a means to characterize key pit features. Key interfaces for this research are the studies that will be performed as part of the primary certification campaign and in DSW surveillance work.

CSAs—The approach to the CSA work is to develop an experimentally benchmarked model to predict aging effects for a design sensitivity study. Manufacturing records have been re-examined to identify important starting conditions and correlate those to performance. There has been examination of aging mechanisms and identification of both the precursors to aging and their signatures. Establishing the means to detect the signatures at a very early stage is currently underway. War Reserve features have been introduced into a recently established 3-dimensional model of materials performance. Work to benchmark the model has begun. The effort to adequately characterize the full range of materials, conditions, and configurations is challenging. Several new diagnostic tools to the Stockpile Evaluation Program have been introduced and the completion of the development of others is on schedule. These tools allow improved characterization of old CSAs in both non-destructive and destructive examination. Development of neutron imaging is in progress and shows promise for early non-destructive examination application. Key interfaces for this work are the studies that will be performed in the secondary certification campaign and DSW surveillance work.

High Explosives—The approach to high explosives work is to measure properties of old high explosives, determine the aging effects, qualify and utilize means for accelerated aging, and project key properties for a design sensitivity study. It has been determined that main charge high explosives are very stable and that they age gracefully. There has been verification that aging does not affect safety for main charges, detonators, and boosters. Recommendations regarding reuse, as needed, have been made. The current efforts are being concentrated on assessing aging effects on components in the initiation chain and on refining lifetime assessments for the full range of high explosives. Important new diagnostics, useful in assessing safety and reliability are being introduced into the surveillance program. Key interfaces for this work are in the engineering certification campaign and the DSW surveillance work.

Systems—The goal of work in the systems area is to avoid surprises by better understanding integrated effects, including subassemblies and especially flight dynamics. The fidelity of flight test systems is being increased and more and higher quality data are being obtained. The benefits of this effort have already been established by recent flight test results. The plan is to steadily introduce new diagnostics while maintaining fidelity until there is establishment of the capability to diagnose all key nonnuclear and nuclear functions during flight testing. There will be significant improvements in the quality of diagnostics in the Enhanced Surveillance Program by introduction of the tools identified in the recently issued 21^{st} Century Surveillance Plan. This approach will allow utilization of a large number of diagnostics already identified as crucial to the Enhanced Surveillance Program. Many of these diagnostics do not require special development and are commercially available. Finally, there are revisions to nonnuclear and nuclear reliability assessments using test data and expert judgement. The key interfaces in this campaign are for engineering certification and DSW surveillance.

Nonnuclear Components—DOE is considering life extensions for selected systems that may involve some nonnuclear components. The approach is to screen (by assessment of importance to performance or safety, pervasiveness, and potential for aging) the full range of nonnuclear components and then focus on the most important items. The screening process is well underway and a number of important issues have been both identified and resolved. Minor flaws in certain components have been analyzed and shown not to be significant. Behavior of other components have been found to be flawless. These results have had a significant effect on life extension planning by better definition of true drivers for refurbishment. Planned research includes risk-based component sampling plans, models for aging of microsystems, and surveillance plans for microsystems, as well as design guides for long life replacement components and deployment of parametric surveillance tools.

Nonnuclear Materials—The approach to nonnuclear materials is to screen in order to identify the most important items and then assess aging effects. Diagnostic tools to assess performance of key components have already been developed and deployed. Assessment results eliminated a potential driver for a particular weapons system. The means to characterize weapon atmospheres and chemical and mechanical performance of cushions have been highly successful. There has been a development of the understanding of aging signatures and the establishment of means to detect these signatures. Introduction of these tools into the Enhanced Surveillance Program is planned. Development and introduction of experimentally validated models into design codes, as well as assessment of aging effects in microsystems are important future efforts. The most important interfaces are with engineering certification and DSW surveillance.

Stockpile Research & Development

Directed Stockpile Work—DSW encompasses all activities that directly support specific weapons systems in the nuclear stockpile. These activities include current maintenance and day-to-day care, as well as planned refurbishments. DSW is executed through an integrated system of plans, such as Stockpile Research and Development, Stockpile Maintenance, Stockpile Evaluation, Dismantlement/Disposal, Production Support, and Field Engineering Training and Manuals that take advantage of the entire nuclear weapons complex, including DP Headquarters, the national laboratories, the production complex, and other DP facilities. DSW represents a robust program that will ensure the future viability of the stockpile by maintaining a balanced effort of both near-term and long-term weapon research activities.

Stockpile Research & Development—Stockpile R&D activity associated with DSW includes development and maintenance of the scientific understanding and engineering development capabilities necessary to support near-term and long-term requirements of the nuclear stockpile. This category includes development of all new weapon designs, pre-production design and engineering activities, design and development of weapon modifications, technical aspects of the laboratory surveillance and flight test program, safety studies and assessments, and technical analysis needed to dismantle and safely store weapons being removed from the stockpile.

Tritium Storage Systems—Nuclear weapons contain limited life components, such as tritium storage systems and neutron generators, that must be replaced periodically. As part of DSW, these components are sometimes redesigned, and the new devices are incorporated into the stockpile. Reliable tritium storage and transfer within a warhead is a complex technology. Absolutely reliable long-term containment is the first criterion because of the radiological hazards associated with tritium. Storage of tritium gas is at high pressure. Hydriding and cracking of the containment materials are the principal concerns. Even small differences in metal alloying can have a large impact on the susceptibility to hydride cracking.

Neutron Generators—Neutron generators, formerly manufactured at the now-closed Pinellas plant, are currently manufactured at Sandia. These systems have had to be redesigned and certified using different production processes and different materials, because some materials are now categorized as carcinogens, and are no longer available for use. Neutron generators operate as compact accelerators that must generate a precisely timed high voltage. Weapon neutron generators must be fully rugged, compact, and reliable in the hostile environment that strategic weapons would potentially face.

Flight Testing—Flight testing provides the most comprehensive manner of testing an integrated weapon system and its nonnuclear surrogates. In high-fidelity flight tests, special nuclear materials are replaced by inert components of the same dimensions and mass distribution. For example, flight tests of Peacekeeper warheads are launched from Vandenburg Air Force Base to Kwajalein Atoll in the South Pacific. Similar tests are performed on bomb systems at the Tonopah Test Range in Nevada. These tests allow as complete an evaluation of nonnuclear system performance in the stockpile-to-target sequence as is possible. With a reduced stockpile and no new production, fewer flights are possible; thus, there is a critical need to further increase the fidelity of these flight tests. Technology development is underway to miniaturize and embed sensors that reduce inherent differences between JTAs and the war reserve weapon systems they mimic.

Baselining and Data Archiving—Baselining is the process of analyzing and assimilating all information regarding the design, production and operation of a nuclear weapon system to provide a database against which future modifications can be measured and assessed. A major effort is underway to understand test data for each weapon in the stockpile and archive information that is available. This effort involves re-examining baseline performance using current computational capabilities and developing a scientific understanding of the difference between these computations, original design calculations, and the underground test data. This will be a substantial multi-year effort.

Production and Manufacturing Science and Technology

Budget: FY99-$109.6M, FY00-$76.4M, FY01-$75.7M

During the coming decade, several weapon systems will undergo refurbishment. A major step in this process will be design and process engineering to provide the detailed specifications for weapon components, subsystems, and the full weapon. It is necessary to improve these design and process engineering steps, because time and dollar resources will be constrained. SSP is investing in this area through the Advanced Design and Production Technologies Campaign, which is described below.

Advanced Design and Production Technologies

The *Advanced Design and Production Technologies (ADAPT) Campaign* develops and deploys technologies to more efficiently refurbish the stockpile. ADAPT technologies help eliminate design and production defects, seek environmentally sound production processes, and increase the responsiveness of the geographically distributed design and production infrastructure.

The *ADAPT Campaign* is comprised of three programs: Enterprise Integration, Integrated Product & Process Design and Agile Manufacturing Program, and the Process Development Program. These programs are co-directed by the Office of Military Application and Stockpile Operations and the Office of Research and Development and Simulation and rely heavily on computational, simulation, material, and other R&D to support the following programs:

- Enterprise Integration Program provides new and improved infrastructure and enterprise tools, including the required new technical business practices.

- Integrated Product and Process Design and Agile Manufacturing Program develops and validates new design and manufacturing approaches, tools, and capabilities.

- Process Development Program improves existing processes, as required to meet new production requirements, to respond to an evolving regulatory environment, and to replace obsolete technologies.

ADAPT's three primary goals are to: 1) reduce the occurrence of design and manufacturing defects in refurbished stockpile hardware by a factor of ten, 2) reduce the time and cost for realizing these products by a factor of two, and 3) develop and maintain the ability to respond to stockpile refurbishment needs. ADAPT draws from promising research and development efforts within the DOE, other Government agencies, universities, and industry when they can be deployed to meet life extension program objectives for stockpile management. Furthermore, the ADAPT Campaign creates a challenging work environment that continues to attract and retain outstanding engineers and scientists in DOE research and development.

The *ADAPT Campaign* relies heavily upon the R&D conducted at the DP laboratories to develop capabilities to deliver qualified refurbishment products on demand. ADAPT accelerates and focuses DP's core R&D (e.g., advanced computational ability) toward specific life extension program requirements. The development of revolutionary improvements in computational capability, driven to a significant degree by ASCI R&D, is providing an unprecedented ability to simulate product performance and manufacturing processing. This capability is a key element in developing an ability to prototype both product and manufacturing in a virtual way. Virtual prototyping speeds and simplifies the "design/prototyping" cycle that is critical to optimization of product design and performance.

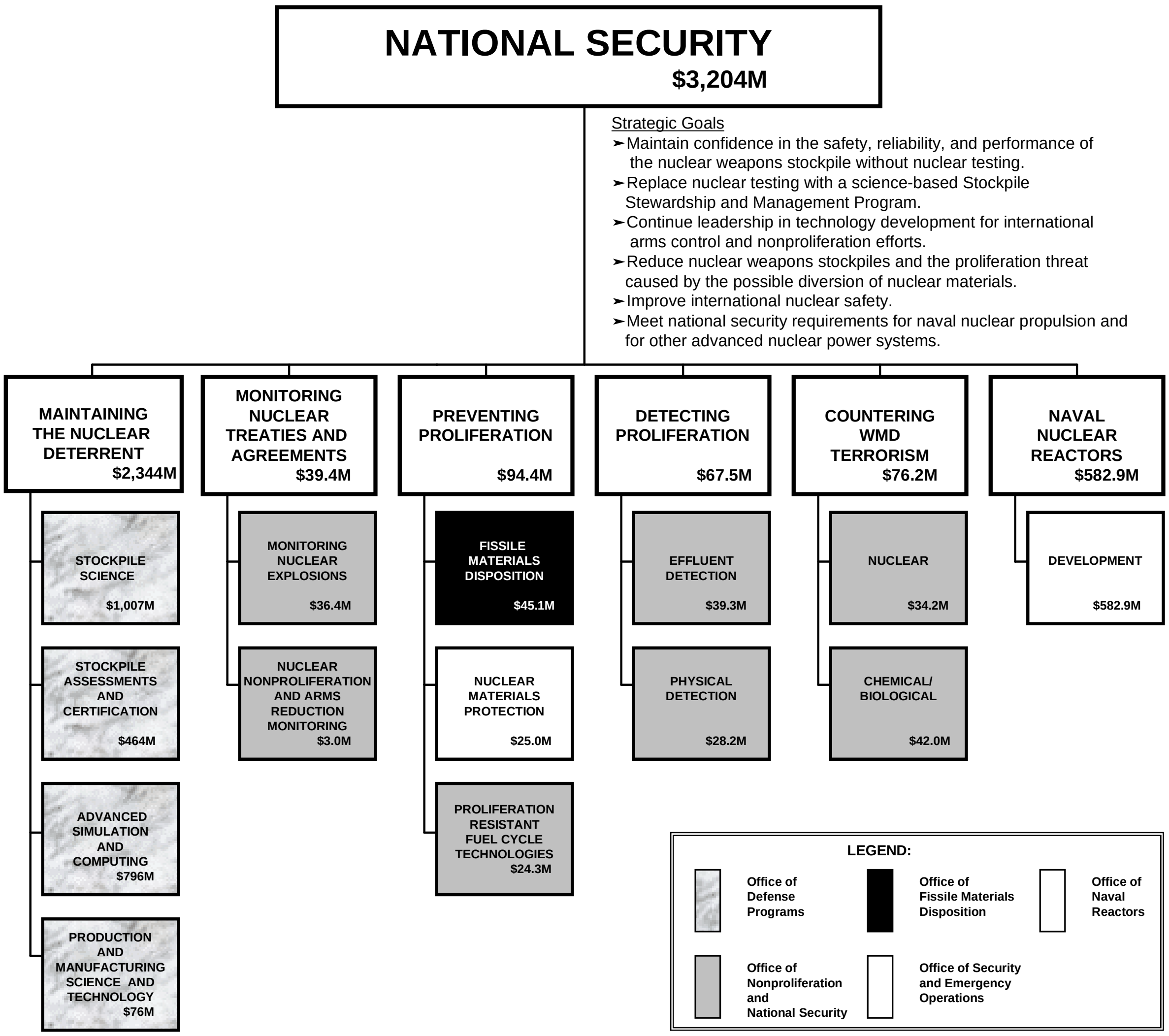
The R&D technologies and methods of highest priority to ADAPT are those that eliminate manufacturing defects and reduce production time and costs. This effort applies modern model-based manufacturing technologies to design and production activities in the nuclear weapons production complex. Various components of this effort support every aspect of nuclear weapons production, from efforts to develop near-net casting models for pit casting, to virtual prototyping – the ability to develop a mechanical model of the entire weapon system to make it easier to explore how to optimize component design and location. Automation is known to improve quality and productivity in commercial industry and is desirable for adaptation to DOE's production complex. R&D is needed to adapt it to DOE's small lot production. The needs of DP are one of the major drivers noted in the Department's crosscutting Roadmap and Program Plan for Robotics and Intelligent Machines.

The *ADAPT Campaign* will develop modeling and simulation tools and information management technologies to enable full-scale engineering development with minimal hardware prototyping and totally paperless processes for the W80 and subsequent weapon refurbishment activities. This will be accomplished by developing multiple, fast turnaround engineering options by using virtual prototypes, and implementing modern product data management and collaboration tools.

Summary Budget Table (000$)

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Stockpile Science	1,208,200	1,140,400	1,007,400
Advanced Computing and Simulation	483,700	660,500	796,200
Stockpile Assessments and Certification	432,900	428,900	464,300
Production and Manufacturing Science and Technology	109,600	76,400	75,700
Total	**2,234,400**	**2,306,200**	**2,343,600**

Chapter 4
Monitoring Nuclear Treaties and Agreements



Chapter 4

Monitoring Nuclear Treaties and Agreements

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Overview

Definition of Focus Area

The goal of this focus area is to develop technologies and systems, and the attendant scientific basis thereof, to (1) enable remote detection, location, identification, characterization, and attribution of nuclear explosions with sufficient timeliness and confidence to permit appropriate and effective national response; and (2) support close-range monitoring activities related to strategic arms reductions. The current focus is largely on development of a robust capability to monitor the Comprehensive Nuclear-Test-Ban Treaty (CTBT), if and when it enters into force. However, the CTBT is only the latest tool to address the underlying world conditions which make it imperative to monitor for nuclear proliferation and testing. U.S. monitoring requirements will remain in effect, whether or not official entry into force of CTBT ever occurs.

National Context and Drivers

For over 35 years, the Department of Energy (DOE) jointly with the Department of Defense (DoD) has provided sensor systems and technology to detect atmospheric and space nuclear detonations (NUDETs) from satellites. Beginning with the first Vela satellite launched in October 1963, these systems have comprised the national capability to monitor nuclear treaties including the Limited Test Ban Treaty and the Nuclear Nonproliferation Treaty. Twelve Vela satellites were launched between 1963 and 1970; the last of these was turned off in 1984 -- after 14 years of successful operation, despite being designed as an R&D system expected to function for only 18 months. Vela optical and electromagnetic pulse sensors detected many atmospheric NUDETs during their operational lifetimes.

In 1965 the Air Force, in planning for the Defense Support Program (DSP) missile early warning satellite system, decided that space and atmospheric NUDET detection (to support the warfighter as well as treaty monitoring) should be added as a secondary mission on these DoD satellites. An Air Force / Atomic Energy Commission Memorandum of Understanding was signed to document the agreement, naming the payload “RAdiation DEtection Capability” (RADEC). With the exception of one Air Force funded optical sensor, the DSP RADEC payloads are provided by DOE to the satellite contractor as government furnished equipment (GFE). The U.S. NUDET Detection System (USNDS) sensors flown on DSP have accumulated an enviable record of success. Since the early 1970s, the Air Force has launched eighteen DSP satellites, most of them carrying RADEC payloads; all of the RADEC payloads have exceeded their five-year on-orbit design life. Five more systems are ready for launch; it is expected that an operational DSP constellation will be maintained until about 2010. In addition to addressing the warfighting and treaty monitoring operational missions, DSP RADEC data from the on-board environmental sensors is routinely provided to the Air Force 55th Space Weather Squadron for use in modeling space weather, and, on request, to other military and commercial satellite operators for anomaly resolution and assessment of environmental threats to their operations.

Since the DSP system consists of a small number of satellites deployed in geosynchronous equatorial orbits, it cannot provide coverage of Earth's polar regions nor does it "see" a given location with more than one satellite for some locations of interest. The resulting lack of complete coverage and limited event location-determining capability led the DOE and the Air Force in 1975 to place additional USNDS sensors on the Global Positioning System (GPS). GPS provides multiple satellite coverage world-wide, permitting accurate location determination for all nuclear events from the surface of the Earth into space. Similar to DSP, GPS-based sensors address both warfighting and treaty monitoring missions, and are supplied as GFE by DOE to the Air Force satellite system contractors with one exception, the Air Force-funded electromagnetic pulse sensor.

To date, USNDS sensors have flown on 33 GPS satellites. The last of the 28 Block IIA satellites was launched in November 1997 to maintain a fully operational 24 satellite constellation. One Block IIR replenishment satellite has been on orbit since July 1997. The last of 21 Block IIR USNDS systems was delivered in 1999. Now, deliveries of the next generation, GPS Block IIF USNDS sensors, will commence. Even though the GPS orbit's harsh radiation environment makes the payloads more susceptible to radiation damage, all of the payloads launched to date have operated well past their design life and have been turned off only when the satellites themselves were no longer operational.

Ground-based monitoring technologies have also been used since the beginning of the nuclear age. With the signing of the Comprehensive Nuclear-Test-Ban Treaty, four technologies (seismic, hydroacoustic, infrasonic and radionuclide) are being installed at stations around the world as part of an International Monitoring System. Data from these stations will be a valuable addition to U.S. National Technical Means whether or not the CTBT ever goes into force.

In the arms reduction area, current program emphasis is on preparing for START III negotiations. The U.S. negotiators will need options regarding technology choices and levels of intrusiveness. Additional, overlapping program drivers are the Mayak Transparency Mandate from the Biden Amendment and the Trilateral Initiative.

Linkage to Requirements

Goals for U.S. nuclear detonation monitoring capabilities are specified in Presidential Decision Directives. U.S. national monitoring requirements are more stringent than those of the international community. Specific requirements for the satellite systems are detailed in an Air Force Operational Requirements Document, which specifies performance parameters for warfighting as well as treaty monitoring missions.

As further support for the nuclear test monitoring goals and objectives, the President, in his August 11, 1995 statement on the CTBT, recognized that our present monitoring systems will not detect with high confidence very low yield tests. Therefore, he put forward the conditions that would safeguard a successful treaty that included "Continuation of a comprehensive research and development program to improve our treaty monitoring capabilities and operations."

