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US Department of Energy

Comprehensive Test Ban Treaty Research and Development FY95-96 Program Plan

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Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Pacific Northwest Laboratory
Sandia National Laboratories
in coordination with
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and the Private Sector

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Comprehensive Test Ban Treaty
Research and Development
FY95-96 Program Plan

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Letter to Stakeholders

As we begin our research and development (R&D) program, we are very aware of the long-term historical efforts that have gone into preparing for a possible Comprehensive Test Ban Treaty. The fact that research issues continue to emerge is a testament to the magnitude and complexity of the task, both politically and technically.

In accepting responsibility for conducting research and development to produce technologies that will support verification of a Comprehensive Test Ban, the Department of Energy realizes that it is essential to address a fundamental question: how can this Department, through the judicious use of available resources, best contribute to this effort in an innovative way in the shortest possible time? We have organized ourselves to provide R&D support to the anticipated operational authorities and organizations that will be charged with implementing the Treaty. We are working with the wide range of diverse stakeholders to address the remaining issues.

We have the flexibility to refine our plans as research results become available and as policy decisions are made that better define the international monitoring systems.

We welcome your comments on our plan now and in the future. Please contact me (202-586-0485, FAX; 202-586-2151, voice) with your suggestions at any time.

Leslie A. Casey

Leslie A. Casey
Director
Regional Monitoring Systems Division
Office of Research and Development
Office of Nonproliferation and National Security

COMPREHENSIVE TEST BAN TREATY RESEARCH AND DEVELOPMENT PROGRAM PLAN

1. INTRODUCTION

The Department of Energy (DOE) is responsible for the United States Government's (USG) research and development (R&D) functions for monitoring nuclear explosions in the context of a Comprehensive Test Ban Treaty (CTBT). This responsibility includes the November 1993 transfer of the Department of Defense's (DoD) CTBT R&D responsibility to DOE. The DOE research program builds on the broad base of USG expertise developed historically and includes R&D for detecting, locating, identifying, and characterizing[1] nuclear explosions in all environments.

The Office of Research and Development (NN-20), within the Department of Energy's Office of Nonproliferation and National Security, formulates and executes the efforts necessary to meet the Department's responsibilities. The following DOE laboratories as a team will support NN-20 in implementing the program plan: Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Pacific Northwest Laboratory, and Sandia National Laboratories.

DOE has committed to a cooperative program that draws upon the core competencies of the national laboratories and upon the strengths of other government agencies and the private sector (academia and industry). The integration of resources under a common direction will allow the program to be flexible and responsive to changing technical and policy requirements while maximizing the effectiveness of funding appropriations. DOE will develop and demonstrate appropriate technologies, algorithms, procedures, and integrated systems in a cost-effective and timely manner. The program comprises seismic, radionuclide, hydroacoustic, and infrasound monitoring; on-site inspection; space-based monitoring; and automated data processing elements.

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[1]The following definitions are used in this report.
Detecting: Determination from the data that an event has occurred.
Locating: Determination of the surface position (latitude and longitude) and depth or altitude of an event.
Identifying: Distinguishing nuclear explosions from other events. In this plan, the term *identification* frequently encompasses detection and location.
Characterizing: Extracting the important features about an identified event (e.g., yield, focal mechanism, device performance, etc.)

2. MISSION

The responsibility outlined above leads directly to this program's mission:

> To carry out research and development necessary to provide the USG agencies responsible for monitoring and/or verifying compliance with a CTBT with technologies, algorithms, hardware, and software for integrated systems to detect, locate, identify, and characterize nuclear explosions at the thresholds and confidence levels that meet US requirements in a cost-effective manner.

Although the program is cast in the context of a CTBT, many of its efforts also relate to remotely monitoring tests by a proliferator, even in the absence of a treaty.

3. BACKGROUND

3.1. History

The possibility of a Comprehensive Test Ban (CTB) has been discussed almost as long as there have been nuclear weapons. In July 1945, the US conducted its first nuclear test and in March 1946, the Acheson-Lilienthal Report was released; this report supported the creation of an international authority to control nuclear weapons and advocated extensive and intrusive on-site inspections as part of the proposed controls. In 1958, President Dwight D. Eisenhower proposed convening a Conference of Experts to examine CTB verification.

In 1959, the US released data from reports on specific underground nuclear explosions. The data showed that verification of a CTBT was more difficult than had been anticipated. Due to disagreement about the significance of these results and a variety of political factors, the discussions ended. In the following years, individuals and nations introduced a variety of CTBT proposals. For various reasons, these failed to come to fruition. Although a CTBT was not negotiated, other limitations on nuclear testing were. These included the Limited Test Ban Treaty (LTBT) (1963), the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) (1970), the Threshold Test Ban Treaty (1974), and the Peaceful Nuclear Explosion Treaty (1976). In 1977, trilateral discussions of a CTBT began among the Soviet Union, the United Kingdom, and the United States. These negotiations adjourned in 1980.

