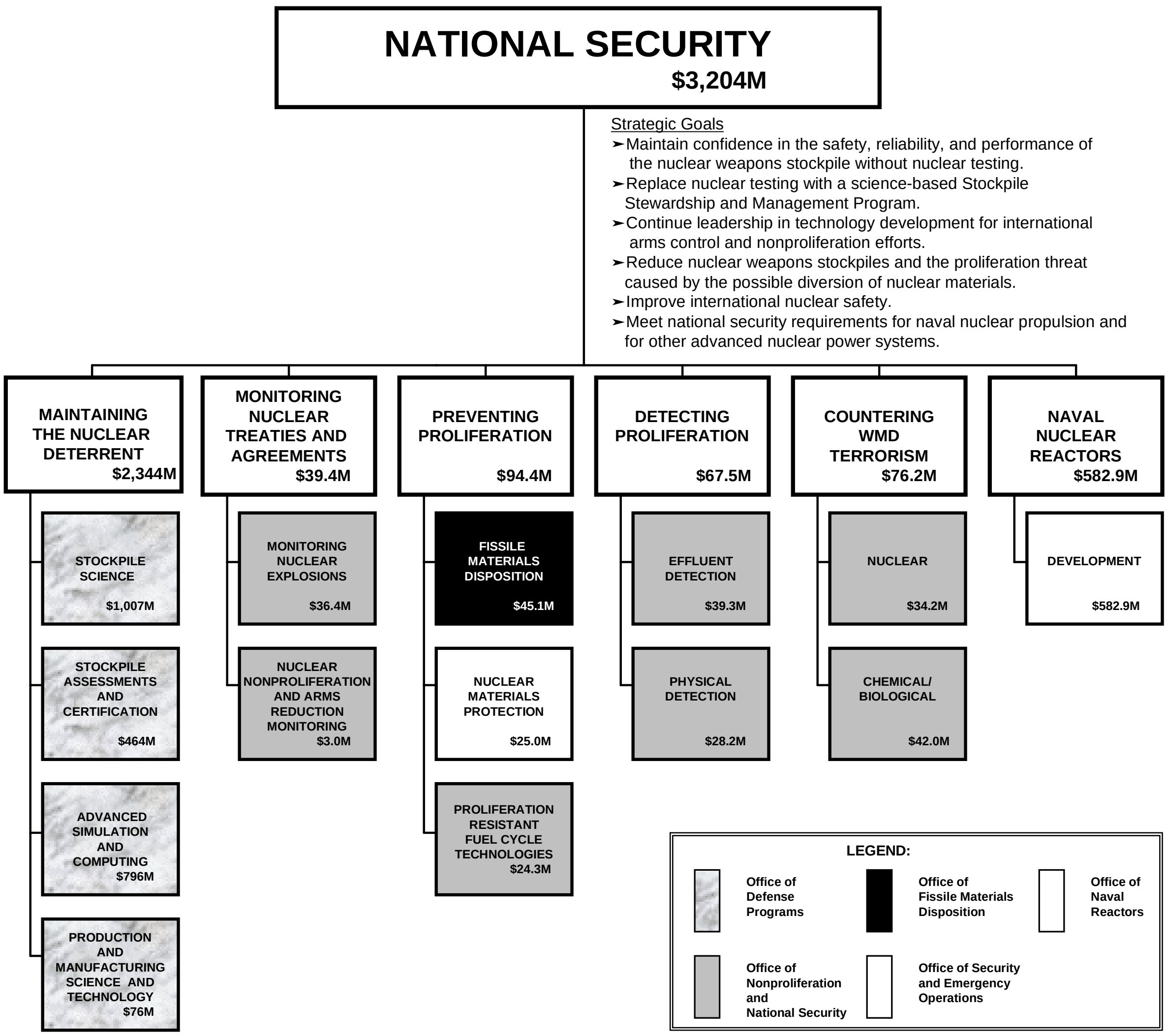
Chapter 4
Monitoring Nuclear Treaties and Agreements