The research and development performed for monitoring nuclear treaties and agreements is being performed in response to the National Security Strategic Goal, Objective 5, Strategy 3, of the U.S. Department of Energy Strategic Plan. Objective 5 is to continue leadership in policy support and technology development for international arms control and nonproliferation efforts.

Strategy 3 specifically requires developing improved sensor systems for treaty monitoring and verification.

Uncertainties

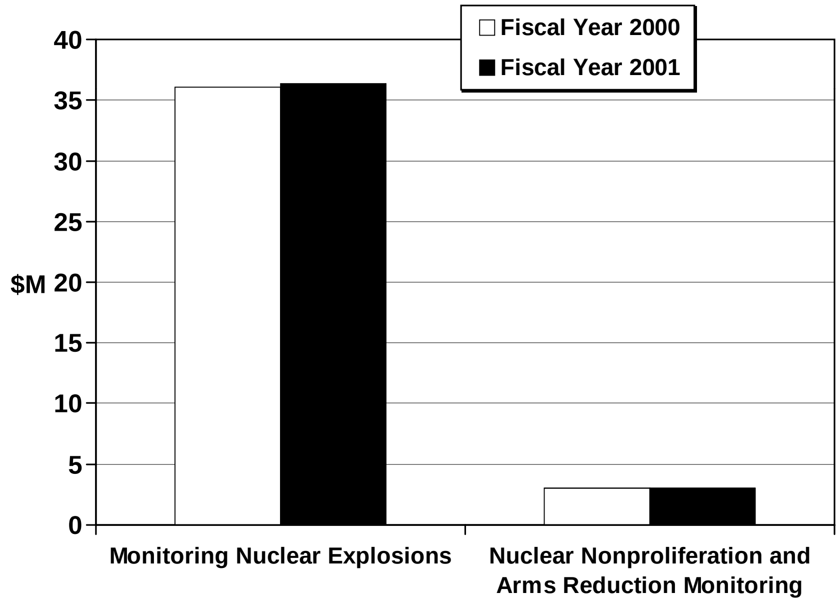
It is uncertain when, or even if, the CTBT will enter into force, banning nuclear tests in all environments, underground as well as underwater, in the atmosphere, and in space. The October 1999 vote by the U.S. Senate to not ratify the treaty increases this uncertainty. Even without a formal treaty, however, nuclear testing will likely be constrained by declared moratoria. In any case, U.S. monitoring requirements will remain in effect, whether or not official entry into force ever occurs.

Likewise, it remains uncertain whether the Russians will ratify the START II agreement, a prerequisite to START III negotiations. However, short of further formal arms reductions, the United States remains engaged in a range of agreements and transparency measures to improve control and monitoring of nuclear weapons and materials in Russia.

Investment Trends and Rationale

Investment in research and development for both nuclear explosion monitoring and arms reduction monitoring is expected to remain approximately flat. This forecast is based on maintaining progress toward meeting monitoring goals, while striking a balance with the needs of competing Departmental programs. The chart shown on the following page shows investments by activity areas that will be discussed in the remainder of this chapter.

Monitoring Nuclear Treaties and Agreements



Federal Role

National security is a constitutional role of the Federal government. DOE's roles in support of the national security goals for nuclear treaty monitoring and arms reduction are, through the expertise and facilities of the DOE national laboratories, to provide policy support and perform research and development for both remote and close-range ground-based systems, for example, for on-site inspections. For the satellite-based systems, after completing the relevant research, development, and demonstrations/validations, DOE actually fabricates monitoring sensors for operational deployment on DoD satellites.

Key Accomplishment

The key accomplishment of the DOE's longstanding nuclear treaty monitoring technology program is that it has resulted in the present U.S. continuous world-wide capability to detect nuclear explosions in all environments under most conditions. What remains to be done is to improve the technologies so they can, in all environments and under all conditions, meet the challenging sensitivity requirements of the present era, as well as to continue to provide technical support for strategic arms reduction monitoring activities.

Monitoring Nuclear Explosions

Budget: FY99-$42.3M, FY00-$36.1M, FY01-$36.4M

Background

The signing of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in September 1996 was a turning point in history, creating for the first time an international norm against all nuclear testing. It marked the end of the negotiations phase, which had been heavily supported by the DOE Nuclear Explosion Monitoring program, and began the preparatory phase to the long-sought Treaty's entry into force. The preparatory phase is organized around two main activities:

- Building the international verification regime [the key element of which is the CTBT worldwide network of sensor stations, the International Monitoring System (IMS) comprised of seismic, hydroacoustic, infrasound, and radionuclide stations] that will monitor global environments to ensure that the Treaty is not violated.

- Gaining ratification of the Treaty by States Signatories.

The October 1999 vote by the U.S. Senate to not ratify the CTBT is at least a timing setback for entry into force. However, the vote by itself did not remove the treaty from the world stage where it is still attracting signatures and ratification by other States Parties. Futhermore, the U.S. continued funding of the Preparatory Commission (commonly known as PrepCom) has been established for this phase. The PrepCom is the precursor to the Comprehensive Nuclear-Test-Ban Treaty Organization that will come into existence at Treaty entry into force.

Program Description

Simply stated, the performance needs for nuclear explosion monitoring sensors and their associated data systems are to detect, locate, identify, characterize, and help to attribute detonations occurring anywhere underground, underwater, in the atmosphere, or in space and to report the results to military and arms control operational users in a timely manner. The research and development program for monitoring nuclear explosions has two key components:

- U.S. Satellite-based Systems.

- U.S. and International Ground-based Systems.

Satellite-based Systems

Budget: FY99-$14.7M, FY00-$12.8M, FY01-$12.8M

Description and Objectives. With each new generation of satellites come changes to satellite subsystem interfaces, command structures, structural form factor, and telemetry data formats. GPS has already transitioned through five such changes, design for the sixth (Block IIF vehicles 1 through 6) is underway, and the seventh (Block IIF vehicles 7 and beyond) is rapidly approaching. This means that the data processing system -- which provides the primary data interface to the spacecraft and also collects data from, and controls, each sensor subsystem -- must be re-designed at each transition. DoD pressure to reduce size, weight, and power demands continuing development of increasingly more sophisticated microprocessor-based on-board systems, and, as sensors become more complex in order to meet new requirements, there will be orders of magnitude more data to sample, filter, and store in memory.

Over the next 10 years the entire existing satellite-based nuclear explosion monitoring system will be replaced with an upgraded system satisfying new presidentially directed monitoring requirements. Recent program developments include an extended-energy-range x-ray sensor, that will improve detection of the evasive testing in space of primitive nuclear weapons, and an enhanced satellite-to-ground communications link. Next generation sensors currently under development include the following:

- **Enhanced Optical Sensor—**To ensure that the satellite-borne non-imaging optical sensors will be able to see even very weak light signals from small nuclear explosions, a next generation optical sensor is under development to improve detection sensitivity. This sensor is planned to be operationally deployed on GPS Block IIF satellites to provide complete worldwide, real-time high-sensitivity coverage and will replace the old bhangmeters.

- **Enhanced Electromagnetic Pulse (EMP) Sensor—**The nuclear detonation monitoring community within the U.S. has long maintained that monitoring multiple nuclear-explosion-induced signals from different physical phenomena is essential to reliable detection, identification, and attribution of evasively conducted nuclear tests. Both optical and EMP signals can provide timely evidence of an atmospheric nuclear detonation with sufficient information to locate the event to the accuracies required for treaty monitoring. But, in addition, EMP data will meet the accuracy requirements for warfighting, and will provide supplementary event characterization information to further aid in attribution.

  Prompt, dual-phenomenology monitoring is also required in order to address evasive testing scenarios. The Department of Energy is sponsoring the development of a new EMP sensor, to be called the V-sensor, that will be sufficiently sensitive to detect evasive nuclear detonations and will also be capable of on-board discrimination against EMP-like background signals. Thus, unlike currently deployed EMP sensors, it will be able to operate autonomously. This sensor will be operationally deployed on GPS Block IIF satellites.

- **Compact Gamma-Ray and Neutron Sensor—**The Space and Atmospheric Burst Reporting System (SABRS) is a DOE-sponsored project to develop a lightweight, low-power, small, inexpensive, and easily accommodated satellite payload for detection and characterization of nuclear detonations in the upper atmosphere and in space. SABRS is intended to replace most of the functionality of the exoatmospheric RADEC sensors currently hosted on the DSP satellites. The programmatic goal is to sustain the required capability to detect gamma-rays and neutrons, after the DSP constellation is retired. This goal supports the treaty monitoring mission as well as DoD warfighting missions.

R&D Challenges. The challenge in achieving the performance improvement targeted for the enhanced non-imaging optical sensor is extreme, involving the development of focal plane array "active pixel" technology. In effect, many individual optical sensors will be implemented in a space not appreciably larger than that required for today's single optical sensor (bhangmeter).

Implementing independent, autonomous EMP sensors is a challenge because of high false trigger rates, but recent work has led to powerful discrimination techniques to mitigate this problem.

The technology challenges for the compact gamma-ray and neutron sensor are to provide sufficient sensor sensitivity and an acceptably low rate of false alarms, using a small, low-cost payload. The immediate technical objective is to develop a SABRS demonstration /validation experiment to be flown in space to prove the new design concepts.

R&D Activities. Preparations are underway for a proof-of-principle flight experiment for the enhanced non-imaging optical sensor to demonstrate and validate this new approach to nuclear test monitoring.

Wide-band radiofrequency signal detection is the key to successful implementation of an enhanced EMP sensor. In this effort wide-band radiofrequency sensor technology is being married to multi-channel trigger technology. Data from the Fast On-orbit Recording of Transient Events (FORTÉ) satellite, a DOE small-satellite, proof-of-principle experiment launched August 29, 1997, is being analyzed to refine the design of the operational EMP sensor.

The planned replacement for DSP is the geosynchronous Space Based Infrared System (SBIRS) constellation. SABRS payloads on SBIRS satellites could provide a means to continue meeting requirements in the post-DSP era. Other possible platforms, such as the Advanced Extremely High Frequency communications satellite constellation, are also being considered. In anticipation of finding a suitable operational host vehicle, preliminary design work is proceeding.

Accomplishments. The prototype detector array for the enhanced non-imaging optical sensor has been integrated into a GPS Block IIF box and is undergoing testing..

Data from FORTÉ has confirmed that the V-Sensor design is both adequately sensitive and capable of discriminating against EMP-like background signals. The V-Sensor will incorporate much of the FORTÉ radiofrequency sensor technology and add an event timing capability and an onboard signal processor for noise rejection.

In early 1998, the Air Force and DoD Space Experiments Review Boards approved and ranked the SABRS demonstration / validation experiment as a valid "space test experiment," and as such the Air Force Space Test Program has identified a host platform for the experiment: DSP Flight

22, to be launched in 2003. The DSP satellite host is ideal, as it also carries the current operational gamma ray and neutron sensors, against which the demonstration data can be compared and validated.

Ground-based Systems

Budget: FY99-$27.6M, FY00-$23.3M, FY01-$23.6M

Description and Objectives. At DOE our nuclear explosion monitoring research and engineering (NEMR&E) mission is to carry out research and development and deliver the research products to the U.S. agencies responsible for monitoring compliance with the nuclear test ban treaties and for operating the U.S. National Data Center. DOE provides technologies, algorithms, hardware, and software for systems to detect, locate, identify, and characterize nuclear explosions in a cost-effective manner at the thresholds and confidence levels that support U.S. goals. In addition, the NEMR&E Program supports the PrepCom in numerous ways.

The requirements for monitoring capabilities specified in the Presidential Decision Directives vary depending upon geographic location. They define specific regions of interest, not all of which are currently addressed by the DOE program. Internationally, however, monitoring needs are driven by statements in the CTBT itself, and they are global. To ensure that effects from a nuclear test anywhere in any of the Earth's environments will be detected, the treaty language specifies networks of atmospheric, underground, and oceanic monitors: two types of radionuclide sensors, infrasound arrays, seismic sensors and arrays, and hydroacoustic sensors. These sensor systems were selected for CTBT monitoring in part because their capabilities complement each other. In addition, the U.S. will maintain and enhance its own National Technical Means, combining monitoring data supplied by the IMS with data from additional ground-based and satellite-based monitoring assets at the U.S. National Data Center.

Monitoring for nuclear explosions in an era of testing bans and moratoria presents difficult challenges. In all environments the task is complicated by the similarities between effects from nuclear explosions and effects produced by non-nuclear sources -- for example, each day there are several hundred earthquakes which produce signals large enough to be detected by the proposed and only partially installed seismic monitoring network. Furthermore, seismic evidence of an underground nuclear event depends not only on the geological environment near the detonation, but also on the physical characteristics of the path between the event and the sensor. For this reason it is vital to calibrate each deployed seismic array with respect to the monitored region. For the verification regime to meet these challenges, work remains to be done in sensor development, in data collection to calibrate the sensor networks, and in data management and analysis techniques that will ensure timely assessment of events. The NEMR&E program (see http://www.ctbt.rnd.doe.gov) to date has been driven by requirements to meet national goals; achieving those goals will be enhanced if the International Monitoring System is a success.

To achieve global monitoring, improved sensors, sensor arrays, array analysis methods, and networks are needed to increase the U.S. ability to detect nuclear explosions and distinguish them from innocuous events. DOE's monitoring system R&D efforts are focused on engineering the radionuclide and infrasound systems, collecting high-quality ground truth data sets from the seismic sensors, determining the best ways to deploy all the sensors, including the hydroacoustic sensors, and developing the tools to analyze the data.

To achieve accurate location and identification capability, the sensor networks must be calibrated. To do this, detailed information is required about the paths over which signals could travel to a sensor station. In general, as a signal propagates from its source, it is delayed, attenuated, and altered in many ways, possibly time-variant, by the path that it takes (for example, by geologic structures, winds, or oceanic conditions). Accurate location and identification are possible only after these effects have been taken into account.

Data collected by the IMS sensors will flow continuously to the International Data Center and be forwarded to the national data centers, where automated and interactive analysis techniques will be used to detect, locate, characterize, and identify the sources of the events. DOE is working on a number of data visualization and interactive analysis and system assessment projects to minimize the manpower required for data management and analysis tasks. We are also developing hardware and software to ensure data authenticity and integrity and system security for data being distributed from national and international data centers.

R&D Challenges. The principal challenges in present-day nuclear explosion monitoring are to detect the signals from very-low-yield nuclear explosions as well as from nuclear explosions conducted under conditions that mask the signals produced, and to distinguish these signals from the ambient background of natural and human-induced sources. The monitoring task is complicated by the fact that many natural and human-induced, non-nuclear events can produce signals that, to a single sensor technology, may appear similar to those from a nuclear explosion -- perhaps causing false alarms. Further, background noise or other interferences can mask or reduce the quality of evidence from events of interest for any of the technologies -- perhaps causing a true event to be missed.

Seismic. Historically, seismic sensors have greatly contributed to monitoring underground nuclear tests. These historical tests were large and readily recorded at teleseismic distances (>2,000 km). However, the small signals and high backgrounds associated with evasively tested underground nuclear detonations force us to go to regional seismic monitoring system as opposed to the more traditional teleseismic systems. This means that data is recorded at distances less than 2,000 km from events of interest, rather than at much greater distances. Regional systems retain the challenge of characterizing the geology around the source and also face the more difficult challenge of characterizing more variable (albeit shorter) transmission paths through the Earth's mantle. Although the seismic monitoring problem is daunting, it is an important technology when it comes to monitoring underground testing, and advanced processing and calibration techniques show promise for extending its effectiveness to the new monitoring regime.

Infrasound. The strength of the infrasound monitoring method is that infrasound is hard to hide. Acoustic evidence will propagate from all impulsive releases of energy into the atmosphere. Infrasound challenges include reducing false alarms by improving discrimination of nuclear from other impulsive releases and maintaining adequate signal-to-noise in the face of wind conditions at the sensor locations. The new generation of infrasound monitoring systems benefit from improved data computational techniques and selective siting of sensor arrays based upon comprehensive calibration studies.

Radionuclide Sampling. This is the unequivocal smoking gun for nuclear reactions within the atmosphere. However, radionuclide sampling does not provide timely evidence and it does not provide location information. Its strength stems from the development of reliable autonomous sensing stations that can process immense volumes of air so that extremely small evidence constituencies can be assayed continuously.

Hydroacoustic. These underwater systems provide undeniable evidence of explosive events, but nuclear detonations cannot be discriminated from other impulsive sources transmitted through the water. Nonetheless, since other technologies cannot operate in water and two-thirds of the Earth is ocean, hydroacoustic sensors play an important role.

Network Calibration. The CTBT requires monitoring smaller explosions (relative to the Threshold Test Ban Treaty, which allowed underground tests up to 150 kilotons) and under evasive testing conditions, which can further reduce the signal output. These small signals require much denser networks to meet our monitoring goals. But reduced signal amplitudes also fundamentally change the nature of the monitoring problem. In the case of seismic monitoring, calibrating the networks for regions of interest to the U.S. will require a detailed understanding of the Earth's interior structure, its oceans, and its atmosphere, as well as development of techniques to make this vast reservoir of knowledge accessible to automated and interactive processing systems.

Calibration Events. In order to calibrate the regions of interest, it is essential to have data on extremely well-located and well-characterized calibration events (e.g., explosions or earthquakes). Currently, only a very small number of events that meet the stringent criteria for sufficient quality have been identified within the regions of highest interest. For example, only a few events have been identified in India or Pakistan, countries that have of late commanded greater interest due to their recent weapons tests. It is clear that, in order to properly calibrate the world's regions of interest, a concerted effort to identify and acquire data from calibration events, along with additional region-specific geophysical and geological information, is needed. Agreements between U.S. and foreign government agencies could greatly facilitate cooperative experiments that could provide the critically-needed data.

Data Management. Although the data flow process is straightforward in concept, there are many challenges that must be successfully overcome. Consolidating gigabytes of data from different technologies in a single data-analysis system with little time delay presents technological challenges for communications, data surety, automated and interactive signal processing, and complex data integration. The challenge in assuring data integrity and system security arises from the fact that the data comes from host-country-owned data sources and must be shared with a wide variety of users. Data surety and integrity are essential -- users must be confident that the data are authentic and have not been tampered with. Sensors need to be physically protected from damage or interference, either inadvertent or intentional, and the commands and data they receive and transmit need to be protected from corruption or falsification.

R&D Activities. Monitoring systems research and development activities include:

- Developing prototype radionuclide particulate and radioxenon sensors based on well known scientific principles but requiring innovative and complex engineering to meet global monitoring specifications including high reliability and automation, low maintenance, and high sensitivity.
- Developing a turn-key infrasound prototype ready for commercialization and deployment.
- Field testing of the radionuclide and infrasound prototypes with independent evaluation by the national user organization, the U.S. National Data Center operated by the Air Force Technical Applications Center.
- Engineering and software support to the commercial vendor selected by the Air Force to commercialize and deploy the radionuclide prototypes.
- Logistical and equipment support to international testing of the radionuclide prototypes, during independent evaluation by other countries.
- Demonstration of the radionuclide monitoring systems fully integrated into the global communications infrastructure including data authentication and data analysis capabilities.

Network calibration research and development activities include:

- Minimizing false events by calibrating the IMS networks for accurate locations and event identifications.
- Collection and integration into the Knowledge Base of seismic data and ground truth information (e.g., accurate location and time of occurrence) on calibration quality events.
- Developing algorithms for using the ground truth data for location and identification.
- Participating in field activities as required to obtain high quality ground truth information.
- Collaborating with other countries on seismic data collection opportunities, particularly dual use events.