3.2 Current Political Environment

Interest in the US and the international community for reopening negotiations for a CTBT has been stimulated by the breakup of the Soviet Union, President Clinton's declaration of a US moratorium on nuclear testing, Congressional legislation directing that a test ban be negotiated by 1996, and the upcoming extension conference for the NPT. The current CTBT negotiations began in January 1994. They are taking place in a multinational context where concern about both violations and confidence building exists. Acceptance of in-country monitoring stations and some level of on-site inspections is widespread, and the negotiations are focusing on the technical details and the costs of acceptable systems. US ratification of a CTBT will depend, in part, on the existence of a combined national and international monitoring system sufficient to meet its requirements for effective verification. Negotiating the rights to implement effective monitoring measures may require the US to describe and demonstrate cost-effective monitoring measures.

3.3 Operational Assumptions

The primary objectives of an international CTBT monitoring system are to deter nuclear explosions in all environments and, if such explosions do occur, to permit identification and characterization with high confidence. It is also important to attribute the nuclear explosion to the proper source. Though technological progress over time should permit improvements in the quality of CTBT monitoring, high standards will be set from the outset in order to create a significant deterrent against those who may be tempted to try to evade detection. The CTBT monitoring system should

- Permit identification of nuclear explosions down to a yield of a few kilotons, even when evasively conducted, and do so in a timely manner.
- Provide credible evidence to the Treaty parties to aid in resolving ambiguities and to serve as the basis for collective or individual action.
- Help verify compliance with the provisions of a CTBT and any declarations or notifications made by Parties.

An international CTBT monitoring system that monitors all environments would employ complementary technologies combined with on-site inspections and associated measures, e.g., exchanges of information. Interactive and mutually supporting technologies appropriate for use in the international monitoring regime include seismic, radionuclide sampling, hydro-acoustics, infrasonics, and OSI technologies including aircraft imagery. The various environments in which these international technologies could generally operate are portrayed in Figure 1 and listed here.

Land: The primary asset for monitoring explosions in the underground environment is the seismic network. The hydroacoustic system could aid in the identification of underground explosions in some circumstances by recording energy transmitted from the ground into the ocean.

Atmosphere: The primary international asset for monitoring explosions in the atmosphere is the global Radionuclide collection network. A global infrasound network could also aid in detection. [Space-based monitoring, not appropriate for the international regime, will utilize optical and electromagnetic pulse (EMP) sensors to detect explosions in the atmosphere.]

Underwater: A global hydroacoustic system would detect underwater explosions and aid location. The seismic system would also detect and locate underwater explosions and aid identification.

