DOE Research and Development Portfolio

National Security

Volume 5 of 5

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U.S. Department of Energy

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

Over the past year, the Department of Energy (DOE) has undertaken a major effort to ensure that our research and development programs are balanced and that our Federal investments are appropriately coordinated with the needs of the national security community. We have begun instituting a new portfolio approach to managing our R&D activities. This entails building a comprehensive document that, for the first time, provides in one place, a clear description of our entire $7 billion research portfolio. Attached is DOE's *National Security R&D Portfolio* covering $2.6 billion of that research. It is Volume V of the DOE's five volume R&D Portfolio.

This document is intended to help (1) describe our current R&D activities and showcase recent accomplishments, (2) evaluate whether our portfolio is appropriately balanced to meet our long term strategic mission goals, (3) align our 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 successfully. We believe that this document will provide the means for illuminating our proposed investments for Fiscal Year 2000 and beyond, as a unified portfolio, and serve as a useful framework and resource for further analysis and dialogue among all interested parties.

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Foreword

National Security is an important part of the Department of Energy's mission, accounting for $6.0B of DOE's $17.9B budget in FY1999. The Department is making significant progress in meeting its national security responsibilities to reduce the global danger posed by weapons of mass destruction while maintaining a safe, secure, and reliable nuclear deterrent. An aggressive R&D component is an important element of the Department's strategy for making further progress.

In FY 2000, 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 and detect proliferation, and counter weapons of mass destruction terrorism. This volume examines the Department's investments from 1998 through the year 2000. 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 them.

Chapter 2 of this document provides an analysis of the National Security Portfolio, including discussions of the uncertainties and other external factors affecting research and development, the distribution of investments by investment areas, and trends in funding levels. Chapters 3 through 7 describe the background and specific details of each problem area and how specific R&D investments are being undertaken to meet the Department's national security strategic goals and objectives. Each of these portfolio chapters further defines the national context and drivers, strategic goals and objectives, uncertainties, investment trends and rationale, federal role, and key accomplishments for each technical challenge.

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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 recent underground nuclear tests of India and Pakistan. 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. The increased activity and technical sophistication of non-state actors is a further concern.

The DOE national security mission is driven by national security policies that have developed in response to this environment. Key among these policies are support to the Strategic Arms Reduction Treaties (START I, II, and planning for III), the Comprehensive Nuclear-Test-Ban Treaty, Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the Nuclear Weapons Stockpile Plan, and Presidential Decision Directives (PDDs) on the Nonproliferation of Weapons of Mass Destruction, and Countering Terrorism. These policies require:

- A science-based stockpile stewardship program to maintain the stockpile without further underground testing,
- An effective nuclear treaty monitoring research and development program,
- A robust verification 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, and
- A counter terrorism program focused primarily on supporting domestic first responders.

Until the current cessation of testing in 1992, underground nuclear testing was the principal means to assure the performance of nuclear weapon systems and to benchmark design codes used in the assessment of nuclear weapon safety, reliability, and performance. The development of computer simulation models to extrapolate system performance from underlying physical models is a primary objective of the Department's national security research and development program. Methodologies must be developed to assess the impact of aging and manufacturing defects and changes based on scientific concepts, research, simulations, and archived test data rather than on further underground testing.

Likewise, uncertainties exist regarding the detection sensitivities for sensing in verification activities and the ability of countries to evade detection of their proliferation activities. The ability to verify 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 not possible with existing state-of-the-art sensors.

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 best interest of the U.S. Government to address this difficult problem.

The National Security R&D Portfolio is accomplished by three principal organizations: the Office of Defense Programs, the Office of Nonproliferation and National Security, and the Office of Fissile Materials Disposition. Fulfilling the Department's national security mission requires these organizations to manage the national security R&D portfolio for:

- Maintaining the U.S. nuclear weapon stockpile design, production and maintenance capability.
- Preventing the spread of WMD materials, technology and expertise.
- Securing nuclear weapon materials.
- Verification or compliance of WMD, treaties and agreements.
- Reversing the proliferation of nuclear weapons capabilities.
- Responding to emergencies.

Federal Role and Linkage to DOE Strategic Goals

DOE has the sole legislated oversight responsibility for maintaining the viability of the nuclear weapon stockpile and for oversight of all classified nuclear weapons technical information and for the production and handling of nuclear weapons components and special nuclear materials. DOE owns and operates, through contractors, the Defense Programs national laboratories and the production plants and facilities to meet its nuclear weapons stockpile mandate. 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. By virtue 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.

In order 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. This R&D is centered on solving the following problems:

Maintaining the Nuclear Deterrent

- Provide a scientific basis for assessing the performance of the stockpile with no further underground testing. Major objectives to accomplish this will 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.
- Develop new technologies for production of special nuclear materials and components in order to reduce cost, minimize environmental impact, and improve component reliability.

Monitoring Nuclear Treaties and Agreements

- Develop technologies to enable nuclear test ban treaty 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 which 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 our nuclear materials accounts, to prevent and detect diversion of nuclear materials from their authorized locations, and reduce employee exposure to radiation.
  - Physical security of the DOE complex.