- Developing Knowledge Base reference event databases to allow events to be interpreted in their proper regional context.

Data management and analysis research and development activities include:

- Develop the Knowledge Base architecture to manage the large amounts of data that human analysts must bring to bear in analyzing events.

- Develop and test the parameters needed to implement detection, location, and identification algorithms.

- Develop advanced computation techniques that will enable the processing system to use the discrete data to analyze events at any location.

- Test identification algorithms on small-magnitude reference events from the regions of monitoring interest.

- Validate advanced waveform-modeling techniques for interpreting signals generated by new events.

- Develop interpretation methods that take advantage of the synergy between the monitoring systems (i.e., events that occur at interfaces between monitoring environments which will be recorded on two or more of the monitoring systems).

- Develop and demonstrate the data authenticity and key management architecture to be used in the International Monitoring System and International Data Center.

Accomplishments. DOE has developed prototypes of two very sensitive, automated, self-contained instruments that meet the Treaty radionuclide monitoring requirements: one detects airborne radioactive particles and the other airborne radioactive isotopes of xenon gas. Both instruments autonomously collect air samples, analyze the samples, and transmit data to the data centers. The key contribution of the radionuclide sensors is their ability to distinguish nuclear explosions from non-nuclear events. The Treaty specifies a worldwide network of 80 radionuclide stations, but when the CTBT negotiations began, economical radionuclide measurement systems that could meet the monitoring goals were not available. Although the relevant science has long been well known, significant engineering was needed to make the systems automated and reliable, and to provide near real-time data reporting.

DOE has also developed a prototype infrasound system to meet CTBT requirements. This system could be used in the new global atmospheric infrasound monitoring network, which will complement the other monitoring technologies. A nuclear weapon test in the atmosphere would release large amounts of acoustic energy (sound). The sub-audible part of the signal (frequencies below 20 hertz) is called infrasound. The Treaty specifies a world-wide network of 60 infrasound stations. Although infrasound sensor technology is relatively well understood (it was widely deployed in the early 1960's), during Treaty negotiations there were no commercially available systems that met the Treaty requirements.

In some of the regions of primary interest to U.S. monitoring needs, DOE has developed region- and station-specific seismic travel-time corrections that will permit location algorithms to produce accurate results, once an event has been detected. The automated processes for determining the location of an event makes use of models which estimate the time required for signals to propagate from a given source location to a given sensor station. Previously existing global travel time models were insufficient to ensure that events will be located within the one thousand square kilometers over which the Treaty allows an on-site inspection to be conducted.

DOE continued development of computer tools for manipulating time series data called SAC2000 and MatSeis. Both programs allow direct access to the database format used at the U.S. and International Data Centers, provide CTBT-specific signal-processing functionality, and have an easy to use graphical interface. Both programs are available through the DOE's NEMR&E web site (http://www.ctbt.rnd.doe.gov).

DOE delivered Release 3 of the CTBT "Knowledge Base" to the U. S. National Data Center in 1999. This provided a near-operational structure for managing large data bases pertaining to multiple technologies, regional geophysical and geologic information, and parameters specific to particular monitoring stations. In future releases, such data will be accessed by automated processing systems and human analysts to provide monitoring and verification information.

Nuclear Nonproliferation and Arms Reduction Monitoring

Budget: FY99-$3.0M FY00-$3.0M, FY01-$3.0M

Background

The Department's nuclear weapons threat reduction responsibilities are part of the Administration's interagency-wide effort to reduce the number of nuclear weapons and amount of weapons grade material both in the U.S. and in the Former Soviet Union (FSU). A joint effort being coordinated between DOE and DoD is to delineate respective responsibilities and define a comprehensive technology development program in support of U.S. nonproliferation agreements. The goals of the coordination are to set priorities, avoid duplication of effort, and take advantage of synergies. Execution will be by the Department of Energy and the DoD Defense Threat Reduction Agency (DTRA).

Initial declarations of warhead, component, and material inventories and periodic updates are a critical part of a lasting regime at reduced levels of nuclear arms. Verification of the declarations is especially important, as the U.S. and Russia proceed to lower warhead levels and fissile materials stockpiles, to ensure that false declarations cannot serve as the basis for rapid reconstitution of nuclear forces. For example, Congress has required that it must be proven that the nuclear material stored under Mayak Transparency came from actual nuclear weapons. This requires that the collected signatures must be unique to nuclear weapons and the measurement information must be passed through an information barrier, which then provides a binary (yes/no) decision that it satisfies or does not satisfy the criteria for nuclear weapons. After a weapon is dismantled, it then will be necessary to track the weapon components to their long-term storage site and continuously monitor the vault to make sure that the material does not return to the weapons stockpile.

Program Description

The two central goals of the strategic arms reduction monitoring program are to develop technologies able to:

- Confirm that an object being examined is a nuclear weapon or is a weapon component.
- Prevent the release of any nuclear weapon design information.

The requirements for warhead transparency agreements and START may vary, but have a common goal of providing confidence that the agreement or treaty is being satisfied. There are numerous signatures, most of them radiation signatures, that can indicate that an object is a nuclear weapon, but as the level of confidence is increased, there is also an increasing level of intrusiveness and possible compromise of sensitive weapon design information.

R&D Challenges. The Russians have sensitivities to the radiation signature measurements on nuclear weapons and components that differ from U.S. concerns. Because we do not know what radiation signatures will define Russian weapons, we must search for solutions that provide an acceptable level of confidence that we are monitoring the dismantlement of actual weapons. We must be able to provide assurance that we are not making measurements on arrangements of excess, weapons grade nuclear material, or spoofs using non-weapons capable radioactive material. Another difficulty is that several types of weapon designs can make it almost impossible, using radiation measurements, to confirm that a declared item is a weapon.

Because of the uncertainties in any treaty negotiations, a layered approach is being taken in order to provide the negotiators with technology options. Measurement and signal processing techniques are being developed that can, when they are conducted in sequence, provide increasing levels of confidence that a declared item is a nuclear weapon. The increasing levels of confidence also require increasing the levels of intrusiveness and the raw data will likely contain sensitive design information. In order to protect this information it will be necessary to develop information barriers, to test them, and by conducting vulnerability assessments (red teaming) to make certain no sensitive information is being revealed. Also, tracking and long-term monitoring of stored weapons components requires a balanced approach that will provide confidence that the storage containers remain intact and the components do not leave the storage area to be reused in nuclear weapons. A combination of micro-technologies, integrated radiation sensor systems using neural networks, and non-nuclear techniques are being developed as alternatives. Also important, is the need to be sure normal site security is not compromised by the treaty monitoring system.

Accomplishments

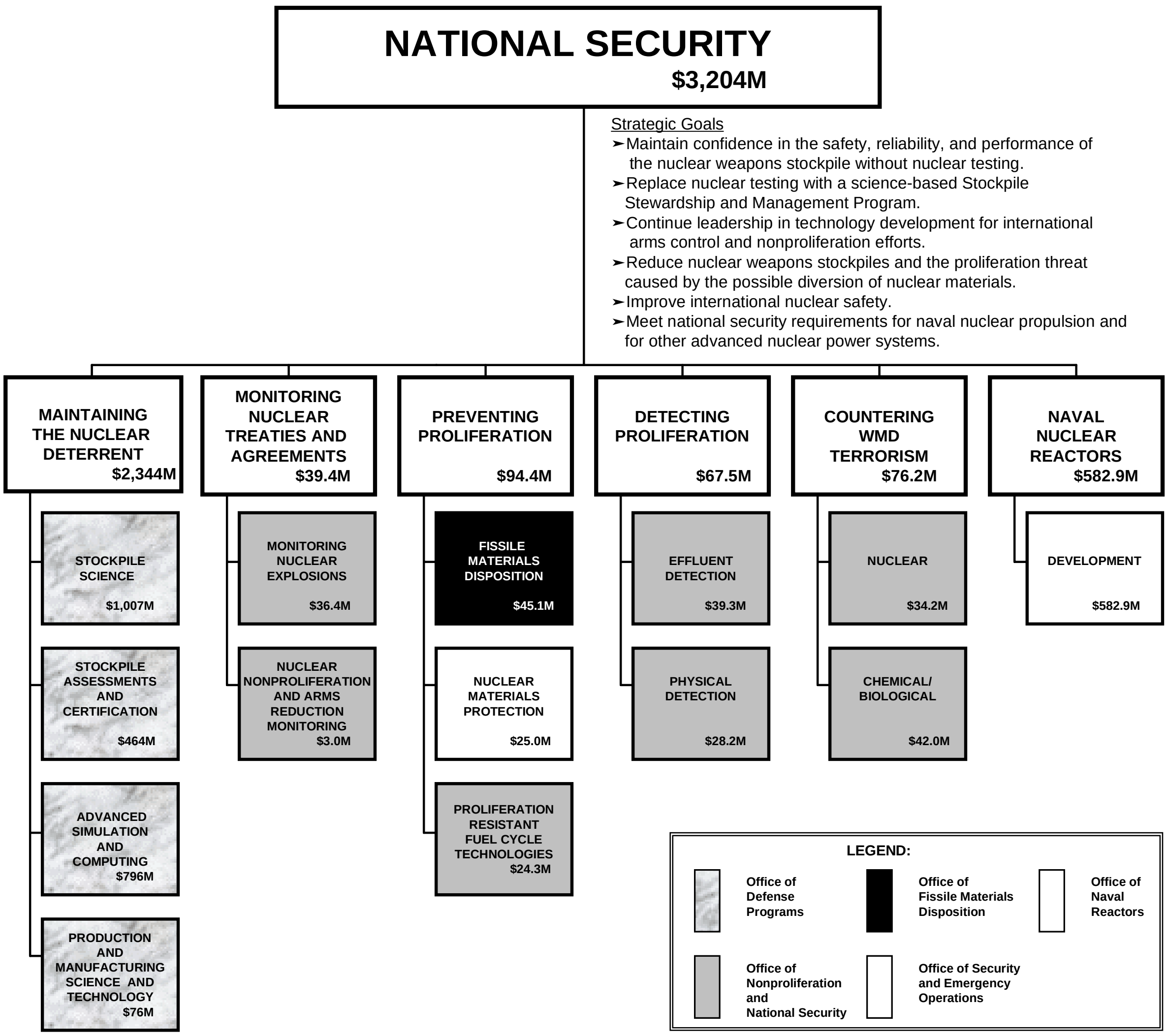
- Developed an approach to measure unclassified nuclear weapons attributes such as threshold mass and $^{240}Pu/^{239}Pu$ isotopic ratio for verification of warhead dismantlement and reductions.

- Developed options for possible START III negotiations, using radiation and alternate signatures, that will provide increasing levels of confidence a nuclear weapon has been dismantled.

Summary Budget Table (000$)

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Monitoring Nuclear Explosions	**42,300**	**36,100**	**36,400**
U.S. Satellite-based Systems	14,700	12,800	12,800
U.S. and International Ground-based Systems	27,600	23,300	23,600
Nuclear Nonproliferation and Arms Reduction	**3,000**	**3,000**	**3,000**
Total	**45,300**	**39,100**	**39,400**

Chapter 5
Preventing Proliferation



Chapter 5
Preventing Proliferation

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Overview

Definition of Focus Area

The current environment of warhead dismantlement and decreased requirements for any new weapons leaves the Department of Energy with more nuclear materials on hand than at any time in history. The Department of Energy has an associated responsibility to protect these materials from theft and diversion and to eliminate, where possible, stockpiles of weapons-usable fissile materials through disposition. The DOE research and development portfolio in the area of preventing proliferation addresses: development and adaptation of technologies that convert U.S. weapons-usable materials to a form that will prevent the plutonium from ever being used for nuclear weapons and assisting Russia in the demonstration of plutonium conversion technologies; development of technologies to control and account for nuclear materials and physically protect these materials; and development of proliferation resistant fuel for commercial reactors to reduce and eventually eliminate the international traffic in highly-enriched uranium (HEU) for commercial purposes.

To enable fissile material disposition, necessary process development and tests must be completed to provide the design and operational bases for surplus plutonium disposition facilities. DOE plans to disassemble "pits" and dispose of the surplus plutonium by (1) immobilizing it in a ceramic form surrounded by vitrified high level waste, the "can-in-canister" approach, and (2) by burning it as mixed oxide (MOX) fuel in existing domestic reactors.

Technologies to control and protect nuclear materials must remain state-of-the-art to ensure these materials do not fall into the hands of increasingly sophisticated terrorists. Detection technologies must accurately gauge and quantify mixed-matrix and shielded nuclear materials, while reducing worker exposures. Intrusion detection, barrier and vault systems, as well as countermeasures, must remain effective against continuously emerging threats.

Highly enriched uranium is used peacefully for civil energy production, research, and medical isotope production, but is also used in nuclear weapons. To reduce the danger of proliferation, the United States has pursued the elimination of HEU commerce by striving to develop low enriched fuel suitable for these necessary functions. The fissionable uranium may be able to be 'diluted' with non-fissionable uranium to lower the enrichment while maintaining the benefits. Fuel and target fabrication techniques must be developed, and fuel and target qualification tests must be performed to ensure successful performance within reactors.

Preventing proliferation is an area of critical importance to U.S. national security and a high-interest research area for the Department of Energy. The U.S. and Russia have similar interests in and responsibilities for reducing the risk of nuclear proliferation from civilian nuclear power, and both are pursuing technology development programs to accomplish that goal. Continuing interactions with Russian officials on this topic will lead to the identification of many areas where the U.S. and Russian philosophies and technologies contributing to the development of proliferation-resistant nuclear systems will overlap. The Department of Energy intends to accelerate development of proliferation-resistant nuclear systems by implementing a new research initiative (the Proliferation Resistant Reactors and Fuels Research Program) during FY 2001.

National Context and Drivers

The Department foresees a future national security environment with continued uncertainties and risks of international terrorism from weapons of mass destruction. In the aftermath of the Cold War, significant quantities of weapons-usable fissile materials have become surplus to national defense needs both in the United States and Russia. The threat that nuclear weapons or materials could fall into the wrong hands through theft or diversion is a clear and present danger. The danger exists not only in the potential for proliferation of nuclear weapons, but also in the potential for environmental, safety and health consequences if surplus fissile materials are not properly managed.

United States policy is to protect and control nuclear materials; to seek to eliminate, where possible, accumulation of stockpiles of highly enriched uranium and plutonium; and to reduce and eventually eliminate the civilian use of HEU in research and test reactors and in targets for medical isotope production. The U.S. will also ensure that, where these materials already exist, they are subject to the highest standards of safety, security, and international accountability. DOE is committed to safely dispose of the nuclear materials made surplus by the downsizing of the nuclear arsenal in conformance with arms control and nonproliferation treaty requirements. The Department has developed several strategies that will contribute to a reduction in the global nuclear danger associated with inventories and supplies of nuclear materials that could be used for the proliferation of nuclear weapons.

Linkage to Goals and Objectives

The R& D efforts for preventing proliferation support the Department's national security strategic goal, Objective 4, to reduce nuclear weapons stockpiles and the proliferation threat caused by the possible diversion of nuclear materials. Strategy 2 of Objective 4 would reduce inventories of surplus weapons-usable fissile materials worldwide in a safe, secure, transparent, and irreversible manner. Reducing/eliminating the civilian use of HEU and taking back the spent research reactor fuel from the U.S. and abroad will remove the threat of theft or diversion from these civilian reactors.

Research and development activities for preventing proliferation are also linked to various external requirements as described in:

- Presidential Decision Directives related to preventing proliferation of weapons of mass destruction.
- Highly Enriched Uranium Purchase and Blending Agreement.
- Department of Defense Cooperative Threat Reduction Program (Senate Language).

- Mayak Transparency Mandate from the Biden Amendment.
- Trilateral Initiative.
- Scientific and Technical Cooperation Agreement on the Management of Plutonium That Has Been Withdrawn from Nuclear Military Programs, July 1998.

Uncertainties

The research and development portfolio in this focus area is directed at establishing a technology base to support the design leading to the construction and subsequent deployment of facilities to disposition surplus plutonium. The technical risks corresponding to successfully meeting the goals and objectives of the investment in the portfolio are considered to be manageable. However, the start of construction of the facilities in the United States is dependent on progress on bilateral agreements with Russia for plutonium disposition. Negotiations with Russia are ongoing and agreements may be reached sometime in early calendar 2000. Were negotiations to be suspended the pace of research and development would probably be affected.

Success in converting research and test reactors from highly enriched uranium to low enriched uranium faces technical and political uncertainties. Technical uncertainties relate to the ability to develop and fabricate low enriched uranium fuels and targets with increased density to match the performance levels of higher enriched uranium fuels and targets. The technical risk is considered manageable because of the success of the advanced fuel development work already accomplished. The political uncertainties involve the willingness of foreign research reactor operators to agree to convert to low enriched uranium fuel and targets, as well as the desire of foreign governments to seek to reduce the civil use of highly enriched uranium. The United States attempts to reduce these political uncertainties with incentives and export restrictions.

The eventual success of the Proliferation Resistant Reactors and Fuels Research Program and the pace of successful implementation will be dependent upon the quality of interactions and cooperation with Russian officials. Recent program collaboration discussions have been very encouraging. The program is also dependent upon Russian adherence to their commitments not to sell nuclear technology to Iran beyond that involved in the Bushehr 1 project.

Investment Trends and Rationale

The investments in development efforts are directed at establishing the information that is needed to design and operate facilities to disposition surplus plutonium in the United States. In addition investments are being made in Russia for small-scale tests and demonstrations in plutonium disposition technologies to facilitate Russian decisions regarding plutonium disposition. The Department’s current plans are to start design and complete design of U.S. plutonium disposition facilities in the FY1999 through FY2004 time frame. Consequently, the investment is front-loaded to support the design efforts. Some development activities would continue at a lower funding level after the completion of design in order to validate specific process operations.

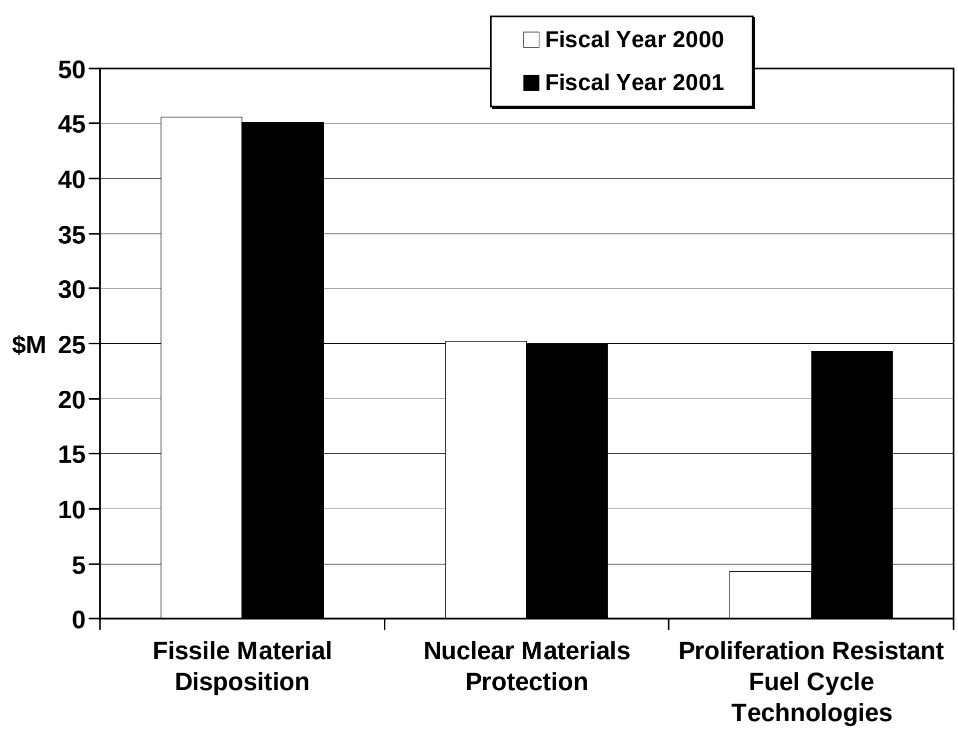
In Russia, the investment is also front-loaded, with most of the investment completed by FY2001. Continuation and expansion of U.S. and U.S.-Russian small-scale testing and demonstration of plutonium disposition technologies is needed to build trust and cooperation and help prepare for reciprocal implementation of future plutonium disposition actions and agreements. This would help fill the gaps in technical knowledge, remove uncertainty regarding the viability of certain technologies, and lead to the successful disposition of surplus plutonium.