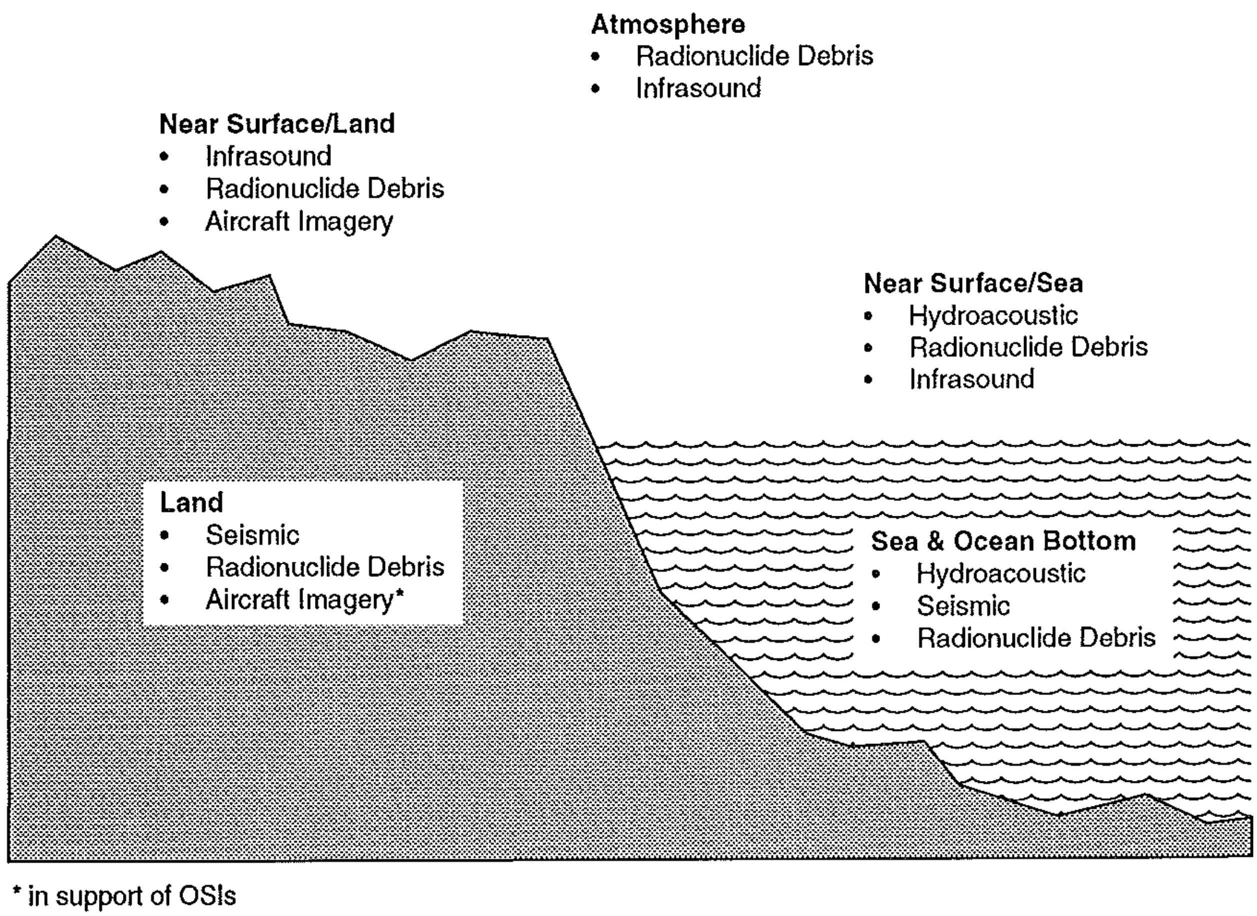

Figure 1. Potential Technologies for International CTBT Monitoring (listed in descending order of importance in each environment).

High altitude--Near Space: The international monitoring system has no technologies that apply to this environment. (Space-based monitoring, not appropriate for the international regime, will utilize x-ray, gamma, and neutron sensors to detect explosions in this environment.)

Explosions near the surface of the land or the ocean can generate signals in both the ground and the air and the ocean and the air, respectively.

Land-Air Interface: In the context of an international monitoring system, a combination of a radionuclide collection network and a global infrasound network could permit identification of explosions in the air near the Earth's surface. The seismic network could be useful if the signal from the explosion is not excessively attenuated. If the event is underground, but near the Earth's surface, it might vent radioactive gas or debris into the atmosphere and/or create a pressure pulse in the atmosphere. Radionuclide monitors and/or infrasound monitors could provide useful information in this case.

Sea-Air Interface: A combination of a radionuclide collection network and a global infrasound network could identify explosions near the water's surface. The seismic and hydroacoustic networks could also aid in event identification if the event is not too high above the surface, which would cause excessive signal attenuation. If the event is underwater, but near the surface, it could vent radioactive gas or debris into the atmosphere and/or create a pressure pulse in the atmosphere. Radionuclide monitors and/or infrasound monitors could provide useful information in this case.

Many factors influence the choice of technologies that will comprise the international monitoring system. System costs, monitoring effectiveness, availability of technology, and false alarm rate are some of the key factors. It is anticipated that the full range of technology options, which includes more technologies than are described here, will not be negotiated or deployed. Nor are all technologies equally emphasized in this R&D program.

4. TECHNICAL PROGRAM ELEMENTS AND PERFORMANCE MEASURES

The DOE community has a unique combination of resources for supporting research and development for CTBT monitoring and verification activities, including its involvement in past test ban verification efforts, its experience with nuclear testing procedures and monitoring technologies, and its breadth of technical expertise. The application of these strengths to the direct support of the operating agencies will provide tools they need to detect, locate, identify, and characterize nuclear explosions and minimize the number of false alarms. The program will also provide methods for evaluating the CTBT monitoring system's performance and assessing the impact of physical, political, and monetary constraints on the system's ability to meet US monitoring goals. These efforts will improve the technical performance of US monitoring efforts and make their outputs more useful to the policy community.

DOE's research program in support of CTBT monitoring has the following elements: (1) seismic monitoring, (2) radionuclide atmospheric monitoring, (3) hydroacoustic monitoring, (4) infrasound monitoring, (5) on-site inspections, (6) space-based monitoring, and (7) automated data processing. These elements are embedded in a larger framework that addresses (1) efficient utilization of resources, (2) the usefulness of various technologies for identifying violations and avoiding false alarms in all environments, (3) the synergism achievable by forming a system that combines data from a variety of sensors with information available from other sources, and (4) the policy applications of the information generated by the monitoring system. This R&D program will be coordinated with the efforts of other agencies responsible for CTBT monitoring and verification.

A brief description of each of the elements and their technical performance measures follows. For detailed program tasking statements and project information, see the Appendix.