Verification Technologies

- Develop verification 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.
- Develop information protection technology to prevent unauthorized access to data and to prevent disruption of classified or sensitive information systems.

Investment Trends

Maintaining the Nuclear Deterrent Through Science-Based Stockpile Stewardship

The requirements for the conduct of research and development to support the nuclear weapons stockpile flow from the necessity to ensure the performance of each warhead in the stockpile. The R&D portfolio is designed to address the following principal functional areas:

- **Primary Initiation**—the electromechanical systems that control the sequence of arming, fuzing, and weapons detonation functions after authorized release and normal trajectory to target.
- **Primary Yield**—ensuring that aged or remanufactured energetic materials, fissile materials and other engineering materials do not affect the ability of the primary to provide the necessary yield to drive the secondary.
- **Secondary Yield**—understanding the impact of variations in primary performance and aging effects on the yield produced by the secondary system.
- **Systems Integration**—ensuring that the integrated system functions in the harsh stockpile-to-target sequence.

- **Safety, Security, and Use Control**—ensuring that the weapon is safe to handle and can only provide a significant nuclear yield under use authorized by the President.

The principal technical areas of investment are:

- **Computing**—including the Accelerated Strategic Computing Initiative (ASCI). In the absence of testing, the nuclear weapons program will rely heavily on computer simulation to assess the impact of changes on nuclear weapons performance. Requirements for 100 Teraflop machines and weapon simulation software are established by the complexity of a nuclear weapon and the level of detail and resolution necessary to capture the relevant physics in the problem in full three-dimensional geometries.

- **Theory and Experiment**—providing and validating detailed physical models used in computer codes to assess weapons' performance margins.

  - High Energy Density Physics Experiments—to provide an understanding of systems and materials under conditions relevant to primary boost and secondary implosion and burn. Inertial Confinement Fusion is a major component of this research, which includes the construction of the National Ignition Facility (NIF).

  - Hydrodynamic Test Facilities—at the national laboratories that are used to implode full-scale systems that mimic primary devices but with simulants for the nuclear materials. Tests will also include "Subcritical Experiments" using non-critical assemblies of special nuclear materials in underground experiments to provide important data on materials properties and as a measure of the readiness of the Nevada Test Site to conduct nuclear testing if directed.

  - Chemistry and Materials Research—including research into the properties of special nuclear materials and the effect of aging or radiation environments on electronic components.

- **Integrated Engineering Tests**

  - Flight Tests—test of mock warheads on ballistic missile flights. This includes the development of improved instrumentation to provide the highest achievable fidelity to the launching of a war reserve system.

  - Above Ground Tests—the Defense Programs national laboratories maintain a suite of facilities for testing the non-nuclear performance of the nuclear weapon system when subject to shock, vibration, thermal transients, and hostile environments. This includes facilities to simulate electromagnetic, blast, neutron, and ionizing radiation effects of a nearby warhead detonation.

- **Surveillance and Production Technology Development**—technologies to monitor the state of the aging stockpile and to develop improved manufacturing capabilities.

The total Stockpile Stewardship research and development budget request for FY 2000 is approximately $2.4 Billion. Within inflation and small variations, this budget is not expected to change in the foreseen future.

Monitoring Nuclear Treaties and Agreements Through Enhanced System Development

- **Ground-based Monitoring Technologies**, including the development of sensors and systems to enable effective U.S. monitoring of the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

- **Improved Satellite Sensors**, including the development of next-generation sensors to detect nuclear detonations in the atmosphere and in space.

- **Improved Radiation Detection Sensors,** including 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 plant. In the immobilization activity, tests and demonstrations will be advanced sufficiently to provide the technical data to establish 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.

Verification Technologies for Improved Sensor Development

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

- **Physical Detection**, including 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**, 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.

- **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.

- **Critical Infrastructure Protection**, including cyber security improvements to assure DOE's information security.

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 increased emphasis in fiscal year 2000, growing from approximately $20M to over $30M, 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 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.

Key Accomplishments

- Established records for computing performance on ASCI computers as milestones to achieving the required computational capability. As an example, 1.6 trillion operations per second (Teraflops) achieved on the Blue Mountain computer on November 11, 1998.

- Revalidated the W76 warhead through a new dual revalidation process without underground testing.

- Obtained data on the behavior of plutonium at near weapons conditions through subcritical experiments at the Nevada Test Site.

- Won the national "Excellence in Plasma Physics" award for research on the behavior of hydrogen at high pressures that matter in nuclear weapon analysis and understanding the planet Jupiter.

- Completed the first arm of the Dual Axis Radiographic Hydrodynamic Test (DARHT) Facility.

- Initiated research and development to see and understand simulation data sets of unprecedented size (see "Data and Visualization Corridors" edited by Paul H. Smith and John Van Rosendale, CalTech Report CACR-164, September 1998, http://www.cacr.caltech.edu/pulications/DVC).

- 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 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.

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

- 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.

- 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.