DOE executes R&D activities associated with the disposition of surplus plutonium through the expertise and facilities provided at the national laboratories. A lead laboratory is assigned the responsibility for the technical work in a program area. In turn, the lead laboratory contracts with other national laboratories and institutions, such as universities and industry. DOE establishes goals, provides guidance and direction in each program area, and in consultation with the lead laboratory, prioritizes the work and activities in each program area.

The Department of Energy intends to accelerate development of proliferation-resistant nuclear systems by implementing a new research initiative (the Proliferation Resistant Reactors and Fuels Research Program) during FY 2001.

The chart shown below shows investments by activity areas that will be discussed in the remainder of this chapter.

Preventing Proliferation



Federal Role

National Security is a constitutional role of the Federal Government. DOE executes research and development activities associated with the detection of proliferation activities through the expertise and facilities provided at the national laboratories. A single laboratory may manage a program activity area. Alternatively, multiple laboratories may be involved in a program activity area. Inter-laboratory programs are managed from DOE headquarters. In turn, individual laboratories contract with other institutions, such as universities and industry. DOE establishes goals, provides guidance and direction in each program area, and in consultation with the laboratories, prioritizes the work and activities in each program area.

The objective of the Office of Fissile Materials Disposition is to manage, store, and dispose of fissile materials from weapons and weapon programs that are excess to the national security needs of the United States. The Office also provides technical support for Administrative efforts to obtain reciprocal disposition of Russia’s surplus plutonium. The head of this office leads these activities and will serve as the Special Negotiator for Plutonium Disposition.

Key Accomplishments

In the area of preventing proliferation, the accomplishments further the technological bases for the design and operation of the disposition facilities. In pit disassembly and conversion, a full-scale demonstration of core functions was designed, constructed, and started at Los Alamos National Laboratory. A number of different pit designs have been disassembled and converted. In Russia, the development of a Russian plutonium conversion and nondestructive assay prototype was initiated and continues. In immobilization, the baseline ceramic form was established and conversion and ceramification equipment was procured in preparation for the integrated demonstration. Cold test pours of simulated high-level waste glass into actual canisters containing cans of simulated ceramic disks verified the feasibility of the can-in-canister approach. Demonstrations of feasibility of several key processes were completed. In Russia, small-scale tests of plutonium vitrification were performed. In the reactor option, the preliminary process parameters for MOX fuel fabrication, using powder derived from weapons plutonium metal conversion, were established. Sample MOX fuel from this process was fabricated, irradiated, and examined.

Accomplishments in materials control and accountability research and development lead to safer inventories of special nuclear materials by furthering the technology base of SNM detection and physical protection. Special nuclear material may now be found in unopened waste drums via non-destructive assay and in vehicles or on persons via enhanced security portals. Remote inventory monitors continue to improve the ability to detect tampering and diversion of SNM while removing the worker from possibly harmful exposures.

Proliferation resistant fuel cycle research and development has demonstrated that all but six western-European high-powered research reactors are able to be converted from using HEU to LEU fuel and, of those that are able to convert, all but ten have plans to do so. The Department has supported reactor conversion in over 20 countries and has supported the acceptance specification policy in over 40 countries.

Fissile Materials Disposition

Budget: FY99-$43.8M, FY00-$45.6M. FY01-$45.1M

Background

The Department, in a Record of Decision on the Surplus Plutonium Disposition Environmental Impact Statement issued January 2000, announced an implementation approach for the disposition of surplus weapons-usable plutonium in a manner such that these materials can never again be used for nuclear weapons. The Department plans to disassemble "pits" and dispose of surplus plutonium (1) by immobilizing it in ceramic form surrounded by vitrified high level waste, the "can-in-canister" approach, and (2) by burning it as mixed oxide (MOX) fuel in existing, domestic reactors. Pursuing both of these approaches provides important insurance against any unforeseen problems in implementing either approach by itself and provides the United States with flexibility and leverage needed for working with Russia and our allies on the critical task of reducing excess Russian weapons plutonium. Accordingly, the Department's plans include completing the necessary process development and small-scale technology tests, including "can-in-canister" immobilization tests and tests of MOX fuel fabricated from weapons plutonium and subsequent irradiation.

Program Description

For the immobilization approach, the Department needs to resolve the technological issues associated with formulating plutonium in ceramic materials, the production processes, and the impact of impurities on the surplus plutonium forms, in order to have confidence that this approach can provide success in a timely and cost-effective manner.

For the reactor approach, the Department will focus on development tasks associated with handling of the specific plutonium and uranium oxides to be used in fabrication of MOX fuel in order to confirm the applicability of existing fabrication processes and procedures to our mission.

In order to deploy either of these disposition approaches, the Department needs to complete operational testing of the processes that would be used to dissemble pits and convert the plutonium from pits and other forms into a plutonium oxide form which would serve as feed material for both disposition technologies as well as be made available for international inspection.

Pit Disassembly and Conversion

Budget: FY99-$17.9M, FY00-$17.4M, FY01-$15.4M

Description and Objectives. The U.S. activities are to develop, demonstrate and document core functional capabilities required to disassemble surplus weapons pits and convert them to plutonium oxide in a manner as safe, environmentally sound, and cost effective as practical.

Development and demonstration of this process will minimize the cost, schedule, and technical risks associated with the upcoming design, construction and operation of the production facility.

For the Russian effort, the work consists of analyses, and testing as appropriate, of different conversion technologies. The objective is for the Russians to select a pit conversion technology leading to a prototype demonstration of the technology. The Bochvar Institute will do the work, with support from U.S. Department of Energy laboratories.

R&D Challenges. The major overall challenge for the U.S. program is developing a technology that accommodates about 30 unique surplus pit designs, and keeping the process robust and cost-effective, while minimizing operator radiation exposure. The challenge in Russia, is the selection of a conversion technology that the Russians can readily deploy.

R&D Activities. The major R&D activities involve the testing of a prototype demonstration at Los Alamos National Laboratory that will provide the process parameters for and operating experience in several core modules. Activities include: development of an optimum joint pit disassembly /plutonium extraction and conversion approach; development of a plutonium oxide long-term packaging and non-destructive assay (NDA) system; development of a non-plutonium pit part disposition approach; and development of robotics for the above functions. For work in Russia, the goal is for the Russians to select a pit conversion technology leading to a prototype demonstration of the technology. Each of these areas is described below:

- **Development of an Optimum Plutonium Extraction and Conversion Approach—**A pit bisector module coupled with a pyrochemical plutonium metal to plutonium oxide conversion module will be operated to obtain operating process parameters.

- **Development of a Plutonium Oxide Packaging and Non-Destructive Assay System—**The basic functions of plutonium oxide canning have been manually demonstrated on a number of pits. Then the canning system will be automated and the automated canning and NDA system will be demonstrated on the remainder of pits to be processed in the demonstration activity, covering all surplus pit types.

- **Development of a Non-Plutonium Pit Part Disposition Approach—**Pit disassembly results in numerous unique pit parts which require development of particular process steps for disposition. Development involves establishing processes, equipment, and procedures for disposition of particular pit parts, such as for the decontamination of uranium hemishells and the declassification of non-Special-Nuclear-Materials hemishells.

- **Development of Robotics—**Several of the process steps are being automated to reduce the radiation exposure to operators. Robots are being fabricated and will be tested in a glove-box environment.

- **Russian conversion—**The options for the conversion of Russian surplus weapons plutonium will be analyzed, and the technology selected will be developed and tested in Russia.

Accomplishments

- Completed an initial integrated pit disassembly and conversion demonstration run with a full scale demonstration system of core functions at Los Almos National Laboratory.
- Operated a full-scale glove box modules for pit bisection and plutonium oxidation at Lawrence Livermore National Laboratory.
- Disassembled and converted plutonium from 12 of 30 different types of surplus pits.
- Cold-test demonstrated robotics for the plutonium oxide packaging system.
- Initiated development of a Russian plutonium conversion and nondestructive assay prototype system.

Immobilization

Budget: FY99-$16.5M, FY00-$21.8M, FY01-$21.6M

Description and Objectives. The U.S. activities are directed at resolving technological issues associated with immobilizing plutonium in a ceramic. Research and development is being conducted to establish the process, and associated parameters, and develop and define the equipment that will support the deployment of the can-in-canister immobilization technology.

For the Russian effort, the work consists of experiments involving the immobilization of plutonium in glass and ceramic matrices. The objective is to demonstrate to the Russians that immobilization can be used for plutonium disposition, even if only for waste streams from the disposition facilities. This work is conducted at the Bochvar Institute and Radium Institute in Russia, with support from the DOE national laboratories.

R&D Challenges. Challenges include developing a product and technology that accommodates the full range of impurities and constituents in the non-pit surplus plutonium while keeping process and equipment simple, flexible, cost effective, and low radiation exposure to operators. The challenge in the Russian program is to convince Russia that recovery of plutonium from very low concentrations of plutonium containing materials is not economical.

R&D Activities

- **Immobilized Form Development—**Development work in this area focuses on providing: compositions of the ceramic immobilization forms that accommodate the range of plutonium feed materials expected; the related processing parameters for fabricating the plutonium forms; important physical and chemical properties of the final form needed for process/equipment development; and a preliminary product control model that establishes acceptable ranges for feed compositions and processing parameters. These development activities involve laboratory experiments with plutonium, uranium, desired neutron absorber elements, and the other materials contained in the expected feed; non-radioactive experiments with surrogate materials; and analysis of data related to the feed material and the physical chemistry of the ceramic form.

- **Immobilization Process/Equipment Development—**Development work in this area involves: converting a wide range of feed materials into a homogeneous oxide feed to the immobilization process using mechanical and chemical process; blending this feed with uranium oxide and other ingredients; pressing the feed blend into disks; firing/sintering them into the immobilized plutonium ceramic form disks; and packaging cans of plutonium ceramic disks into arrays inside large canisters, which are then filled with molten high-level radioactive waste glass. Key process steps and equipment that need to be developed and tested for the specific ceramic formulation with actual plutonium feed materials include design of the canister package and internals, glass pour testing of prototype canisters, canister loading, and use of surrogate test materials.

- **Russian Process Development—**Work involves tests on the immobilization of plutonium in glass and ceramics and tests on the recovery of plutonium from glasses and ceramics.

Accomplishments

- Established baseline ceramic form that accommodates the expected range of impurities.

- Full-scale plutonium conversion test equipment was procured and assembled to support integrated testing this year. Prototype ceramification test equipment was procured and is nearing final assembly, for subsequent integrated testing this year.

- Tests confirmed the overall feasibility and practicality of the “can-in-canister” technology. Three pours of simulated high-level waste glass into actual canisters containing cans of simulated ceramic disks showed that glass would fill all the spaces around the cans with no detrimental effect on their support structure.

- Performed small-scale tests of plutonium vitrification in Russia.

Reactor Option

Budget: FY99-$9.4M, FY00-$6.4M, FY01-$8.1M

Description and Objectives. The MOX technology is used in Europe and does not require extensive research and development for implementation in the U.S. The effort is directed at fabricating samples of MOX fuel and conducting limited experiments and tests of the sample MOX fuel to assess the effect of gallium contained in weapons-grade plutonium on fuel performance. The objective of this effort is to assure the plutonium and uranium material forms used for fabricating MOX fuel will produce acceptable fuel, and examine key issues related to the successful performance of MOX fuel in commercial nuclear reactors.

R&D Challenges. The challenge is understanding and reconciling the differences between MOX fuel produced from weapons-derived plutonium and that which is commercially produced in Europe. Differences include variation in plutonium oxides, isotopics, and the presence of impurities introduced in the manufacturing of nuclear weapons, i.e., pits. In addition, the MOX fuel containing small amounts of gallium may need to be shown to be acceptable for commercial power plant use.

R&D Activities

- **MOX Fuel Qualification—**Activities involve irradiating sample fuel made from weapons origin plutonium and completing post-irradiation examination to determine fuel performance.

Accomplishments

- Established preliminary process parameters for MOX fuel fabrication using powder derived from weapons plutonium metal conversion.
- Developed bench-scale analytical method for detecting gallium in Pu oxide powder/fuel and completed basic R&D on gallium/fuel cladding interactions.
- Developed draft plutonium oxide feed specification.
- Fabricated, irradiated, and began examination of demonstration MOX fuel.

Nuclear Materials Protection

Budget: FY99-$21.3M, FY00-$25.2M, FY01-$25.0M

Background

In recent years, the worldwide proliferation of weapons of mass destruction has emerged as one of the most serious dangers confronting the United States. This is a continuing and evolving problem with far-reaching consequences for international and domestic security and stability. In response to this emerging threat to our security, the President directed the prioritization of a number of initiatives and programs throughout the United States government and the Department of Energy. One of these priorities is the effective protection, control, and accountability of nuclear materials, technology, and expertise in the United States.

The Department of Energy has more nuclear materials on hand than at any time in history, and has an associated responsibility to protect these materials. Should a terrorist gain access to special nuclear materials (SNM) there is considerable potential for radiological sabotage which could endanger not only Department of Energy employees but also the general public. This scenario must be protected against. Other assets of national security significance requiring protection include nuclear weapons, weapons design information, and the national energy infrastructure.

Maintaining a technological "edge" over potential adversaries is an essential part of the DOE protection strategy, and since terrorists are becoming increasingly sophisticated and well funded, continued investments in protection technologies are required. Not only must the Department protect against the use of traditional terrorist tools such as bombs, explosives, and armed teams, but also insiders, lethal agents, directed energy weapons, and the terrorist use of computers.

For over 30 years the Department has invested in the development of safeguards and security measures and technologies at almost every national laboratory to help counter these threats and ensure the preservation of national security and public safety. It does not appear that investments in this area can be relaxed without accepting considerable risk to Departmental assets requiring protection, or the general public.

Program Description

The nuclear materials protection activity is focused on the following three areas:

- Nuclear Material Control and Accounting.
- Physical Protection.
- Information Security.

Technologies emerging from all of these areas are used by DOE facilities to offset specific threats. In order to make sure that projects funded under this program reflect capabilities that are truly needed, the program is formulated based on user needs that have been submitted by field sites. These needs are then expanded into requirement documents that can be used by laboratories and quality panels to provide input and oversight of projects that receive funding. Technologies often make their way to field users initially as part of a beta test program so that laboratory developers can receive direct feedback on the adequacy of their designs. Continuous dialogue with field users throughout the development cycle has lead to the successful fielding of numerous technologies and an improved security posture for the Department.

Materials Control and Accountability

Budget: FY99-$6.8M, FY00-$7.9M, FY01-$8.8M

Description and Objectives. Nuclear Materials Control and Accountability (NMC&A or MC&A) is that part of safeguards that detects or deters theft or diversion of nuclear materials and provides assurance that all nuclear materials are accounted for appropriately.

Materials accounting establishes and tracks nuclear material inventories and detects loss or diversion of nuclear materials. A materials accounting program employs physical inventories, measurements, accounting records, and reports to ensure that inventory records are correct and complete. It provides credible assurance that diversion has not occurred and that other functions of the safeguards system have been effective in protecting these materials.

Materials control limits access to nuclear materials to authorized personnel in authorized locations, ensures the integrity of accounting systems, and deters theft or diversion of materials.

Our objective is to develop technologies, technical expertise, and information that supports DOE field sites in their efforts to design, implement, and manage nuclear material control and accounting systems that meet the policy requirements of the Department.

R&D Challenges. Maintaining control and accountability of nuclear materials within the defense nuclear complex requires:

- Measurement technologies that can accurately quantify alternative nuclear materials to prevent the proliferation of these materials for use in the creation of weapons of mass destruction.
- Advanced methods for detecting shielded nuclear materials and for identifying specific materials (versus simple recognition of radiological material presence).
- Automated and unattended verification of vaulted inventories (in storage) to enhance worker safety, while simultaneously protecting those materials by reducing physical access.
- Self calibrating measurement equipment and non-nuclear standards to reduce exposure of employees to nuclear materials.
- Measurement capabilities that can measure the amount of special nuclear material in spent fuel assemblies which is not sensitive to geometry or configuration.

R&D Activities. DOE's approach involves:

- Application of advanced technologies to address the shortcomings between user needs and available solutions including:
  - Advanced calorimetry technologies for enriched uranium.
  - Detection technologies for shielded and mixed matrix materials.
  - Non-destructive assay systems for difficult-to-measure materials.
  - Calibration and standards technologies.
  - Spectrum analysis software for nuclear materials measurements.
  - Unattended vault surveillance.
  - Standardized materials accounting database.
- Maintenance of core competencies in nuclear materials detection, measurement, control and accountability.
- Provision of DOE site support for nuclear materials measurement and control issues.

Accomplishments. Recent accomplishments include:

- Fielded a radionuclide identification system.
- Developed advanced technologies to prevent the theft or diversion of special nuclear materials, including the unattended, on-line gamma-ray monitor.
- Developed a portable measurement tool for gross nuclear material mass determinations.
- Provide matrix correction techniques that provide accurate measurement of large crates to prevent smuggling of special nuclear materials.
- Provide a low-wattage electrical calibration heater system to calibrate calorimetry instruments.
- Developed nondestructive assay standards.
- Developed sensors for detection of SNM and other property for use at vehicle and pedestrian portals to prevent theft or diversion of special nuclear materials.
- Developed an electro mechanically cooled HPGe gamma-ray detector to replace liquid nitrogen cooled systems when liquid nitrogen is not practical.
- Developed a Pu isotopic analysis capability for use with room-temperature CdZnTe detector systems.
- Developed a Compton suppression system based upon digital signal processing techniques. This system will significantly reduce the time it takes to make nuclear materials accountability measurements and thus reduce personnel radiation exposures as well as the time nuclear material sources have to be handled.
- Provided a cost-effective technique for rapid nondestructive assay of plutonium in residues and impure materials.
- Completed software for calorimetry measurements of fissile materials in DOE facilities.
- Provided a new instrument to measure uranium that is less time intensive and more cost effective.

Physical Protection

Budget: FY99-$10.3M, FY00-$11.4M, FY01-$13.8M

Description and Objectives. DOE develops technologies, technical expertise, and information that supports DOE field sites in their efforts to design, implement, and manage protection systems that meet the policy requirements of the Department and mitigate the official DOE design basis threat.

Protecting the people and physical assets present throughout the national defense nuclear facilities requires continuous measurement of the vulnerabilities and performance characteristics of deployed and emerging protection systems. Specific threats that must be countered by protection, detection, and mitigation technologies include protection against terrorist attacks, the activities of malicious "insiders", and the adversary use of explosive, chemical, or biological agents. Additionally, protective forces within nuclear facilities face a number of unique operational constraints (for example, nuclear process equipment must not be struck by a ricocheting bullet).