4.1 Seismic Monitoring Research

Seismic monitoring research will use both theory and the analysis of measurements made during controlled experiments and events of opportunity to develop methods that will improve the monitoring system's ability to detect, locate, identify, and characterize seismic events to the extent necessary to meet US monitoring goals. It will consider the monitoring challenges posed by nuclear explosions, conventional explosions, earthquakes, and rockbursts and will develop/apply statistical measures of monitoring performance. The performance measures will consider misclassifications of all types. The research will be applied to and benefit from studies of specific regions of interest.

Key research issues include the following:

- Decoupling -- What are the effects of cavity size, shape, and emplacement material on regional seismic signals from decoupled nuclear explosions?
- Masking -- Can seismic signals from industrial explosions, etc., mask the signals from nuclear explosions?
- Discrimination -- How do source and path variations affect regional discrimination?

Performance in the Seismic Monitoring Research Program Area will be assessed by the following measures:

- Development of statistically significant improvements in event identification.
- Development of solutions to the monitoring challenge posed by conventional explosions.
- Development of the ability to predict and rapidly improve the monitoring performance in new regions given information about their regional geological and geophysical characteristics.
- Effectiveness of procedures and methods to characterize the factors affecting monitoring performance in new regions.

- o Thoroughness and integration of the efforts made to characterize the regions of interest.
- o Extent to which USG requirements are met or are changed to reflect new understanding of technical or cost limitations.

Significant milestones in FY95 and FY96 will be:

- o Acquisition of the basic geological and geophysical data for the areas of interest.
- o Definition of the performance measures for the monitoring system.
- o Determination of the baseline performance of the current monitoring system in the regions of interest.
- o Definition of the metrics for evaluating the performance of new algorithms.
- o Definition of the performance of the monitoring system in the regions of interest and the factors that determine it.
- o Definition of the monitoring challenges posed by conventional explosions and identification of possible mitigating measures.
- o Completion of the testing of new and/or improved discriminants (including combinations of discriminants).
- o Determination of the factors controlling the performance of discriminants.
- o Execution of field experiments that provide definitive information about specific factors thought to affect monitoring performance.
- o Incorporation of the new and/or improved algorithms in the national and international operational systems.

4.2 Radionuclide Atmospheric Monitoring Research

Radionuclide atmospheric monitoring research will address real-time detection and analysis of noble gases and particulate debris from nuclear testing. The program will provide the instrumentation systems necessary to identify atmospheric and subsurface nuclear explosions that vent into the atmosphere. This equipment will be suitable for international deployment and will be coordinated with anticipated end users.

Key research issues include the following:

- o In-Situ Analysis -- How can the airborne, short-lived radionuclides of greatest diagnostic value be monitored in real time?
- o Separation from Air -- How can radionuclides be most rapidly and efficiently separated from large volumes of air?
- o Measurement -- What measurement technologies provide the most practical means for near-real-time analysis of key radionuclides?
- o Sensitivity/Interference -- How can measurement sensitivity best be maximized while minimizing interference?
- o Automation -- How can the mechanics of sample collecting, analysis, and data transmission best be automated?

Performance in the Radionuclide Atmospheric Monitoring Research Program Area will be assessed by the following measures:

- Ability of the radionuclide monitoring instrumentation to identify subsurface and atmospheric nuclear explosions at the levels established by the USG requirements.
- Improvement in sensitivity levels provided by using real-time radionuclide monitoring instrumentation instead of sample collection and laboratory analysis.
- Fieldability of radionuclide monitoring instrumentation as indicated by compliance with the requirements for ruggedness, reliability, low weight, and low power usage.
- Extent to which USG requirements are met or changed to reflect new understandings of technical and monetary limitations.

Significant milestones in FY95 and FY96 will be:

- Development of a Noble Gas Radionuclide Analyzer for Real-Time Measurement of ^{133}Xe (half-life of 5 days) and ^{135}Xe (half-life of 9 hours).
    - Design, construction, and testing of an initial laboratory prototype of the concentrator/analysis unit.
    - Documentation of instrument performance.
    - Design of a rugged field prototype.
    - Testing of the field prototype and optimization with user organizations.
    - Determination of the natural background at selected monitoring sites.
- Development of a Particulate Radionuclide Analyzer for Real-Time Measurements of Short-Lived Fission Products.
    - Design, construction, and testing of a laboratory prototype unit.
    - Demonstration of the laboratory prototype in the field.
    - Documentation of instrument performance.
    - Construction and testing of a ruggedized field prototype.
    - Testing of the field prototype and optimization with user organizations.

4.3 Hydroacoustic Monitoring Research

Hydroacoustic monitoring research will identify likely scenarios for evasive nuclear testing at sea. It will examine gaps in current hydroacoustic coverage and develop options for systems to eliminate them. It will develop algorithms to automate identification. Hydroacoustic monitoring complements seismic monitoring in those cases where both technologies detect an event. (The hydroacoustic technique enhances event identification in this case.)

Key research issues include the following:

- Signatures -- What is the hydroacoustic signature of nuclear tests?
- Network Design -- What hydroacoustic coverage is required?
- Feasibility -- Can a new hydroacoustic system provide coverage in a cost-effective manner?
- Automation -- Can detection, location, and identification functions be automated at an acceptable false alarm rate?

