DOE Research and Development Portfolio

National Security

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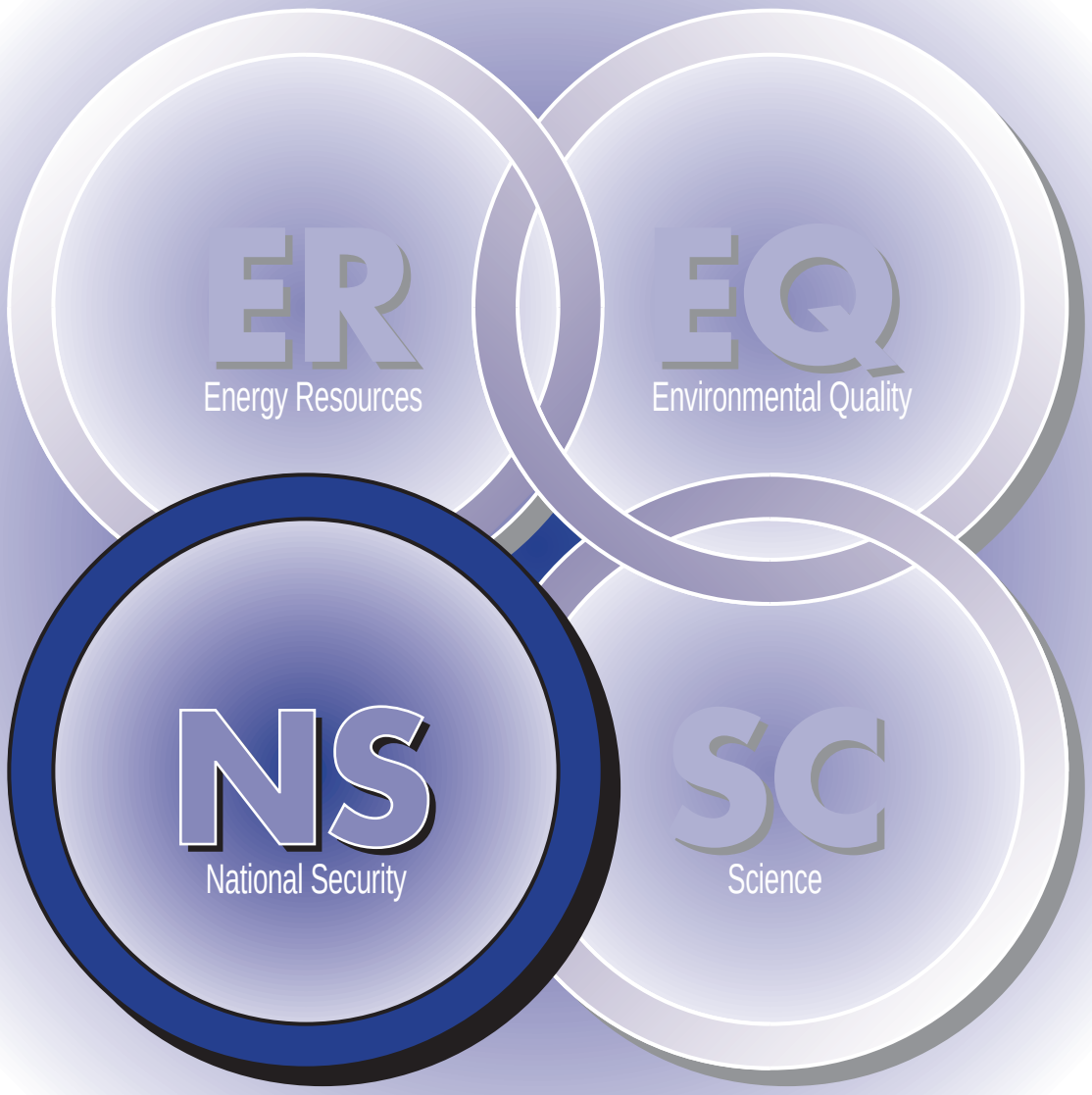

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Maintaining a safe, secure nuclear deterrent while reducing the global danger posed by weapons of mass destruction is one of the most important elements in our country's national security strategy. Since its inception, the Department of Energy (and 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.