R&D Challenges. Achieving physical protection objectives requires overcoming a number of challenges:

- To enable design and management of effective security systems, good security system modeling and vulnerability analysis techniques must be available. Good modeling systems rely on accurate security system performance information originating from solid testing programs. Current resources do not permit adequate performance information to be generated.

- Recent tests have shown that barriers and vault systems used by the Department are not as robust as once thought. An activated barrier that supplements existing physical barriers is therefore required.

- Balancing the above requirements against planned developmental improvements in critical existing security systems such that they do not become obsolete.

- Development of technologies to address known vulnerabilities within current budget constraints.

R&D Activities. The Physical Protection program invests in the following seven areas:

- Quantification of the performance of security equipment against current and emerging threats:
  - Interior and exterior sensors.
  - Explosives detection equipment.
  - Access delay equipment.
  - Video equipment.
  - Entry control and biometrics.
  - Vehicle and personnel screening.

- Elimination of specific protection system vulnerabilities and deficiencies.
- Explosive detection and protection.
- Protective system modeling and analysis.
- Alarm annunciation and access control improvement (ARGUS).
- Protective force equipment improvement.

Accomplishments. Technological means have been applied to develop, modify, test, or implement numerous physical protection, detection, assessment, delay and response capabilities throughout the DOE complex:

- Redesign of an activated barrier currently in use throughout the DOE complex to extend operational shelf life and confidence.
- Fielding of frangible non-lead ammunition.
- Fielding of an automated closed-circuit television (CCTV) camera tester.
- Fielding of a relocatable security system.
- Fielding of a high security wireless alarm communications link.
- Fielding of a technology capable of screening vehicles for hidden people.
- An advanced operator training simulation tool for high-security dispatch application where the protection of critical national assets and national security are at stake.
- Modernize the Department's standardized alarm and access control system (ARGUS) to prevent unauthorized access to DOE facilities and assets. Efforts include replacing outdated software, re-engineering the database and user interface, and adding neuron chip based smart sensors.
- Provide a wind-suppression algorithm for the human presence detection system which detects unauthorized humans hidden within a vehicle.
- Develop a high energy compact cartridge which can be inserted into a shotgun to provide for the selection of a less than lethal to a lethal response to intruders.
- Provide recommendations to DOE sites on the use of high-intensity acoustics for access delay applications.

Information Security

Budget: FY99-$4.2M, FY00-$5.9M, FY01-$2.4M

Description and Objectives. The facet of national security that involves protecting information and information systems that exist within the defense nuclear complex continues to expand in scope and complexity. Weapons design data must be carefully protected (confidentiality); the integrity of various forms of research data must be assured (integrity); and many systems that affect worker and public safety must not be disrupted (availability). Detection of unauthorized cyber activity, that may be distributed over time or geographical location, remains a true challenge for the technical and operational communities. The capability to respond to cyber attacks and to reconstitute affected systems requires tools and methods that provide understanding of how systems act and react under widely varying conditions.

R&D Challenges. As mentioned in the report by the President's Commission on Critical Infrastructure Protection:

> "A satchel of dynamite or a truckload of fertilizer and diesel fuel have been frequent terrorist tools. The explosion and the damage are so certain to draw attention that these kinds of attacks continue to be among the probable threats to our infrastructures. Today, the right command sent over a network to a power generating station's control computer could be just as effective as a backpack full of explosives, and the perpetrator would be harder to identify and apprehend.
>
> The rapid growth of a computer-literate population ensures that increasing millions of people possess the skills necessary to consider such an attack. The wide adoption of public protocols for system interconnection and the availability of "hacker tool" libraries make their task easier.
>
> While the resources needed to conduct a physical attack have not changed much recently, the resources necessary to conduct a cyber attack are now commonplace. A personal computer and a simple telephone connection to an Internet Service Provider anywhere in the world are enough to cause a great deal of harm.
>
> Of the many people with the necessary skills and resources, some may have the motivation to cause substantial disruption in services or destruction of the equipment used to provide the service."

The DOE cyber security program faces many dynamic and complex challenges involving critical government functions that impact national security. These challenges include:

- The detection of unauthorized cyber activity that may be distributed over time or geographical location is important.
- The interconnectivity of computer systems makes it increasingly important to prevent and detect unauthorized access to computer systems due to many vital processes and systems being threatened by one unauthorized individual.

- The proper technologies must also be in place to prevent an authorized insider from adverse activities.

- The dynamics of the computer industry cause currently available tools for detecting adversary action to become quickly outdated, and thus there is a constant requirement to remain on the cutting edge.

- The capability to immediately respond to cyber attacks and to reconstitute affected systems is essential.

R&D Activities. DOE activities are directed towards:

- Developing an automated protection system that will detect anomalous activities on a computer network and automatically respond to mitigate any potential damages.

- Developing advanced tools and technologies to detect/prevent penetrations to computer networks.

- Providing an automated low-cost, experience-based, training capability for network system administrators.

- Providing technical assistance on current threats to DOE information networks.

- Determining attack mitigation strategies.

Accomplishments. In no other area do technology-based vulnerabilities and solutions "leap-frog" each other as rapidly as in the world of information technology. Examples of DOE accomplishments fall in the following areas:

- Automated security profiling tools to assess general system security capabilities.

- Network intrusion detection tools.

- Computer Incident Advisory Capability (CIAC) services.

Several tools and documents have been created as part of funded DOE projects. These tools tend to be finished products, developed for a particular information system/network or, alternatively, for the DOE at large. Programs such as SPI-Net (Security Profile Inspector for Networks), SSDS (Secure Software Distribution System), and NID (Network Intrusion Detector) fit in the later category. Not all of these tools are available to the general public for obvious reasons.

The Security Profile Inspector for Networks (SPI-Net) software product provides a suite of security inspections for most Unix systems at the touch of a button. This security inspection suite includes Quick System Profile, Access Control Test, Binary Authentication Tool, Password

Security Inspector, Change Detector Tool, and Promiscuous Mode Checker. The Security Profile Inspector is a vulnerability and intrusion detection tool for both Microsoft Windows NT and UNIX systems. Among its features, it inspects for binary file modifications, vulnerable system versions, weak passwords, vulnerabilities from security misconfigurations, and changes on files and directories, thereby protecting from inadvertent user modification as well as intrusions and viruses. The Security Profile Inspector is freely available to all U.S. Government agencies and to contractors directly supporting the U.S. Departments of Energy and Defense.

The Secure Software Distribution System (SSDS) provides automated analysis of network-based computer systems to determine the status of security patches. SSDS determines what patches need to be installed. For the patches that are installed, SSDS checks the permissions and ownership of the files referenced in the patch and ensures that the system software is authentic. SSDS is composed of two components: a Patch Server and a Vendor Server. Currently, SSDS detects patch deficiencies on Sun systems that run Solaris 2.3 or newer. SSDS is freely available to all U.S. Government agencies, and to contractors directly supporting the U.S. Departments of Energy and Defense.

The Network Intrusion Detector (NID) software product provides a suite of security tools that detects and analyzes network intrusions. NID provides detection and analysis of intrusions from individuals not authorized to use a particular computer, and from individuals allowed to use a particular computer, but who perform either unauthorized activities or activities of a suspicious nature on it. NID is available for use by all authorized Department of Energy offices, national laboratories and facilities; Department of Energy contractors who directly support DOE; and U.S. Government civilian federal agencies.

The Workstation Daylock is a combination of software and a hardware alarm card for protecting a PC workstation from access by unauthorized personnel.

The DOE Information Security Server (DOE-IS) is an advanced server on the Internet whose goal is to enhance information security data sharing within the United States Department of Energy (DOE) community. The DOE community includes all DOE sites and contractors. The Server contains tools and documents related to information security that have been made available by many sources both within and outside of the DOE.

The Computer Incident Advisory Capability (CIAC) group assists the Department of Energy in its information protection efforts by providing computer security incident response related services. CIAC provides on-call technical assistance and information to Department of Energy (DOE) sites faced with computer security incidents. This central incident handling capability is one component of all-encompassing service provided to the DOE community by CIAC. The other services CIAC provides are: awareness, training and education; trend, threat, and vulnerability data collection and analysis; and technology watch.

Proliferation Resistant Fuel Cycle Technologies

Budget: FY99-$3.8M, FY00-$4.3M, FY01-$24.3M

Background

Reducing the threat of the proliferation of nuclear weapons continues to be one of the foremost goals of United States foreign policy. A key element of this policy is the reduction, and eventual elimination, of highly enriched uranium (HEU) in civil commerce. HEU is used as fuel for nuclear research and test reactors and as targets for medical isotope production, but can also be used in nuclear weapons.

Since the 1950s the United States has provided peaceful nuclear technology to foreign nations in exchange for their promises not to develop nuclear weapons. A major part of this program has been to provide research reactor technology to allow recipient nations to pursue medical, agricultural, and industrial applications of nuclear energy.

To reduce the danger of nuclear weapons proliferation, the United States in 1978 began the Reduced Enrichment for Research and Test Reactors (RERTR) program. One of RERTR's most important and successful activities has been the development of low enriched uranium (LEU) fuels to permit conversion of research reactors from HEU.

Both the U.S. and Russia have interests in and responsibilities for reducing the risk of nuclear proliferation from civilian nuclear power, and both are pursuing technology development programs to accomplish that goal. Continuing interactions with Russian officials on this topic will lead to the identification of many areas where the U.S. and Russian philosophies and technologies contributing to the development of proliferation-resistant nuclear systems will overlap. Successful collaboration between the United States and Russia will identify areas of mutual interest. The Department of Energy intends to accelerate development of proliferation-resistant nuclear systems by implementing a new research initiative (the Proliferation Resistant Reactors and Fuels Research Program) during FY 2001.

Program Description

The fundamental objective of the RERTR program is to provide the technical means needed to minimize, and eventually eliminate, international traffic in highly enriched uranium (HEU) for civilian purposes, and thereby to reduce the nuclear weapons proliferation potential of such material. To achieve this goal, the RERTR program develops the technical means needed to fabricate and qualify low enriched (less than 20% fissionable U^{235}, remainder non-fissile U^{238}) fuel and other research reactor devices such as targets for producing molybdenum-99, and to develop and test new targets and modified chemical processes to produce molybdenum-99. Currently, these fuels and targets are fabricated and qualified using highly enriched uranium (90 to 93% fissionable U^{235} and less than 10% U^{238}).

The Proliferation Resistant Reactors and Fuels Research Program is a collaborative research and development effort with Russia. The initial objective of the program is to develop proliferation resistant requirements and design modifications to existing Russian systems and develop new concepts for next-generation proliferation resistant reactor systems with improved safety. Following a review and assessment of existing, operating reactors in Russia, research will focus on development of reactor modifications for improvement of proliferation resistance and development of a plan leading to a new nuclear power system design to achieve the proliferation resistance objectives.

R&D Challenges. The major obstacle to converting the most sophisticated high-power research reactors is the lack of fuel with adequate density. In the past, HEU was used in order to provide enough fissile uranium within the density achievable for these fuels and other devices. In order to convert the reactor to LEU fuel, while still providing enough fissile uranium, more non-fissile uranium must be incorporated into the fuel matrix, resulting in a denser fuel. The current effort, which began in March 1996, is focused on developing fuels with a uranium density in the range of 8 to 9 grams of uranium per cubic centimeter of fuel. While progress has been made, the best density achieved thus far has been around 4 to 5 grams of uranium per cubic centimeter.

The eventual success of the Proliferation Resistant Reactors and Fuels Research Program and the pace of successful implementation will be dependent upon the quality of interactions and cooperation with Russian officials. Recent program collaboration discussions have been very encouraging

R&D Activities.

RERTR Program research and development activities are focused on two activities:

- Fuel Development to:
  - Develop fabrication techniques for research and test reactor fuels of very-high-density, but low-enrichment, uranium for use in the more powerful and sophisticated research reactors unable to use current technology LEU fuels.
  - Perform the tests needed to qualify the new LEU fuels.
  - Demonstrate the same performance with the new LEU fuels as achieved with current HEU fuels.

- Target Development to provide alternative targets and chemical processes which will allow the use of LEU to produce fission-product molybdenum-99 for use in medical applications including:
  - Development of target fabrication technology.
  - Development of chemical process technology for recovery and purification of the molybdenum-99.
  - Adaptation or development of technology for disposing of radioactive waste.
  - Obtaining FDA approval to market the drug product produced using LEU instead of HEU.

Proliferation Resistant Reactors and Fuels Research Program research and development activities are focused on two activities:

- Near-term technologies that might be developed and implemented such as
  - increasing the burnup of current fuel systems.
  - additives to the fuel to make reprocessing difficult.

- Longer-term technologies that require substantial research and development activity.

Many ideas have been proposed, both in the United States and Russia, to improve the proliferation resistance of existing nuclear systems as well as those being constructed or designed now. Many of these ideas will require substantial research and development to realize and it is likely that this research and development will take several years.

A number of alternative light water reactor fuel and fuel cycles, as well as enhancements to existing fuel cycles, have been proposed which can increase the proliferation resistance of both current and new (yet not constructed) reactors. Those destined for new systems may have a higher potential for success because those plants have not been constructed and hence costly modifications, and/or component replacement is not required. Some ideas suggested include:

- New Fuel and Fuel Cycle - High burnup, long cycle length cores (36 month or more cycle time), possible use of Th/U, or other fuel technologies. Advantage: increase the time between refueling, less fuel handling, very difficult to remove fissile material because of high gamma radiation levels.

- Advanced Proliferation-Resistant Fuel - elimination of fertile material in fuel, e.g. elimination/replacement of U^{238} with an equivalent Doppler absorber, hence no generation of Pu^{239}.

Meeting the new and increasingly difficult challenges facing nuclear power will likely require development of nuclear power systems radically different than those now in use or even those considered in the past. Given this opportunity to rethink the design requirements, including the fuel and fuel cycle, opens the door to the next generation of reactors that are being referred to as “Generation IV” nuclear power systems. The motivation of Generation IV is to provide the technologies necessary to achieve the goals of competitive economics, improved safety, improved environmental benefits and enhanced proliferation resistance. Generation IV systems and technologies will also be based on meeting the particular needs of potential clients, including, for example, reducing the need for a complex “in country” nuclear technology infrastructure of systems designed for the developing world. Generation IV technology is defined as revolutionary, and not necessarily limited to extrapolation of today’s technologies.

Next-generation fuel cycle technologies must consider, as an integral part of their designs, the complete fuel cycle including the waste stream and proliferation risks. At least one concept has been proposed that avoids the generation of additional fissile material, most notably Pu^{239}. This technology is referred to as “non-fertile fuel” (NFF). Limited research for civilian application has taken place, however, the interest in this area has expanded recently as part of the DOE Fissile Materials Disposition activity related to the Russian plutonium disposition program.

There are various options for reducing the vulnerabilities at the back-end of the fuel cycle. Some, such as reprocessing schemes that avoid complete separation of plutonium, could reduce the proliferation risks associated with closed fuel cycles sufficiently to resolve many of the policy objections to the closed fuel cycle. Others have been proposed to burn the actinides (again mostly Pu) found in spent fuel using either reactors or accelerator-driven sub-critical assemblies. These approaches could reduce the long-term proliferation risks associated with both spent fuel storage and geologic disposition of spent fuel.

Accomplishments

- Approximately two-thirds of the work required to eliminate use of HEU in U.S.-supplied research reactors has been accomplished. The program's development of a low enriched fuel makes it possible for all but six western reactors (with power greater than one megawatt) to convert. Of the U.S.-supplied reactors with power greater than one megawatt that are able to convert, most have planned to do so.

- The RERTR program has supported reactor conversion efforts in two dozen countries and supports the Foreign Research Reactor Spent Fuel Acceptance Policy, involving over forty countries.

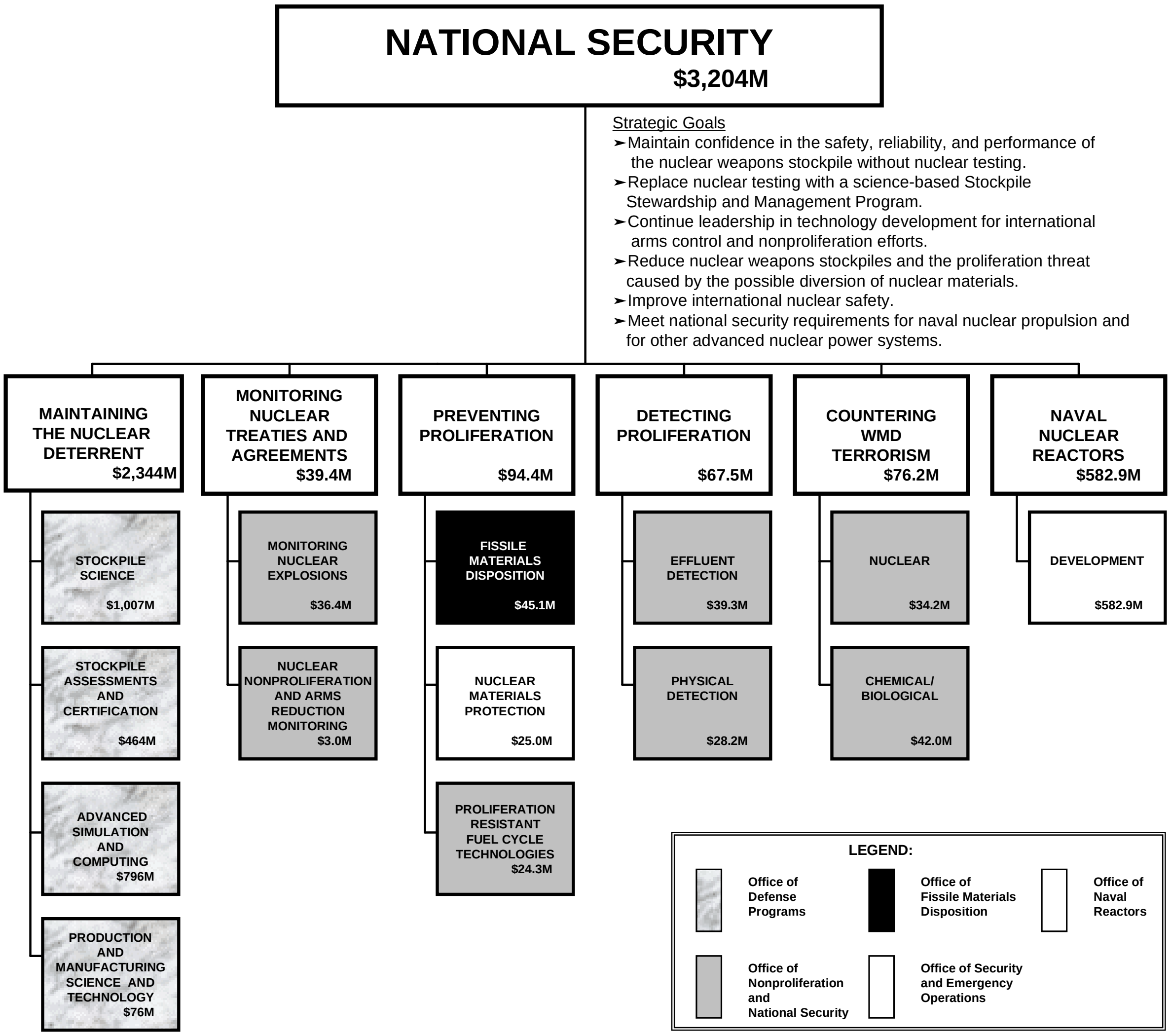
- Recent irraditation tests of a low enriched uranium-molybdenum alloy fuel sample have shown excellent results, exceeding the potential of uranium-silicide alloy fuel.