- Synergy -- Can costs be reduced by trading off hydroacoustic and seismic systems or discrimination improved by combining such systems?

Performance in the Hydroacoustic Monitoring Research Program Area will be assessed by the following measures:

- Thoroughness and extent of the efforts made to acquire and integrate oceanographic data with strong shock, weak shock, and acoustic propagation models.
- Development of the ability to predict and verify acoustic blockage.
- Accuracy and completeness of maps of acoustic blockage (attenuation), location capability [root mean square (rms) location error], and probability of correct event identification for oceanic regions.
- Development of statistically significant improvements in event identification through completion of new sensor systems (if required) and signal processing methods.
- The acoustic noise floor, reliability (data availability), platform survivability, fabrication, and maintenance costs of a new hydroacoustic monitoring asset (if required).

Significant milestones in FY95 and FY96 will be:

- Completion of the specification of the new platform, the sensor system, the on-board processing subsystem, and the communication subsystem.
- Design and fabrication of a prototype and initiation of field trials, if necessary.
- Completion of the software necessary to extend the weak shock model into the linear acoustic wave propagation model at long range.
- Completion of estimates of the hydroacoustic signature of nuclear tests (above and below water) at long range and comparison with historical data.
- Completion of maps of acoustic blockage (attenuation), location, and discrimination capability worldwide.
- Completion of detection, location, and discrimination software for oceanic explosions.

4.4 Infrasound Monitoring Research

The goal of this task is to characterize the performance of a global system of acoustic sensors to detect the low-frequency acoustic signal from atmospheric, shallow buried, or moderately shielded explosions separately and in conjunction with other monitoring systems. Arrays of microbarographs and infrasound microphones would be employed that are capable of detection of kiloton-type explosions out to 3,000 to 5,000 km. Using available propagation information, global detection capability will be estimated as a function of source size, number of stations, and background level. These results will help determine the operational characteristics of an acoustic monitoring system.

Key research issues include the following:

- Detection -- What are the effects of source size, number of arrays, time of year, and background level on the worldwide detectability of atmospheric explosions?

- o Evasion -- What is the system effectiveness for detecting evasively conducted tests?
- o Scaling -- What is the yield dependence of the frequency content of acoustic signals?
- o Sparse Arrays -- What is the utility of advanced signal processing algorithms for sparse acoustic arrays in low signal-to-noise environments?

Performance in the Infrasound Monitoring Research Program area will be assessed by the following measures:

- o The extent to which automated detection and characterization algorithms can be applied to the acoustic data.
- o The ability to improve detection capability and bearing estimation for low signal-to-noise environments through advanced beam forming and processing.
- o The impact of acoustic data, when combined with data from other systems, on resolving ambiguous events.
- o The extent to which USG requirements are met or changed as a result of this effort.

Significant milestones in FY95 and FY96 will be:

- o Detection probability contours as function of source size, number of sites, and local noise.
- o Improved estimates of false alarm rates from examination of historic existing data and recently collected data.
- o Transmission of data from three DOE arrays to the prototype National Data Center.
- o Evaluation of acoustic detection performance for evasive tests.

4.5 On-Site Inspection Research

The On-Site Inspection (OSI) research area will determine techniques for identifying evasively conducted underground nuclear explosions and other types of events by using measurements taken in the local region around the event. We will consider the following technologies, among others, for earthquake/explosion aftershock discrimination; venting and seepage of radioactive gases and debris; methods to detect disturbed ground from commercial satellite imagery; and discriminants for nuclear and industrial explosions based on measurements at shot time.

Key research issues include the following:

- o Aftershocks -- What is the radius of detection, and can explosion/earthquake Aftershocks be discriminated?
- o Radionuclides -- What are the best times and places to look for diagnostic gases?
- o Optical Detection of Disturbed Ground -- Can low-altitude imagery be used to detect spalled regions?
- o Electromagnetic pulse -- Can on-site EMP measurements made at the time of an announced chemical explosion discriminate between nuclear and chemical explosions?
- o Strong Ground Motion -- Can on-site seismic methods detect and locate a masked nuclear explosion?

Performance under the OSI program area will be assessed by the following measures:

- o Degree to which there is a statistically significant improvement in the ability of the individual technologies to determine the event type.
- o Degree to which the integrated methods can identify initial event types with high confidence.
- o Development of a complete set of recommendations and performance criteria for OSI equipment.
- o Degree to which research techniques and currently available technologies (e.g., multispectral imaging) enhance OSI capabilities.