Chapter 4

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Overview

Definition of Focus Area

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

National Context and Drivers

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

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

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

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

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

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

Linkage to Requirements

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

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

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

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

Uncertainties

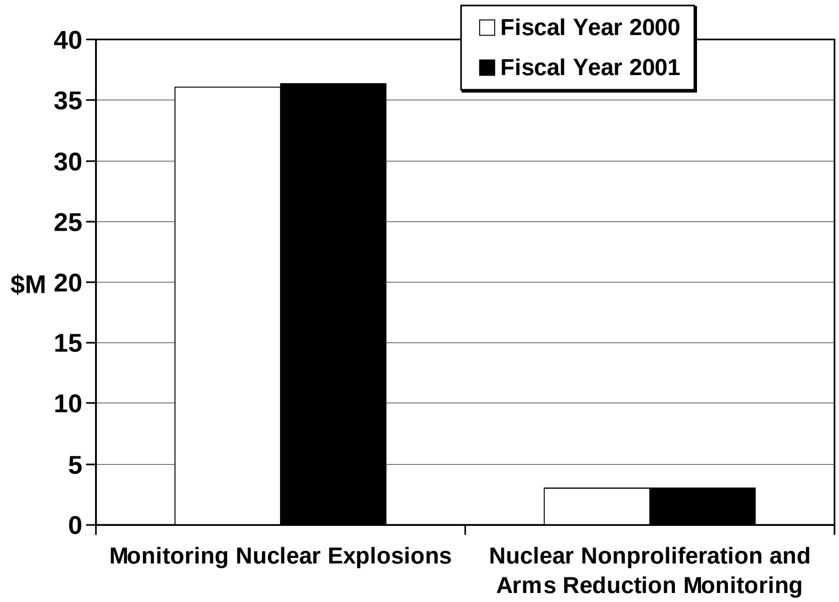
It is uncertain when, or even if, the CTBT will enter into force, banning nuclear tests in all environments, underground as well as underwater, in the atmosphere, and in space. The October 1999 vote by the U.S. Senate to not ratify the treaty increases this uncertainty. Even without a formal treaty,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

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

Investment Trends and Rationale

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

Monitoring Nuclear Treaties and Agreements



Federal Role

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

Key Accomplishment

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

Monitoring Nuclear Explosions

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

Background

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

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

- Gaining ratification of the Treaty by States Signatories.

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

Program Description

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

- U.S. Satellite-based Systems.

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

Satellite-based Systems

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Ground-based Systems

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- Developing prototype radionuclide particulate and radioxenon sensors based on well known scientific principles but requiring innovative and complex engineering to meet global monitoring specifications including high reliability and automation, low maintenance, and high sensitivity.

- Developing a turn-key infrasound prototype ready for commercialization and deployment.

- Field testing of the radionuclide and infrasound prototypes with independent evaluation by the national user organization, the U.S. National Data Center operated by the Air Force Technical Applications Center.

- Engineering and software support to the commercial vendor selected by the Air Force to commercialize and deploy the radionuclide prototypes.

- Logistical and equipment support to international testing of the radionuclide prototypes, during independent evaluation by other countries.

- Demonstration of the radionuclide monitoring systems fully integrated into the global communications infrastructure including data authentication and data analysis capabilities.

Network calibration research and development activities include:

- Minimizing false events by calibrating the IMS networks for accurate locations and event identifications.

- Collection and integration into the Knowledge Base of seismic data and ground truth information (e.g., accurate location and time of occurrence) on calibration quality events.

- Developing algorithms for using the ground truth data for location and identification.

- Participating in field activities as required to obtain high quality ground truth information.

- Collaborating with other countries on seismic data collection opportunities, particularly dual use events.

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

Data management and analysis research and development activities include:

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

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

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

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

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

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

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

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

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

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

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

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

Nuclear Nonproliferation and Arms Reduction Monitoring

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

Background

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

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

Program Description

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

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

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

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

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

Accomplishments

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

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

Summary Budget Table (000$)

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