- A prototype LEU target for medical isotope production has been developed and is being tested in Indonesia. The RERTR program is conducting joint development work on LEU targets for medical isotope production with Indonesia, Argentina, Canada, and South Korea and is beginning joint work with Australia.

Summary Budget Table (000$)

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Fissile Material Disposition	**43,800**	**45,600**	**45,100**
Pit Disassembly and Conversion	17,900	17,400	15,400
Immobilization	16,500	21,800	21,600
Reactor Option	9,400	6,400	8,100
Nuclear Materials Protection	**21,300**	**25,200**	**25,000**
Materials Control and Accountability	6,800	7,900	8,800
Physical Protection	10,300	11,400	13,800
Information Security	4,200	5,900	2,400
Proliferation Resistant Fuel Cycle Technologies	**3,800**	**4,300**	**24,300**
Total	**68,900**	**75,100**	**94,400**

Chapter 6
Detecting Proliferation

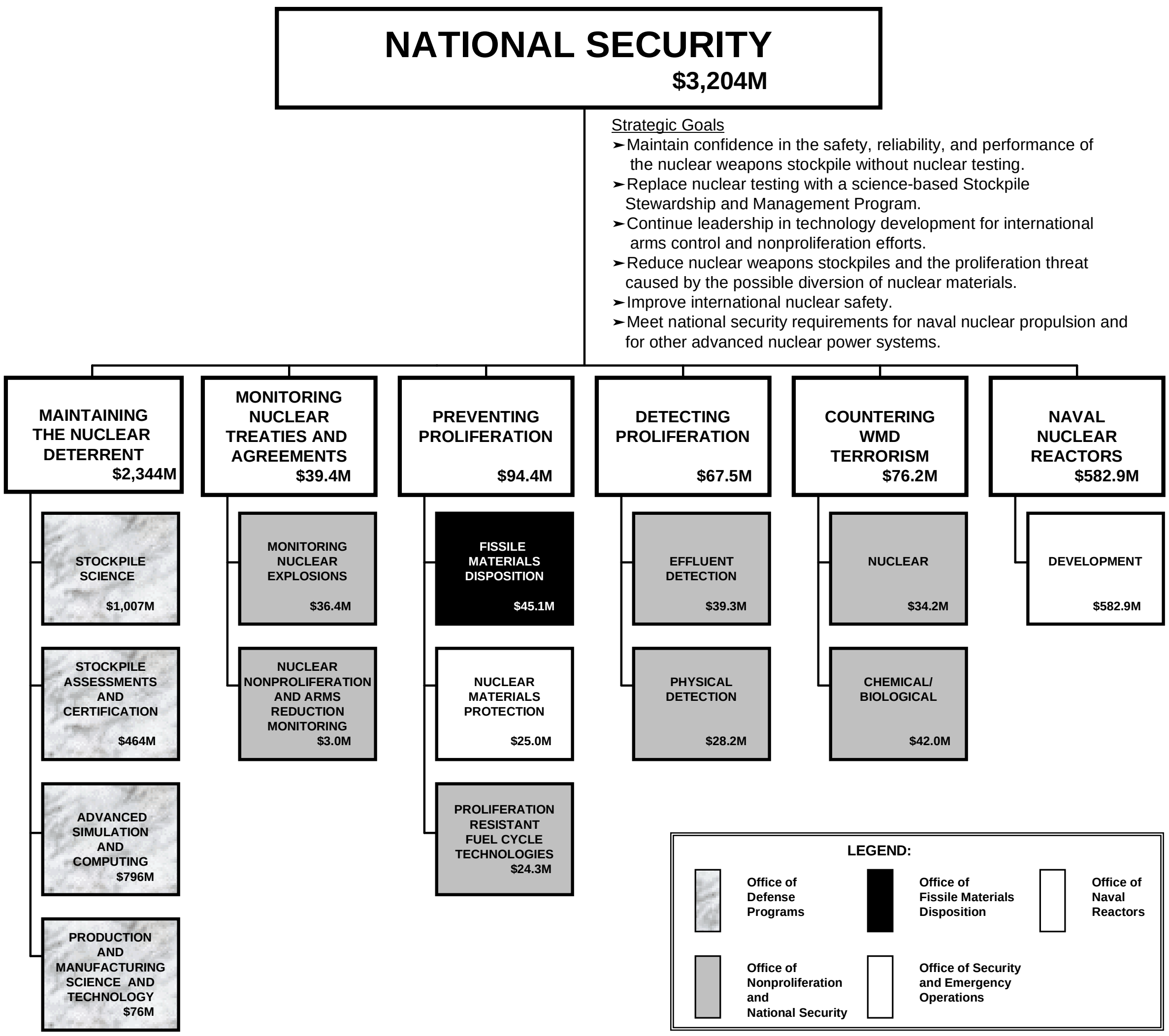


Chapter 6.

This chapter will be issued as a separate supplement.

Chapter 7

Countering Weapons of Mass Destruction Terrorism



Chapter 7

Countering Weapons of Mass Destruction Terrorism

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Overview

Definition of Focus Area

The research and development focus area on countering weapons of mass destruction terrorism is concerned with all forms of weapons of mass destruction. The scientific basis for the research spans a very broad spectrum including nuclear science, physics, engineering, chemistry, and biology. The Department of Energy has a comprehensive program to provide the means to provide protection to the national nuclear complex, special nuclear material, classified information, and other critical assets of the Department of Energy. The two primary research and development activities include nuclear materials control and responding to chemical/biological proliferation.

The Nuclear Challenge

The Department of Energy is the lead government agency for nuclear materials issues. Insuring the security of nuclear weapons and materials in Russia and the other states of the Former Soviet Union is crucial; and, thus, aggressive continuation of the Nunn-Lugar nuclear safeguard initiatives begun several years ago is a top priority. The U.S. must develop the capability to dispose of surplus weapons plutonium as soon as possible in order to enter into a bilateral agreement with Russia to enable the disposition of surplus Russian plutonium (as described in the chapter on Preventing Proliferation).

A 1997 task force of the Defense Science Board found that with a continued, comprehensive long-term program capabilities could be developed to deal effectively with nuclear terrorism over a wide range of possible scenarios. Throughout the process of building and transporting a nuclear device, there are signatures which can be exploited by improved intelligence, improved law enforcement operations, and enhanced detection capabilities. An improved posture to defend against the nuclear transnational threat includes many elements: information and intelligence, security, detection, disablement, mitigation, and attribution. A comprehensive program, developed within the overall architecture for responding to transnational threats, should integrate each of these elements

The Chemical and Biological Challenge

Chemical and biological agents share characteristics that make them especially grave threats. They are relatively easy to obtain, can be developed and produced with modest facilities and equipment, can be lethal even in small quantities, and can be delivered by a variety of means. But there are also substantial differences, which must be taken into account when devising strategies and postures to deal with the threats. For example, the effects of many chemical agents occur rapidly and present unique challenges for emergency response personnel. The effects of biological agents, conversely, may not be seen for many hours or even days; the first indication of an attack may be victims arriving at hospitals. These differences between the numerous agents that might be used require that the response architectures be carefully developed, and recognize these distinctions.

There is no "silver bullet" in the fight against chemical and biological terrorism; the complexity of this problem requires the development of an architecture that broadly addresses the threat - from deterrence, to detection and response, to recovery and attribution. In each of these areas a robust capability is required that integrates operations and training with key technological components. The technological challenges in this area are legion - in many cases our ability to prepare and respond to the potential use of chemical or biological agents is constrained by the present state of technology.

National Context and Drivers

With the end of the Cold War, we are facing increased threats to the United States and its interests by organizations and individuals with motives and methods quite different from those posed to the nation during the era of confrontation with the former Soviet Union (FSU). Among these threats is international terrorism, often by groups without a traceable national identity.

There is a new and ominous trend to these threats: a proclivity towards much greater levels of violence. Transnational groups have the means, through access to weapons of mass destruction and other instruments of terror and disruption, as well as the motives to cause great harm to our society. For example, the perpetrators of the World Trade Center bombing and the Tokyo Subway nerve gas attack were aiming for tens of thousands of fatalities. These examples also indicate the intent of groups to radically alter a nation's political strategy and resolve.

A component of what makes these threats different is that they are difficult to deter, detect, and control. The difficulty of attribution that arises with transnational threats allows attacks against the United States and its allies that nation states would not risk directly for fear of retaliation. As such, national boundaries are not effective barriers and are used to the adversary's advantage. This situation results in the denial of an entire arsenal of traditional and well-developed political, diplomatic, and military strategies for addressing threats to our nation.

While deterring terrorism is not new to the Department of Energy, which has sustained a modest Nuclear Emergency Search Team (NEST) program within its Stockpile Stewardship and Management Program, the breadth of the weapons of mass destruction (WMD) terrorism problem and its overlap with nonproliferation programs is much greater than before the dissolution of the Soviet Union.

An effective response to these threats requires the interaction of the federal, state, and local law enforcement and emergency response agencies, the broader national security community, and the international community – agencies and parts of society that have had little history of integrated planning, strategy, or action. The collective efforts of these organizations will play an important role in increasing the nation's security against transnational threats. There are many customers for our technology.

Linkage to Goals and Objectives

The research and development performed for countering weapons of mass destruction terrorism is being performed in response to the National Security Strategic Goal, Objective 5, Strategies 2 and 3, of the U.S. Department of Energy Strategic Plan. Objective 5 is to continue leadership in policy support and technology development for international arms control and nonproliferation efforts. Strategy 2 addresses inspection systems capable of identifying radiation signatures of potential nuclear smuggling packages. Strategy 3 specifically addresses developing improved sensor systems for early detection, identification, and response to weapons of mass destruction proliferation and illicit materials trafficking.

The DOE has formulated a program of research and development that support U.S. Government requirements to respond to weapons of mass destruction terrorism and proliferation threats. The activity is responsive to the relevant Presidential Decision Directives that outline what the U.S. response must be.

Uncertainties

In the post Cold War era, there is a great deal of uncertainty due to the fact that significant amounts of surplus special nuclear material are under foreign control. In particular, the control of nuclear material in the former Soviet Union is problematical, considering their very poor economic conditions. One particular problem for reducing uncertainty is insuring the disposal of surplus weapons grade material under foreign control without direct access that would expose sensitive weapons design information. Sensors are needed which will ensure that the material is in fact surplus weapons material. Another source of uncertainty is that foreign commercial nuclear industries over which we have no control also generate nuclear material that can have weapons applications. Such material can be used not only by the nations operating the facilities, but could potentially find its way to transnational organizations. Packaging and a small amount of shielding can make detection of such materials difficult even in the controlled environment of border entry points. Nuclear material detection in larger areas, such as within a city, is even more difficult. Trained law enforcement officials, foreign and domestic, must be made willing and able to use the sensor systems. Sensor systems with sufficient detection capability, simplicity of design, and reasonable cost must be developed. Even if illicit nuclear material is intercepted, we may not know who was responsible. This intercepted material must be analyzed for any clues to the source of the material so that countermeasures can be taken.

Developing technologies to respond to the proliferation and potential use of chemical and biological weapons presents many challenges and uncertainties. The range of chemical and biological agents available for the purpose of domestic terrorism is much broader than those previously studied in detail. Also, technologies and systems must be developed for users with minimal training, and with potentially unrealistic and shifting perceptions of the threat and our ability to respond.

With respect to organization and coordination, preparing a response to the domestic use of WMD presents unique challenges in that the organizations with operational responsibility, and those with scientific and technical capacity, reside in different sets of organizations. This will continue to require sustained coordination.

Investment Trends and Rationale

Approaches to reducing the threat from nuclear smuggling include both effective control of nuclear material at its source and detection of nuclear material in transit.

Foreign proliferation signatures can be similar to commercial activities or masked by large-scale commercial chemical production. Power production reactors can produce plutonium (Pu) and the Pu can be separated from the spent fuel. This makes it possible for third world countries with nuclear power reactors to produce weapons useable material.

The procedures used to obtain samples influences the outcome for any forensic analysis. Depending on the physical form of the signature, i.e., solid, liquid or gas, and the operational situation, different sampling protocols must be applied. Typically, forensic applications require the most rigorous protocols. In the case of most effluent species, careful consideration must also be given to approaches that will enhance sensitivity. The problem is further constrained by operational considerations that demand that sampling be quick, easy, simple, and efficient. Finding the optimum combination of sampling methods and conditions is a challenging problem to solve.

To protect large areas modular search systems, adaptable for either vehicle or fixed applications and incorporating next generation data processing and networking, as well as advanced detectors, must be developed. Present technology could, at best, provide a low probability of intercept. There is a need to develop a movable, rapidly deployable array of several hundred (perhaps even a thousand) networked sensor modules for nuclear search and screening over large areas and determining whether a network of multiple detectors is substantially better than the sum of its parts. Particularly of interest to technology development is an understanding of the scenarios against which detection equipment might be arrayed and their respective priorities.

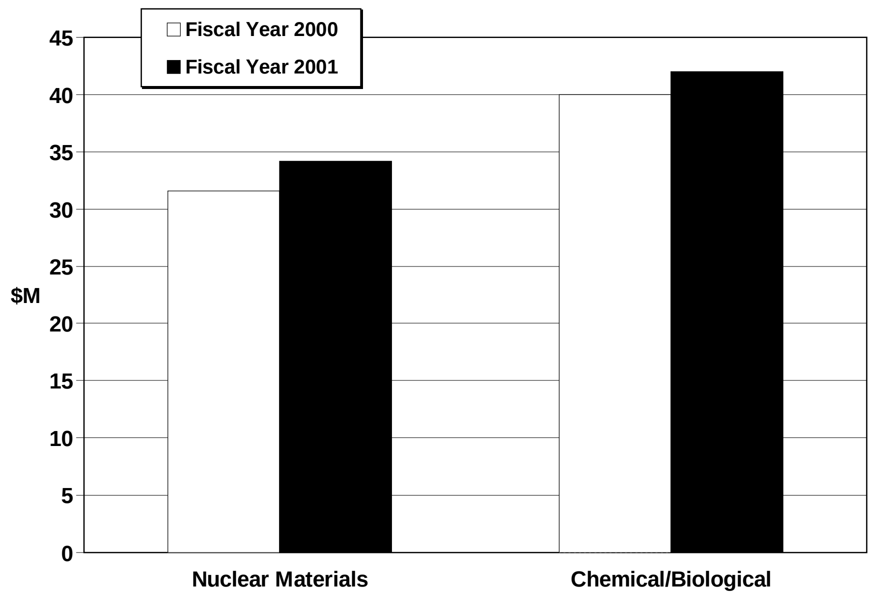
A multi-faceted approach is being used because there are numerous aspects to reducing the nuclear threat. Our activity ranges from basic research to develop new high-resolution, room-temperature radiation detection materials to the development of small, smart systems that can be integrated to monitor a storage facility or provide a broad area intercept capability.

Existing radiation detectors use low-resolution materials or use materials that require cooling to liquid nitrogen temperatures. Some detectors provide the user the capability to detect radioactive material, but it is difficult to resolve the isotopic lines in order to identify the material, while others require excessive power or storage of liquid nitrogen to cool the detector. Any of these options make it difficult for the user in the field. For this reason, research goals include development of processes to routinely grow inexpensive, uniform material for use in next generation radiation detectors.

Investments in the areas of chemical and biological defense/nonproliferation/counterterrorism are increasing across the Government due to increasing concern over biological terrorism in particular. This is also true within the DOE where our budget is significantly higher for Fiscal Year 2000. It is important to note that our investment in this technology area is heavily leveraged against existing biological/chemical expertise resident at the DOE national laboratories.

The chart shown below shows investments by activity areas that will be discussed in the remainder of this chapter.

Countering Weapons of Mass Destruction and Terrorism



Federal Role

National Security is a constitutional role of the Federal Government. DOE executes research and development activities associated with the detection of proliferation activities through the expertise and facilities provided at the national laboratories. A single laboratory may manage a program activity area. Alternatively, multiple laboratories may be involved in a program activity area. Inter-laboratory programs are managed from DOE headquarters. In turn, individual laboratories contract with other institutions, such as universities and industry. DOE establishes goals, provides guidance and direction in each program area, and in consultation with the laboratories, prioritizes the work and activities in each program area.

In the chemical and biological areas, at least at the present time, the Federal Government will play the primary role in developing terrorism response technologies. This is particularly true in the development of new technologies and systems for use in domestic preparation and response. As President Clinton recently stated: “there is no market” in the chemical and biological weapons area. This will likely evolve if the threat continues to increase, and after more equipment is available.

Key Accomplishments

The countering weapons of mass destruction terrorism research and development activity has made significant progress toward meeting its goals and objectives. Broad accomplishments include:

- A DOE-developed handheld gamma ray and neutron material identification system was recently used by the United Nations Special Commission (UNSCOM) for Palace inspections in Iraq.

- A notebook-size time-of-flight mass spectrometer for detecting chemical compounds such as explosive residues was developed.

- Key miniaturized components were developed that will enable a hand-held chemical and biological toxin detector.

- The DNA sequencing of the virulence plasmids of the threat pathogens *B. anthracis* (anthrax) and *Y. pestis* (plague) were completed. These data provide new insight into the genes that are responsible for the action of these pathogens and are key components to identifying engineered organisms.

Nuclear Materials

Budget: FY99-$38.4M, FY00-$31.6M, FY01-$34.2M

Background

The long-range research and development strategy presented here addresses domestic and international safeguards and enabling technologies as well as nuclear smuggling and terrorism. The technologies are used close to the source (as opposed to remotely) and concentrate on nuclear material. Support includes technology for WMD detection, e.g., material analysis, environmental monitoring under new International Atomic Energy Agency (IAEA) protocols, or computer systems which might automate and link a network of detectors.

Program Description

The vision of the nuclear materials research activity is the development of enabling technology to inhibit nuclear materials diversion in nonproliferation and counterterrorism applications. The long-term R&D program is within the context of the overall DOE program for stewardship of nuclear weapons and materials. It is part of a comprehensive, end-to-end architecture for reducing the nuclear threat. It integrates capabilities to:

- Warn of nuclear materials transit.

- Analyze materials, including support to law enforcement agencies.

- Detect and attribute the presence of nuclear materials.

The technology in the areas above is closely linked with the Department's activities to:

- Diagnose, access, disarm and render safe threat devices.
- Respond to the consequences of a nuclear terrorist incident.

Warning of Nuclear Materials Transit

Budget: FY99-$20.9 M, FY00-$17.0M, FY01-$18.4M

Description and Objectives. This activity is part of an integrated strategy for provision of technology to the intelligence community and international partners such as law enforcement. The aim is to detect illicit nuclear materials at points along an integrated pathway from the source, including source protection, to their application by an adversary. In this section we highlight our efforts for two applications:

- Transparent warhead and materials reductions.
- Detection of illicit nuclear materials traffic.

R&D Challenges. Research and development challenges for transparent warhead and materials reductions include:

- **Remote Means to "Measure" Bulk Amounts of Pu and HEU—**The technical challenges are to acquire data in choke points or perhaps even from outside facility boundaries using unattended sensors.
- **No "Net Production"—**The technical challenges are to gain confidence in Russian declarations of process flow, to distinguish between warheads and components in their dismantlement program and those associated with stockpile refurbishment, and to assure that operations within the stockpile refurbishment program do not mask a reconstitution effort.