Significant milestones in FY95 and FY96 will be:

- o Development of earthquake/explosion aftershock discriminants for use during challenge OSIs.
- o Development of a capability to predict the areal extent and travel time of gas transport to the surface for generalized geologic models.
- o Development of a method to use on-site, zero-time, close-in measurements to distinguish a nuclear explosion from a nearby conventional explosion (e.g., as part of a cooperative transparency measure such as mine monitoring).
- o Development of a fundamental understanding of the mechanisms by which nuclear and conventional explosions generate electromagnetic waves and incorporation of this understanding into an effective discriminant for use on site at time of detonation.

4.6 Space-Based Monitoring Research

Space-based monitoring research will develop sensors to detect, locate, identify, and characterize nuclear explosions in the atmosphere and in space. The genesis of this program was the requirement to verify the LTBT and later the NPT. In the future, this research could contribute key elements for verifying compliance with the CTBT and meeting worldwide nonproliferation monitoring obligations.

Key research issues include the following:

- o Low-Technology Devices -- What is the sensitivity for detecting tests of low-performance entry-level devices?
- o Evasion -- What is the effectiveness for detecting evasively conducted tests?

Performance in the space-based monitoring research area will be assessed by the following measures:

- o Percentage of satellite operational payloads delivered to the integrating private sector representative on schedule.
- o Percentage of satellite operational payloads whose functional lifetimes equal or exceed the lifetime of the host satellites.
- o Number of candidate technologies developed that are recognized by the user community as potentially worthwhile for operational deployment.

- o Number of satellite flight experiments that successfully demonstrate desired results.
- o The community's level of confidence that the US has worldwide nuclear explosion surveillance capability that meets CTBT verification requirements in the atmosphere and in space.

Significant milestones in FY95 and FY96 will be:

- o Design review for an enhanced-sensitivity optical sensor.
- o Successful execution of the Fast On-orbit Recording of Transient Events space experiment.
- o Design of the Active Radio Interferometer for Explosion Surveillance system.
- o Incorporation of the Nuclear Detonation Detection System Augmentation Payload sensor data downlink on Global Positioning System (GPS) satellites.
- o Design review for a combined x-ray sensor/dosimeter for GPS satellites.

4.7 Automated Data Processing Research

Automated data processing research will provide the significant data processing improvements necessary to automatically and reliably detect, locate, identify, and characterize nuclear events. The emphasis will be on processing very large volumes of data and analyzing critical events.

Key research issues include the following:

- o System Throughput -- How can event processing be automated to improve system throughput?
- o Analyst Effectiveness -- How can computer-human interface improvements enhance critical event analysis?
- o Data Acquisition -- How can verification-quality data be collected and transmitted affordably?
- o Data Surety -- How can system security, reliability, and data integrity be assured in open (shared) environments?
- o System Performance -- How can the effectiveness of the monitoring system be assessed?

Performance under the Automated Data Processing area will be assessed by the following metrics:

- o Degree to which the automated data processing research enhances the International Data Center's ability to automatically and reliably acquire data from the global seismic network and use those data to detect, locate, and characterize global seismic events in real time.
- o Degree to which the automated data processing research enhances the USG National Data Center's ability to automatically detect, locate, identify, and characterize global seismic events. Critical performance parameters include detection, location, and

identification thresholds; location accuracy; depth accuracy; false alarm rate; confidence factor associated with identifications; and ability to operate in real time.

- Degree to which operational users (the prototype National Data Center and prototype International Data Center) accept and utilize products and capabilities resulting from this research.
- Extent to which USG requirements are met or are changed to reflect new understanding of technical and cost limitations.

Significant milestones in FY95 and FY96 will be:

- Development of algorithms utilizing the full seismic waveforms. Automated prototype processing software that can handle the volumes of data that are required for the global CTBT monitoring system.
- Completion of a beta version of improved signal processing techniques (detection, location, identification, and characterization) and acceptance of these techniques by the monitoring community.
- Completion of the improved signal processing code and acceptance of the code by the monitoring community.
- Automation of tasks that currently require human data analysts.
- Prototype software for acquiring and integrating multisource data.
- Demonstration of prototypes of techniques for improving the analysis environment.
- Analysis of problems and solutions concerning authentication and security within the Global Monitoring System.

5. MANAGEMENT APPROACH

5.1 Internal to DOE Community

Within DOE, CTBT R&D will be managed and executed as an integrated, multilaboratory program. The program responsibilities are structured to take maximum advantage of existing strengths (e.g., facilities, expertise) within the participating laboratories, other government agencies, and the private sector. The relevance, quality, and uniqueness of their contributions and the timeliness and cost effectiveness of the proposed efforts will be major factors in assigning responsibilities.

The R&D program will occur within a highly cost-constrained environment that will dictate a continuing evaluation of cost effectiveness. Several components of the system will evolve in parallel. The overall system performance will be continually monitored as changes in the various sub-elements occur so that incremental changes in one area may be factored into decisions about investments in other areas of the system.

