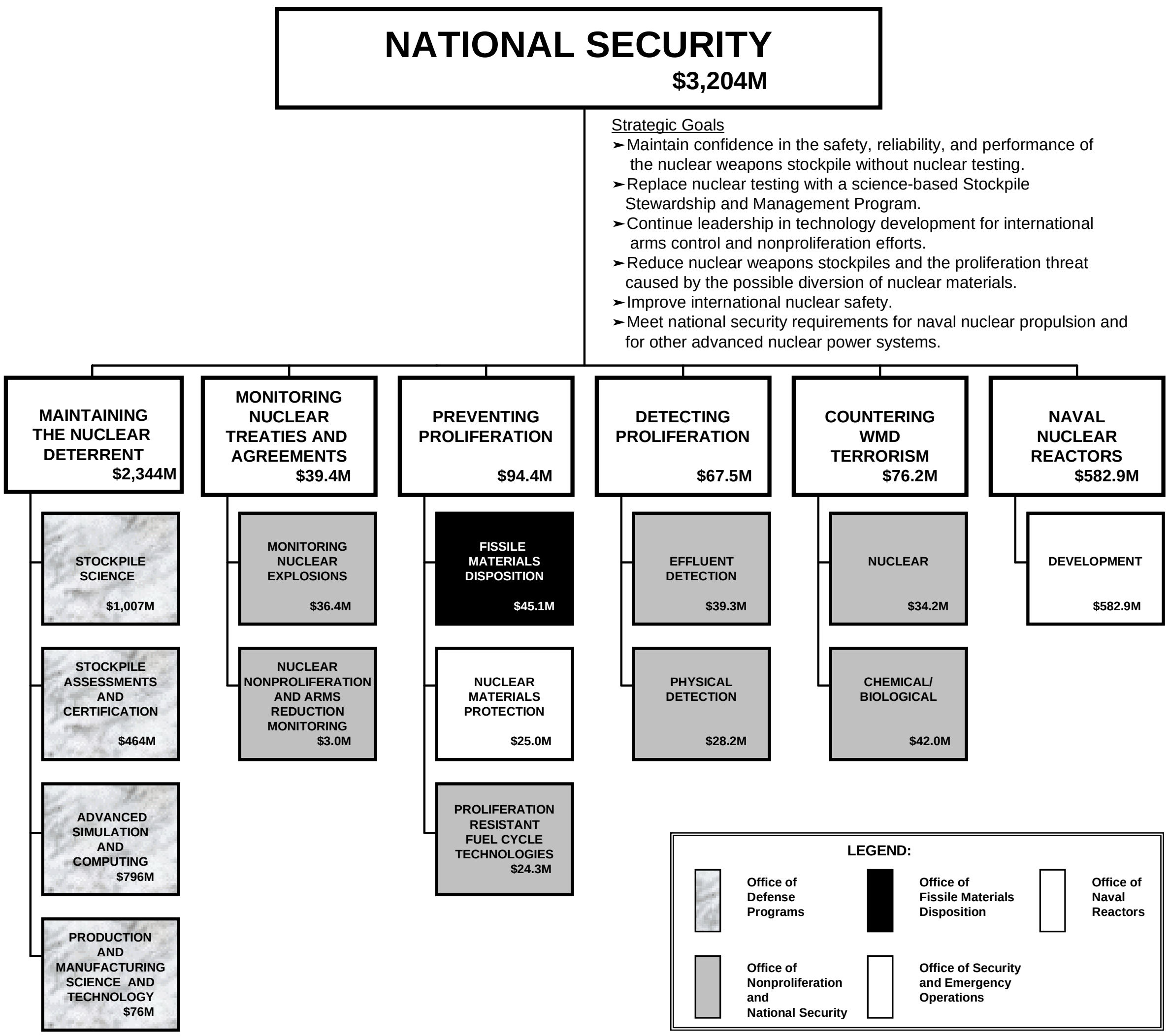
Chapter 7
Countering Weapons of Mass Destruction Terrorism



Chapter 7

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Table of Contents

Page

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.

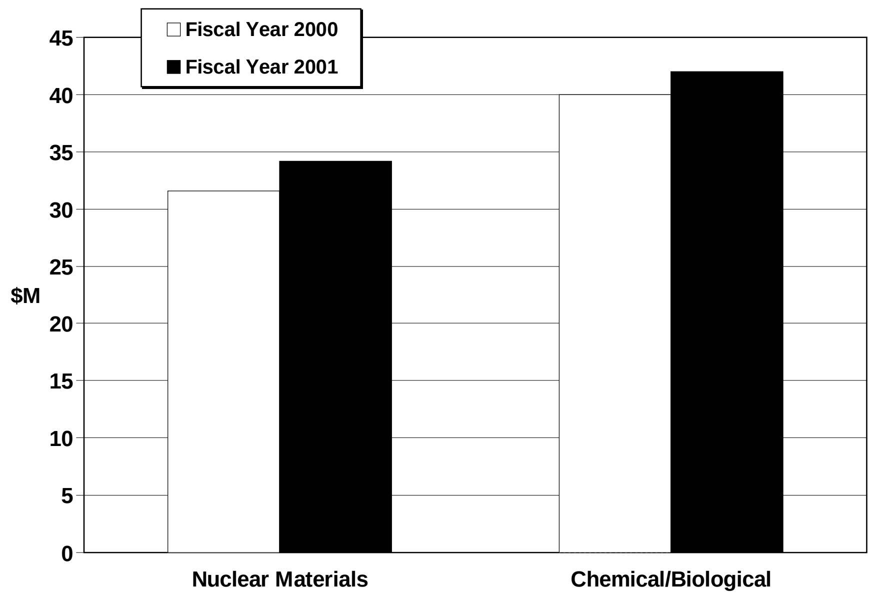
A multi-faceted approach is being used because there are numerous aspects to reducing the nuclear threat. Our activity ranges from basic research to develop new high-resolution, room-temperature radiation detection materials to the development of small, smart systems that can be integrated to monitor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