As the U.S. and Russia proceed to lower warhead levels, we must be sure that previously dismantled nuclear weapons and weapons components, nonstrategic weapons, and fissile materials stockpiles cannot serve as the basis for rapid reconstitution of strategic nuclear forces. Russia has not reciprocated to previous DOE declarations of material inventories and locations. This is urgent given the substantial asymmetry in knowledge of each side's stockpile and because it will take time for reciprocal verification arrangements to build confidence in these declarations.

The technical challenges of verification and collection to support arms control agreements apply not only to Russia but to other nuclear states as well. Of course, the opportunities to access such information will vary from case to case. The accessibility and openness of travel within the U.S. makes locating transiting special nuclear materials particularly difficult because of the large number of locations that must be under surveillance, the large numbers of people and product crossing our borders, and the short detection range of existing nuclear detectors.

R&D Activities. The 1997 Defense Science Board Summer Study made several recommendations for improving the capability of U.S. and allied intelligence and law enforcement to detect transnational threat operations of all kinds, including nuclear. These include:

- Accelerated development of knowledge engineering tools, including a worldwide internet-like information system with contributions from and (managed) access for law enforcement and intelligence, world-wide.
- Particular focus on detecting nuclear threats because signatures of nuclear threat operations are likely to be larger and/or more exploitable than for other types of threats.

Accomplishments

- A system of distributed networks of sensors to expand capabilities for detection of radioactive materials in transit was conceived and demonstrated. Potential end users are validating the technology.
- A solid state fiber optic neutron and gamma ray detector technology won an R&D 100 award and was successfully transferred to the commercial sector resulting in a Federal Laboratory Consortium Award. The detector technology is currently being deployed on the Austrian-Hungarian border as part of the Illicit Trafficking Radiation Assessment Program.
- A neutron detector designed for detecting neutron sources at distances of 50 to 100 meters has been developed and tested. The long-range detector provides a new enabling technology to detect remote neutron sources including sources in moving vehicles.
- A human presence detection system was developed and commercialized to ensure that unauthorized persons cannot enter or exit a facility by hiding in a vehicle.
- A DOE-developed handheld gamma ray and neutron material identification system was recently used by the United Nations Special Commission (UNSCOM) for Palace inspections in Iraq.

Materials Analysis

Budget: FY99-$10.7M, FY00-$9.0M, FY01-$9.7M

Description and Objectives. International sanctions and law enforcement require solid evidence. The materials analysis activity element seeks to advance the state-of-the-art in the detection and analysis of activities that threaten the National Security and the public safety by identification and quantitative measurement of chemical and physical signatures. Historically, the focus has been on nuclear proliferation by nation states. Although this remains a valid concern and the mainstay of the activity, the scope of our activity has recently been broadened to include the potential for deployment of WMD by sub-national (terrorist) groups and assistance to law enforcement agencies under the Statement of Principles signed by the Secretaries of Energy and Treasury and the Attorney General. By definition, analyses that provide information suitable for a policy decision or a court of law are "forensic" in nature. Many of the technologies developed under the materials analysis activity are targeted toward forensic applications or ultimately will be applied in that manner.

The research and development approach to deterring proliferant or terrorist activities has two principal components: the identification of potential signatures and the application of useful analysis techniques. These requirements are addressed through improved understanding of WMD production processes, by the development of enabling analytical technologies, and by coupling state-of-the-art techniques in sample collection, analysis, and data reduction.

Over the last 50 years, signature analysis has evolved from simply using available analysis capabilities and relatively random samples to the development of application specific technologies and well-coordinated sampling efforts. The nuclear materials analysis activity exploits not only the world class intellectual and physical assets of the DOE Laboratories, but also their unique understanding of nuclear and chemical materials, as well as their broad experience with proliferation and terrorism issues. R&D needs in four areas are addressed:

- Selection of useful signatures.
- Development of improved sampling methods.
- Development of new analytical instruments and improved procedures.
- Evaluation of analysis technologies.

R&D Challenges. Research and development challenges related to development of alternative signatures are due to a number of changing operational and analytical considerations. There is a continuing need to evaluate the efficacy of new or different signatures. The drive for alternate signatures and for improved sampling are being driven by:

- Countermeasures by proliferants or terrorists to suppress the signatures generally known through international (e.g., IAEA, UNSCOM) fora.
- The need to acquire samples from more remote locations.

Research and development challenges related to improved sampling methods are constrained by operational considerations that demand sampling be quick, easy, simple, and efficient. Aside from quantitative analysis, sampling must often address collateral informational needs such as the dating of materials and processes or establishing the chronology of certain proliferation activities. Such concerns can have a significant influence on what is collected along with the species of interest, as well as how it is collected (e.g., instantaneous versus long term). Actually finding the optimum combination of sampling methods and conditions is not trivial nor is it often intuitively obvious.

Research and development challenges for advanced analytical technologies stem from the principle requirements for new technology: miniaturization and field application. Examples of specific needs are:

- Developing forensic methodology for nuclear contaminated materials.
- Identifying trace metals and the origin of seized nuclear materials.
- Developing an architecture for a grid of samplers within a geographic region to obtain environmental samples.
- Achieving high sensor sensitivity in cluttered backgrounds with low false alarm rates.
- Developing portable, high sensitivity devices that will allow inspectors to screen environmental samples and select only the most promising ones for return to the laboratory -- resulting in more rapid and less expensive laboratory analyses.

Research and development challenges for performance evaluation is related to what is perhaps the most important facet of technology developments, testing the product of these R&D efforts against realistic sources or samples. This serves three purposes. First, it provides valuable feedback to the development cycle that can be used to refine the technology. Second, it gives potential users an opportunity to assess the technology. Third, it generates “real” data that can be used to improve interpretation of results and to enhance attribution techniques.

R&D Activities. The “life-cycle” of a nuclear or chemical weapon starts with the procurement of the raw materials, proceeds to the production of special nuclear material (SNM) or chemical agents to weaponization and implementation of a device. There are many possible chemical signatures of both nuclear and chemical weapons, but the tendency has been to concentrate analysis efforts on a small subset. Even analytic applications tend to avoid trying to measure every possible chemical species; opting instead to strike a balance between the analysis effort required and the amount of information obtained.

With any chemical analysis, the way in which samples are obtained directly influences the outcome. Depending on the physical form of the signature (i.e., solid, liquid, or gas) and the operational situation, different sampling protocols must be applied. Typically, analytic applications require the most rigorous protocols. In the case of most effluent species, careful consideration must also be given to approaches that will enhance sensitivity. Fortunately, selectivity and sensitivity tend to be compatible goals when developing sampling methods.

A variety of modern analytical instruments, including mass spectrometers as well as a host of other devices and systems, provide the means to meet many (but not all) requirements for sensitivity and selectivity, from small, hand-held devices to large, laboratory instruments. Today, the many unique applications found within the nuclear materials analysis activity continue to drive the need for R&D in this area with particular emphasis on miniaturization and a subsequent shift toward handheld or portable systems. This is particularly true of some forensic applications that are starting to move from their traditional laboratory environments to the field in order to provide more real-time information. There is also a need for improved methods for detecting stable elements and compounds.

The IAEA's Strengthened Safeguards System is generating a new set of requirements for "environmental" monitoring to detect the clandestine production of weapons grade material either by reprocessing or enrichment. Field trials have begun within declared nuclear facilities with nearly 1,500 samples obtained as "swipes" and a wide network of trusted laboratories to analyze the samples in order to obtain baselines. The cost per sample was said to be $5K to $10K. Ultimately it will be the application to wide area sampling which provides assurance against clandestine activities.

Accomplishments

- The Lab-on-a-Chip, a miniaturized system for performing wet chemistry operations has demonstrated separation of compounds faster than full-size laboratory instruments. This technology has been licensed to industry and has been declared by R&D Magazine to be one of the 40 most significant technological achievements since the magazine began their R&D 100 Awards program in 1963.

- Over 50,000 environmental samples, collected around the world over the last 40+ years, were catalogued and made available for study via a searchable database and website (http://www.eml.doe.gov).

- Micromachining technology has enabled the development of a battery-operated, handheld gas chromatograph, sensitive to parts-per-billion (ppb) and parts-per-million (ppm) levels of organic compounds, thus bringing laboratory sensitivity to the field.

- A rapid (approximately 15 minutes) method called Matrix-Assisted Laser Desorption Ionization Mass Spectrometry (MALDI-MS), developed for screening unknown biological pathogens, was successfully tested in a blind laboratory study and is now in the process of being transferred to the FBI's Hazardous Materials Response Unit.

- A new thermal model for characterizing nuclear reprocessing facilities has been developed and successfully tested.

- Stable rare gasses have been used to model nuclear fuel types, burnup, and other attributes.

- Specialty absorbent materials have been designed and produced for specific chemical compounds indicative of proliferation.

- A unique magnetic separation method has been developed for removing micron-size particles of SNM from large samples prior to analysis.

- A notebook-size time-of-flight mass spectrometer has been developed for detecting chemical compounds such as explosive residues.

- The first and only flow-through radioactivity detector for the capillary electrophoretic analysis of low level liquid samples has been developed.

- A prototype hand-held gas chromatograph that can analyze gas samples at field locations was developed and successfully transferred to end users.

- A prototype portable Raman Lidar system was fielded in a recent terrorist exercise in New York City, demonstrating the ability to identify an unknown chemical at a distance of 15 meters in a driving rainstorm.

- Samples of opportunity associated with ongoing criminal investigations (e.g., Unibomber) have been analyzed using unique capabilities developed under the nuclear materials analysis activity.

Detect and Attribute Nuclear Materials

Budget: FY99-$6.8, FY00-$5.6M, FY01-$6.1M

Description and Objectives. A system of integrated technologies will be required to prevent the introduction of nuclear materials into the U.S. and to prevent its application against U.S. interests. Our R&D highlights developments in two areas:

- Systems of detectors to cover larger areas.

- Next generation detectors.

R&D Challenges

- Developing modular search systems adaptable for vehicle or fixed application that incorporate next generation data processing and networking capability as well as advanced detectors.

- Developing a movable, rapidly deployable array of several hundred (maybe even a thousand) networked sensor modules for nuclear search and screening over large areas and determining whether a network of multiple detectors is substantially better than the sum of its parts.

- Operational issues of cost and response time/capability. In the long term, a network or modular search systems would be based on advanced detectors and methods developed in the activity described below. Particularly of interest to technology developers is an understanding of the scenarios against which detection equipment might be arrayed and their priority.

- Developing smart detectors to eliminate false and nuisance positives - emphasis on room-temperature operation, reduced size and unit costs, and automated spectral analysis.

- Miniaturizing detectors (e.g., a pager-sized neutron detector), while achieving enough nuclear cross-section in small size.

R&D Activities. Today, assets to detect and localize terrorist nuclear materials or explosives can be effectively deployed only at restricted choke points (e.g., ports of entry) or with warning that closely specifies threat location and time. It would be desirable to have continual coverage of much larger areas (e.g., cities) as might be done with large arrays of detectors or perhaps with fewer mobile detectors that could sweep large areas rapidly. However, high false alarm rates have made large arrays of non-specific detectors impractical. In addition, end-game detection demands close connectivity between operations and technology. Recently, however, progress has been made in ameliorating this problem by using a network logic that correlates “hits” among a large number of detectors, thereby filtering out most false alarms. This, in combination with the potential for improvements in individual detectors of various kinds, for the first time opens the serious possibility of “terminal defense” of larger areas than practical today. Although the Defense Science Board alleged a good chance that such capabilities can be developed, this concept still requires significant R&D and will require substantial investment to demonstrate.

The next generation of detector technologies will enable smaller, smarter, less expensive radiation detectors. These detectors will have the capability to detect and identify nuclear materials either as hand-held or remotely emplaced instruments. This enables not only detection and interdiction of stolen nuclear material (e.g., at U.S. and foreign borders) but also enforcing arms reduction agreements and safeguards applications. A managed mix of both evolutionary and high-risk technologies is appropriate.

Accomplishments

- A fully solid-state, low power, no moving parts cryogenic cooling system was developed, transferred to industry, and is being evaluated for field use by the International Atomic Energy Agency.

- A gamma ray imaging film, based on optically stimulated luminescence materials and portable reader, was developed for arms control applications. The low cost, solid state imaging film has a much higher dynamic range than conventional photographic films, can be read multiple times in the field without the use of chemicals, and erased for re-use.

- A field portable instrument for measuring the isotopic composition of uranium compounds has been developed based on Laser Ablation, Laser Induced Fluorescence (LALIF). The new capability fills a critical gap in our ability to support in-field nonproliferation and monitoring activities that were first identified in Iraq.

- Radiation detectors have been deployed at several U.S. ports of entry for limited amounts of time in order to determine which radioactive materials are seen in normal commerce. Knowledge of this background is necessary for development of systems with low false alarm rates.

- The GN-4 handheld gamma ray and neutron system with the capability to automatically identify nuclear materials has been commercialized as the Quantrad Ranger. It is being evaluated for use by other DOE organizations for transparency applications.

Responding to Chemical and Biological Proliferation

Budget: FY99-$19.0M, FY00-$40.0M, FY01- $42.0M

Background

An important goal of the DOE research and development program is to reduce the U.S. vulnerability to the use of chemical or biological agents through the development of advanced technologies and capabilities. A key element of the program is the formulation of architectures that bring together operational and technological components to develop systems that address key elements of the chemical and biological threats. This effort builds upon ongoing efforts in other agencies, and addresses key areas in which the DOE has expertise.

Program Description

Preparing and ultimately responding to the use of chemical or biological agents is a complex problem to which there is no "silver bullet." While production of large quantities of the traditional chemical and biological agents would require a substantial effort and investment, production of small quantities, or the procurement of toxic species not generally considered to be "traditional" chemical or biological agents is not difficult. Small quantities of agents, or use of non-traditional agents, are likely to constitute the terrorist threat. This threat presents enormous challenges. The quantities of agents are small and the possible spectrum of agents is broad, presenting formidable detection difficulties. The operational issues for responding to chemical or biological events involving civilians are formidable and are distinct from the issues the military faces where training and equipment are readily available. Finally, recovery and cleanup will present new difficulties in urban areas.

Because of these challenges, chemical and biological terrorism is most effectively addressed in an end-to-end, layered approach. Such a layered approach must involve deterring the use of such weapons, preparing key facilities and cities for the possible use of such agents, having systems in place to rapidly detect the use, and should use be detected, being able to effectively respond.

Finally, following an incident we must be able to restore contaminated land, facilities and equipment and to conduct the forensic analyses that would be required for investigation and attribution.

The DOE program has three key components:

- The development of architectures to comprehensively consider how to best prepare and respond. For example, how does one best protect, and ultimately respond, to the use of chemical or biological agents in subway systems? In airports? During sporting events?

- The use of accelerated programs to field the best available systems and technology to meet these needs defined during development of the architecture.

- The development of key technologies that are required for effective preparation and response at various phases of a threat scenario, including pre-incident intelligence, monitoring and warning of agent use, initial response to a release, post-release restoration and attribution.

Understanding the spectrum of preparation and response possibilities in dealing with each phase is critical to developing effective systems. Candidate system concepts in each of these phases are developed in concert with prospective end users of the system (e.g., local “first responders,” law enforcement, intelligence agencies).

DOE has developed a five-year plan in which R&D at the DOE laboratories is guided by system concepts that address both operational and technological factors. These system integration efforts, including both existing and emerging technologies, will result in fielded prototype systems targeting the principal phases of a chemical or biological threat scenario. Over the next 3 to 4 years we anticipate fielding systems in four areas:

- Preparation and response for key infrastructure assets.

- Crisis and consequence management for special events.

- Recovery and restoration for domestic facilities.

- Forensics and attribution.

These system integration efforts form a baseline for follow-on systems in which improved technologies would be incorporated, as they become available. Initial efforts are currently underway in the first two areas, which will be described below.

Identification of Needs

In formulating the DOE program we worked closely with other Federal agencies and with representatives of state and local emergency response organizations to clearly define the shortfalls in existing capabilities, with emphasis on areas where technology could make a difference. This process included representation from the Department of Defense, the Intelligence Community, the Public Health Service, the Federal Emergency Management Agency, the Department of Justice and the Federal Bureau of Investigation, the Department of Transportation, and others. Some of the key technology needs identified through this process are shown below:

- **Detection**—Need for detectors that are suitable for a broad spectrum of agents, and subject to minimal false alarms. Need for improved sample collection techniques. Additional requirements include being inexpensive and portable. Need for new technologies to enable detection of agent production or transport.

- **Prediction—**Need for models that can accurately and rapidly predict the impact of chemical and biological agents in urban areas.

- **Restoration and Recovery—**Need for environmentally sensitive decontamination techniques with minimal logistics tails. Need for non-aqueous techniques. Need for new techniques to rapidly decontaminate personnel.

- **Protection—**Need for improved personal protection equipment that enable personnel to operate for longer periods of time.

- **Therapeutics—**Need for improved vaccines and therapeutics for many biological agents.

- **Forensics**—Need for more detailed understanding of the DNA/RNA structure of many pathogens to enable strain identification and differentiation. Need for new techniques to rapidly screen samples. Need for collection of samples from throughout the world. Need for improved epidemiological systems to identify anomalous outbreaks.

- **Systems Analysis**—Need for detailed analysis of how to optimally prepare and respond across the threat timeline. Need to understand the role of technology in these operations.

This list of needs has proven valuable in structuring an R&D program around a few integrating themes, described in the next section. Each theme consists of a complementary set of projects that address selected needs from the above list. The overriding goal of the program is to provide high-payoff solutions in 3 to 5 years from the start of an initiative. This perspective differentiates the DOE program from other important Federal activities such as the Chemical and Biological Defense Command Domestic Preparedness Program and the Technical Support Working Group (TSWG) Counterterrorism Program. These programs target incremental contributions that can be made rapidly, typically in the 12 to 18 month time frame.

R&D Challenges to Meeting Needs

The program is structured to capitalize on existing DOE technical strengths in developing capabilities that can have a major impact in the preparation and response to chemical and biological incidents.

Addressing the needs shown above presents many R&D challenges. In focusing the DOE program, primary consideration was given to areas in which the DOE has substantial expertise. The relevant expertise stems from DOE's historical investment in R&D that supports its primary nuclear mission; this amounts to over $1 billion/year in the chemical and biological sciences, sensor technologies, and computation at its national laboratories. These programs range from micro-sensor development, to DNA sequencing for the Human Genome Project, to advanced computing used to predict the transport of toxic gases. Together they constitute the technical foundation for the DOE chemical and biological program. In addition, the program builds upon the work supported by other agencies. These efforts, particularly those supported by the DoD, have made major strides in recent years. The DOE national laboratories receive over $50 million/year from other agencies, specifically in the chemical and biological defense area.

Many other Federal programs are also addressing this important problem. To avoid duplication of effort, several areas initially identified as candidate areas for the DOE program were not included. For example, the program is not pursuing R&D in protective equipment, personal decontamination, or therapeutics. The program that ultimately resulted from the capabilities/needs assessment is structured around four focus areas—Biological Foundations, Modeling and Prediction, Chemical and Biological Detection, and Decontamination and Restoration.

These four areas, along with their associated R&D challenges and initiatives created by the DOE program to address the challenges, are described below.

Biological Foundations

Budget: FY99-$5.0M, FY00-$11.2M, FY01-$11.2M

Description and Objectives. The goal of this initiative is to develop the ability to identify, at the strain level, biological pathogens of concern; to determine their geographical origin (where possible); and to track the spread of diseases on a molecular level. A secondary goal is to develop the underlying biological science that will support the detection and treatment of biological agents.