Overall program direction and ultimate responsibility for CTBT R&D resides with the Office of Research and Development (NN-20). Senior personnel from each participating laboratory will work with the Office of Research and Development to establish the program goals, guidance, and resource limitations and to define and oversee the execution of the projects that make up the CTBT R&D program. The Office of Research and Development has flexibility to adapt to changing requirements.

5.2 External to the DOE Community

The products of the CTBT R&D program will be major factors in ensuring that US CTBT monitoring goals will be achieved within cost constraints. In its management role, DOE will coordinate the CTBT R&D efforts with the US interagency verification community to assure that the program addresses the community's consensus view of these goals. To this end, DOE will participate in interagency meetings and will hold both ad hoc and regularly scheduled formal meetings with the community. These meetings will help shape the DOE program in the context of dynamic policy and technical developments. In addition, the meetings will keep other agencies informed of the status of the evolving DOE program. To ensure that the technical aspects of the program are proceeding in an appropriate manner, DOE will also seek continuing input from various elements of the technical community (e.g., the private sector, including university personnel, and others). For this purpose, DOE will sponsor and participate in informal and regularly scheduled formal meetings with stakeholders and experts within this community.

Table 1 lists the US stakeholders in CTBT verification R&D that have been identified.

Although DOE has the primary responsibility for research and development functions in support of monitoring nuclear explosions, other agencies and organizations have resources that can contribute to both national and international monitoring capabilities. DOE's program will place a high priority on coordinating these resources in order to avoid duplication and ensure full utilization of results. Representatives of DOE's CTBT R&D program (Headquarters and/or Laboratory personnel as appropriate) will be active members in the relevant interagency working groups and committees.

6. CLASSIFICATION AND SECURITY ISSUES

The US's use of the prototype International Data Center and US National Data Center data in conjunction with its national verification efforts will result in a classified/unclassified data interface. This may require efforts to develop procedures and hardware to protect the classified data. The Air Force Technical Applications Center (AFTAC) Seismic Network Security Guide (dated 28 February 1990), the Air Force Space Command Security Classification Guide for Defense Support Program (dated 1 February 1993), a comparable document for the Global Positioning System that is now being drafted, and DOE's Classification and Unclassified Controlled Nuclear Information (UCNI) Guide for Arms Control and Verification Technology, CG-ACVT-1 (dated 6 January 1992) will provide classification guidance. Additional guidance will be generated as necessary.

TABLE 1. US STAKEHOLDERS IN CTBT VERIFICATION RESEARCH AND DEVELOPMENT

- Arms Control and Disarmament Agency
- Arms Control Intelligence Staff
- Department of Defense
  - Advanced Research Projects Agency
  - Air Force Office of Scientific Research
  - Air Force Space and Missile Systems Center
  - Air Force Space Command
  - Air Force Technical Applications Center
  - Defense Intelligence Agency
  - Defense Nuclear Agency
  - Joint Chiefs of Staff
  - Naval Research Laboratory
  - On-Site Inspection Agency
  - Phillips Laboratory
  - United States Navy
- Department of Energy
  - Office of Nonproliferation and National Security
    - Office of Arms Control and Nonproliferation
    - Office of Research and Development
      - Lawrence Livermore National Laboratory
      - Los Alamos National Laboratory
      - Pacific Northwest Laboratory
      - Sandia National Laboratories
  - Environmental Measurements Laboratory
  - Nevada Operations Office
- Department of Interior
  - US Bureau of Mines
  - US Geological Survey
- Department of State
- National Academy of Sciences/National Research Council
- National Oceanic and Atmospheric Administration
- National Science and Technology Council
- National Science Foundation
  - Incorporated Research Institutes in Seismology
  - International Seismological Centre
- National Security Council
- Office of Science and Technology Policy
- Private Sector (academia and industry)
- Taxpayers

7. SCHEDULE AND COST

Pacing time factors are the Group of Scientific Experts Technology Test number three GSETT-3) experiment that will begin in 1995, the Conference on Disarmament's discussions of a CTBT that began in January of 1994, preparation for negotiations for the 1995 extension of the NPT, early completion of the CTBT negotiations (as mandated by Congressional legislation), and policy makers' expectations that verification will be fully functional by an as-yet-to-be-determined date at or after the conclusion of the CTBT negotiations. The actual completion date of the CTBT is unknown. It will be strongly influenced by the scope of the verification regimes negotiated.

Although this plan shows a fairly high level of funding for FY95 and FY96, by FY2001, CTBT-specific R&D activities should reach a relatively low level consisting of assistance to the operating agencies, ad hoc improvements in the system, and assistance in interpreting events that are unidentified. The treaty implementation area, outside the R&D arena, is a possible exception. DOE personnel could have significant direct or supporting operational roles by virtue of their expertise and past responsibilities in this area. Another likely exception is the space-based monitoring research area, because of the long lead times associated with space-qualified hardware procurements. Treaty implementation roles in general are yet to be determined.