R&D Challenges. Significant challenges exist for the analysis of samples containing biological agents. This area is still in the early stages of development, but is moving forward rapidly with the advent of new DNA analysis techniques. These techniques are able to identify specific strains of biological agents that can suggest the source of the sample. Computational tools are also required to enable the tracking of the spread of a communicable disease (i.e., molecular epidemiological tools); such techniques can allow the reconstruction of an epidemic that might be started with a terrorist event. Finally, a significant effort is required in mapping the worldwide distribution of the strain variation of organisms that might be used as biological agents; knowledge of this distribution will be essential in understanding the possible origin of a biological agent.

R&D Activities. This work builds upon DOE capabilities in DNA sequencing and in the advanced light sources used for structure determinations. Ongoing work in this initiative can be divided into three broad-based efforts: Nucleic Acid-based Signatures, Toxin Structural Signatures, and Molecular Epidemiology and Tracking. Within three years the program will develop the capability to geo-locate samples of the top two threat pathogens and to partially locate an additional six pathogens, and will have an initial capability to recognize engineered organisms.

Accomplishments. Over the last 12 months we have completed the DNA sequencing of the virulence plasmids of the threat pathogens *B. anthracis* (anthrax) and *Y. pestis* (plague). These data provide new insight into the genes that are responsible for the action of these pathogens.

Modeling and Prediction

Budget: FY99-$3.0M, FY00-$5.2M, FY01-$5.2M

Description and Objectives. The ability to predict accurately the dispersion, concentration profiles, and ultimate fate of chemical and biological agents released into the environment is fundamental to safeguarding human life and to the effective operation of emergency response teams. A modeling capability must thus be able to accurately predict the transport and fate of chemical or biological agents in a multitude of scenarios that might occur in an urban environment.

R&D Challenges. Methods of predicting atmospheric dispersion are commonly applied on transport scales of hundreds of meters to several kilometers over simple configurations of terrain and surface obstacles. However, the particular needs of predicting, diagnosing, controlling, and responding to clandestine chemical/biological releases in the urban setting, with complex building configurations, present formidable modeling challenges.

Computational fluid dynamics models of the highly distorted wind and turbulence fields created by complexes of tall buildings, subway tunnels and other urban structures are in the very early stages of development and application. Models of airflow inside buildings and subways have been developed to some degree but do not incorporate deposition losses to interior surfaces, a large effect due to the high surface to volume ratios. A comprehensive knowledge base of surface phenomena and agent/analyte deposition and fate, including chemistry and bio-agent viability, must necessarily be incorporated into these capabilities. In addition, there is a need to couple the predictive model results at different scales (e.g., around building transport to interior building transport) and different levels of model complexity (e.g., three-dimensional subway station flow to parameterize subway system transport involving tunnels and other stations). And finally, the acute nature of clandestine events places severe requirements on the timeliness and accuracy of transport and fate model predictions of exposure at all spatial scales.

R&D Activities. This effort builds upon substantial investments by DOE at its national laboratories in high-performance computing. The modeling effort is aimed at developing a robust, operational modeling capability suitable for use in urban areas. Work in this area includes model development for building interiors, subways, outside in urban areas, and the linking of these models. Crosscutting issues, including understanding the deposition of chemical and biological agents and their fate under typical conditions, are also being investigated. Together, advancements in these areas will enable accurate predictions of the extent and impact of a chemical or biological incident. Within two years we expect to be able to use these models to provide guidance for incidents in subways and buildings, and within five years expect to have the outdoor urban models incorporated into an operational, validated system (e.g., National Atmospheric Release Advisory Capability--NARAC).

Accomplishments. We have performed numerous computer simulations of chemical and biological releases in urban areas, both indoors and outdoors. We have provided some of the first data on the exterior effect of *indoor* chemical and biological releases. Authorities responsible for emergency planning for subway systems are currently using these data.

Chemical and Biological Detection

Budget: FY99-$7.5M, FY00-$12.3M, FY01-$12.3M

Description and Objectives. The goal of this initiative is to develop a suite of detection systems that will significantly improve the domestic chemical and biological detection capability. Implicit in this goal is a recognition that there is no “silver bullet” and that detection systems must be suitable for use with the many chemicals and biological species that might be used as agents.

R&D Challenges. The challenges in this area are legion, and are as difficult, or more so, to address as those encountered when developing detectors for use on the battlefield. The counterterrorism mission must deal with a broader set of agents—unlike the battlefield mission, the set of potential agents is not limited by factors such as weaponization, large scale production, stockpiling, or delivery systems. The terrorist is free to choose from well over 100 potential agents. Because one cannot predict in advance which agent(s) might be used, any effective detection system must identify a wide range of agents, and be able to easily add new agent detection capabilities based on intelligence sources. In addition to having high sensitivity, detectors to be used domestically have very demanding false positive requirements. Law enforcement personnel are unwilling to accept false positives that might lead to the evacuation of subway stations or large office buildings, for example. Simple calculations demonstrate that in order to monitor for chemicals continually for a year over 100 million individual measurements will be made. Over this time period, even one or two false alarms may not be acceptable. Finally, in many cases there is minimal supporting infrastructure domestically. This places significant constraints on the cost, ease of use, and maintainability of detection systems.

R&D Activities. This work builds upon DOE advances in laser technology, capabilities in micro-fabrication, and work in the development of DNA-based diagnostics. Key efforts include the development of: an autonomous biological agent detector, a DNA fragment-sizing system, a hand-held chemical agent detector, and an improved mass spectrometer. These efforts are directed at the development of a suite of portable, modular instruments that cover a significant portion of the "threat space" when operated singly but provide greater coverage and lower false alarm rates when operated in combination. Each instrument detects different but somewhat overlapping portions of the chemical-biotoxin-pathogen threat space and detects a different physical property, thereby providing independent confirmation when two or more techniques identify an agent. The different techniques also differ in their level of technical maturity, risks and benefits and comprise a well-balanced detection portfolio.

Accomplishments. Advances have occurred in several areas of our detection initiative. Key components have been fabricated for our "chemical laboratory on a chip" project. New detection limits were demonstrated in a field trial involving a miniature polymerase chain reaction (PCR) amplification-based detector. Advances have been made in our ability to rapidly differentiate strains of biological agents. Finally, calibration of a wind-tunnel facility is complete and detector testing is now possible in a realistic, controlled environment.

Decontamination and Restoration

Budget: FY99-$2.0M, FY00-$2.3M, FY01-$2.3M

Description and Objectives. The objective of environmental decontamination is rapid, effective and safe (non-toxic and non-corrosive) treatment of a range of chemically or biologically contaminated surfaces. This treatment should result in the complete restoration of contaminated areas (e.g., facilities and large urban areas) and equipment to normal operation. In addition, it is desirable to have a single formulation for use on the entire range of chemical and biological hazards. Such a formulation and/or reagent should be deployable in various delivery systems (e.g., liquids, sprays, foams, gels, gases). Ideally, these systems will be readily transportable and operationally simple to use. Additionally, systems will need to be developed and implemented which allow for field and/or laboratory verification of acceptable clean-up criteria. The establishment of realistic clean-up criteria will drive the decontamination technology to be chosen for a specific field application.

R&D Challenges. There are numerous R&D challenges in the safe and effective decontamination of urban facilities. A key issue is to develop a formulation that will destroy (or detoxify) hazardous chemicals or pathogens, but will be harmless to both people and property and/or degrade to harmlessness in a reasonable period of time. Additional constraints are imposed by the desire to have a common formulation that would be suitable for all chemical and biological agents, as well as being effective for a variety of construction materials. There are major logistical and operational issues to which any new technology must be sensitive. For example, different applications (e.g., outdoors, semi-enclosed, indoors, sensitive equipment) will require different dispersal mechanisms and/or methods, including liquid-based, gas-based, gel-based, and foam-based systems. Any proposed reagent must be deployable in a variety of such systems, with easy-to-use delivery systems. Even new technologies, such as plasma-based and/or other energy driven systems, will require simple operating procedures in real applications.

Finally, it will be important to develop appropriate sampling and analysis methods that can be used to show the adequacy of decontamination as it proceeds. These techniques must be able to determine the extent of contamination on a multitude of materials in reproducible ways.

R&D Activities. Existing efforts in the program focus on methods that are minimally corrosive and yet effective for decontamination. The present effort includes the development of improved reagents, the development of improved delivery systems (e.g., gels and foams), the development of new decontamination techniques such as plasmas, and a program to address the environmental issues that will require attention. Over the next three years systems will be fielded that will be suitable for decontaminating sensitive, exposed surfaces.

Accomplishments. We have developed a number of new decontamination technologies, including a revolutionary decontamination plasma jet that is suitable for sensitive materials and is environmentally benign. Additionally, major advances have been made in the incorporation of new reagents into foams and gels.

Systems Analysis and Technology Integration

Budget: FY99-$1.5M, FY00-$9.0M, FY01-$11.0M

Description and Objectives. Much has been written about the vulnerability of the U.S. to a chemical or biological attack and the potential consequences. Currently lacking, however, is a coherent analytical structure for characterizing the threat (over ranges of magnitude, distribution, and agent), developing preparedness and response options, assessing the performance of various capabilities against various threats, and finally deciding on investment priorities. Systems analysis is the program element that takes on these tasks.

R&D Challenges. As mentioned above, a key component of the DOE program is the development of system architectures for specific preparation and response applications. An architecture defines the roles of infrastructure, operations and technology in responding to the threat. It also serves as a structure for determining how multiple technologies should be integrated into an overall system. In making this assessment, system performance objectives are clearly defined and tradeoffs among system elements are explored to arrive at an optimal balance. The systems perspective encompasses the entire *threat-response timeline*, from threat monitoring prior to an incident to cleanup and attribution that could occur much later. The various phases of the timeline and examples of response elements in each phase are shown below:

- Intelligence and Prevention
  –Background monitoring of key threats
  –Denial
  –Deterrence/interdiction

- Crisis Management
  –Incident detection
  –Source localization
  –Impact assessment
  –Device disablement

- Consequence Management
  –Damage/contamination assessment

–Evacuation and protection
–Medical treatment
–Decontamination and restoration

- Forensics and Attribution
  –Identification of agent and its source

The overall success of any preparedness and response system architecture depends on the effectiveness of each of these response elements. This effectiveness, in turn, depends on R&D, training, and acquisition decisions made in each element. Indeed, the system ultimately implemented is determined by the resources allocated to areas such as training, monitoring and mitigation systems, medical supplies, and equipment for intelligence gathering, emergency response, law enforcement, and clean-up.

R&D Activities. We have identified four application areas for developing initial system concepts:

- Protection and response to incidents in key facilities.
- Protection and response during incidents at "special events".
- Recovery and restoration of urban facilities.
- Forensics and attribution.

Of these, the first two efforts are currently supported to develop initial concepts and tools in conjunction with prospective users of the systems. These efforts are designed to look comprehensively at particular elements of the response system, and to develop the most effective response strategy, while drawing on the best available technology. Each of these systems will provide "application pull" to help guide technology development efforts underway in the four R&D thrust areas. For example, the two current protection and response systems draw on the modeling thrust area for plume dispersal prediction. In addition, concepts are being developed for making best use of information likely to be available from sensors such as those under development in the detection thrust area. DOE's two current system integration efforts are described below.

Protection and Response to Incidents in Key Facilities. The objective of the Program for Response Options and Technology Enhancements for Chem/Bio Terrorism (PROTECTS) project is to field technologies and analysis tools that will support protection of "at risk" facilities; the pilot study focuses on the Washington Metro subway. Our current assessment confirms the nation's subway systems are not prepared to detect or respond to chemical and biological threats. By studying and modeling the problem, we are supporting sensor development and integration and the development of decontamination technologies, so that by the year 2002 there will be an integrated sensor network at five subway stations, with interior modeling and prediction codes linked to those sensors. Lessons learned from the project will be transferred to all subway systems in the United States.

Protection and Response During Incidents at "Special Events." The objective of the Biological Aerosol Sentry and Information System (BASIS) project is to provide one system to a major city to protect special events and determine alert conditions. Currently, state and local authorities have no means for detecting biological agents and predicting the subsequent hazard zone. For many situations, Federal assets may not be able to react quickly enough to be able to sufficiently limit casualties. This effort includes systems architecture development, sensor development and integration, modeling, and testing regimes, so that by the year 2001 the following will be available:

- A bio-sensor network with approximately 50 sensors.
- Urban hazard assessment models that receive and process sensor inputs.
- Integrated planning tools, databases, and communications tools needed to support the network.

Work on the following systems began in FY 2000 with the increased funding in the Department's FY 2000 budget.

Recovery and Restoration. The objective of this effort is to field a recovery system capable of restoring a medium-sized building and then to transfer the system to local or Federal authorities. Currently, there is no national capability for efficiently restoring an urban facility that has come under chemical or biological attack, nor are the required clean-up standards known. Beginning with design studies, and progressing through testing and evaluation of both sensors and decontamination technologies, this effort will provide a first generation capability by 2003.

Forensics and Attribution**.** The objective of this effort is to provide law enforcement personnel with the ability to establish within 48 hours the regional origin of the most threatening biological pathogens. Currently, there is a very limited ability to determine the origin of a pathogen, and several weeks of testing and analysis are required before results can be known with confidence. Biological strain variation of the leading pathogens and their regional variations and background levels will be studied, and through work in microbial genomics, low-cost, rapid signature identification technologies will be developed for those agents. By 2003, we anticipate a capability that will allow geo-location of two of the top pathogens, partial geo-location of six additional pathogens, and an initial capability to recognize engineered organisms.

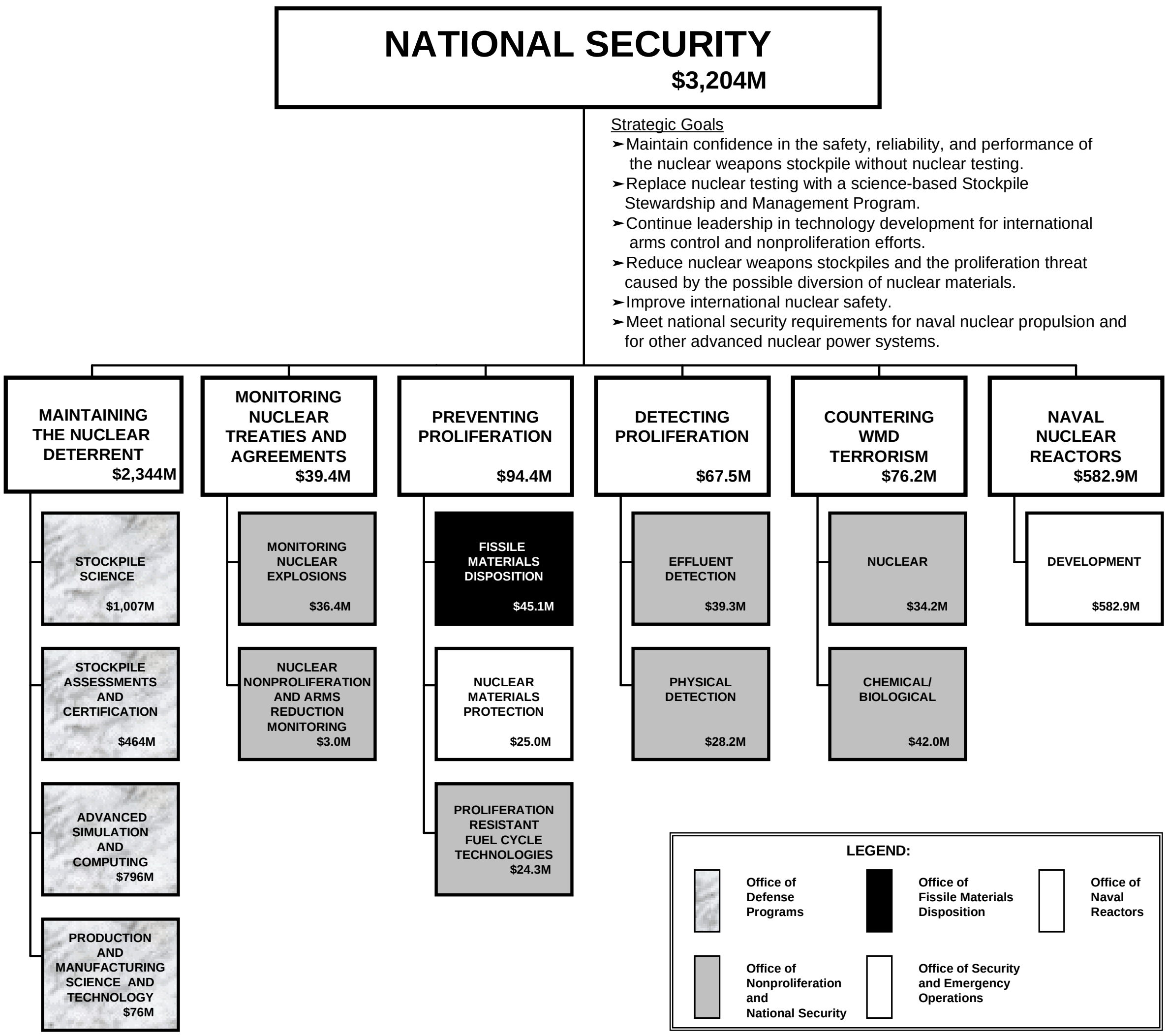
The R&D initiatives are designed to develop the key capabilities required for technology integration efforts that culminate in a fielded capability. In addition, the R&D initiatives will result in single instruments or capabilities that will have utility outside of the particular technology integration efforts pursued under this program.

The technology integration efforts bring together the best available technology in the context of architecture development to address particular capability needs. They will draw upon DOE technology as well as commercially available technology to form the fielded capability. It is expected that there will be follow-on generations of these programs as our technology development efforts mature.

Summary Budget Table (000$)

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Nuclear Materials	**38,400**	**31,600**	**34,200**
Warning of Nuclear Materials Transit	20,900	17,000	18,400
Materials Analysis	10,700	9,000	9,700
Detect and Attribute Nuclear Materials	6,800	5,600	6,100
Responding to Chemical and Biological Proliferation	**19,000**	**40,000**	**42,000**
Biological Foundations	5,000	11,200	11,200
Modeling and Prediction	3,000	5,200	5,200
Chemical and Biological Detection	7,500	12,300	12,300
Decontamination and Restoration	2,000	2,300	2,300
Systems Analysis and Integration	1,500	9,000	11,000
Total	**57,400**	**71,600**	**76,200**

Chapter 8
Naval Nuclear Reactors



Chapter 8.

This chapter is under development.

Appendix

Budget Profiles (000$)

Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Maintaining The Nuclear Deterrent	**2,234,400**	**2,306,200**	**2,343,600**
Stockpile Science	1,208,200	1,140,400	1,007,400
Advanced Simulation and Computing	483,700	660,500	796,200
Stockpile Assessments and Certification	432,900	428,900	464,300
Production and Manufacturing Technology	109,600	76,400	75,700
Monitoring Nuclear Treaties and Agreements	**45,300**	**39,100**	**39,400**
Monitoring Nuclear Explosions	42,300	36,100	36,400
Nuclear Nonproliferation and Arms Reduction Monitoring	3,000	3,000	3,000
Preventing Proliferation	**68,900**	**75,100**	**94,400**
Fissile Material Disposition	43,800	45,600	45,100
Nuclear Materials Protection	21,300	25,200	25,000
Proliferation Resistant Fuel Cycle Technologies	3,800	4,300	24,300
Detecting Proliferation	**67,400**	**66,100**	**67,500**
Countering WMD Terrorism	**57,400**	**71,600**	**76,200**
Nuclear Materials	38,400	31,600	34,200
Responding to Chemical and Biological Proliferation	19,000	40,000	42,000
Naval Nuclear Reactors	**586,200**	**572,400**	**582,900**
Total	**3,059,600**	**3,130,500**	**3,204,000**