The DOE has been directed to perform the CTBT R&D Program out of its existing budget. A budget summary is shown in Table 2. Tasks and deliverables, shown in the Appendix, will be adjusted periodically to maximize research performance within budget limitations. The detailed two-year planning will be routinely updated as part of the budget process, taking into account research results and changes in technical and policy requirements. Funding is contingent upon budget authorization.

Table 2. BUDGET SUMMARY

Research Area	FY95 Planned ($k)	FY96 Planned ($k)
Underground Environment		
Seismic	14 450	14 550
Automated Data Processing	6 100	6 090
Underwater Environment		
Hydroacoustic	1 988	2 070
Radionuclide Debris	0	0
Atmospheric Environment		
Radionuclide Debris	1 700	600
Ground-Based Infrasound	360	360
Space-Based Monitoring*	29 830	27 000
International Regime		
On-Site Inspection	1 810	1 810
TOTAL	56 238	52 480

*The space-based entries include both LTBT research funding that has dual application to a CTBT and research funding that is specifically dedicated to a CTBT.

8. SUMMARY

DOE has the responsibility for the research and development essential to provide the US agencies responsible for monitoring compliance with a CTBT with the integrated systems necessary to detect, locate, identify, and characterize nuclear explosions. Successful fulfillment of this responsibility will increase confidence in the performance of the monitoring system by reducing the number of false alarms to the lowest level consistent with effective detection of treaty violations. The program will focus on seismic, radionuclide, hydroacoustic, and infrasound monitoring, on-site inspection monitoring, space-based monitoring, and automated data processing technologies.

To address these responsibilities, DOE and its National Laboratories have committed themselves to a cooperative, structured program that draws upon the core competencies of each DOE organization; the strengths of other agencies, the private sector, and universities; and frequent interaction with end users. The integration of resources and coordination with the users will allow the program to develop and demonstrate effective monitoring technologies, algorithms, procedures, and integrated systems in a cost-effective and timely manner. The introduction of a formal, multilaboratory structure for program management will support integrated system development, provide a means for evaluating the costs and benefits of current developments and future improvements, and facilitate interaction with the agencies responsible for monitoring and/or verifying compliance with a CTBT.

US Department of Energy

Comprehensive Test Ban Treaty Research and Development FY95-96 Program Plan

Appendix:
Research, Goals, Products,
Approaches, and Tasks

Contents

RESEARCH GOALS, PRODUCTS, APPROACHES, AND TASKS

1. SEISMIC MONITORING RESEARCH

Goal: The seismic monitoring research element's goal is to provide improvements in the seismic monitoring capabilities, primarily in regional location and identification and, to a lesser extent, in detection and characterization, to meet US national requirements for CTBT monitoring. Improvements in all these functions will be made in the context of evolutionary upgrades to the prototype US National Data Center (NDC). To the extent appropriate, these improvements will also be incorporated into the prototype International Data Center (IDC) being developed by the Advanced Research Projects Agency (ARPA) for use in the GSETT-3 experiment planned by the Group of Scientific Experts (GSE).

Products: The seismic monitoring program element will provide methodologies that define and improve the monitoring performance in high-interest regions and, to a lesser extent, the remainder of the globe; proven, documented algorithms for accurate event detection, location, identification and characterization; a basic understanding of the factors that control the performance of the algorithms so that they can be tailored to specific sites and regions; and an overview of the monitoring challenges posed by conventional explosions and the measures that can be taken to address these challenges. Supporting databases, raw input information, procedures, and reports will accompany the final versions of the regional characterizations to AFTAC. The information that is acquired and the algorithms that will be developed will be applied (due to budget constraints) to two regions of interest only: southern and central Asia and the Mid-East/N. Africa.

Approach: Event detection, location, identification, and characterization functional elements of the CTB monitoring problem have common requirements for seismic data and regional characterization information. Task S1[1] is intended to provide regional geophysical and geological information about the Mid-East/N. Africa and southern and central Asia that can be acquired from existing sources. Tasks S2 and S3 address the detection and location capabilities, respectively, in these regions. Task S4 develops an empirical understanding of existing identification concepts (discriminants) by testing them on data from the Mid-East/N. Africa and southern and central Asia and quantifying their performance. Tasks S5 and S6 are efforts to understand the physical basis for location and discrimination, respectively, in order to develop methods that can be transported from one region to another. Task S7 defines and executes field studies to obtain significant new information or to resolve critical location and discrimination issues.

Task S8 integrates the various elements across the projects in a comprehensive report.

Task Overview:

Task S1. Regional Characterization

The goal of this task is to provide geological and geophysical information for the regions of high interest for use by Tasks S2-S6. Sources of natural and man-made seismicity and cultural noise will be identified and characterized. This information will be acquired from research either in the region of interest, including possible calibration experiments conducted under Task S7, or from technical contacts in the region and from seismic monitoring. It will be synthesized into reports on

[1]The following abbreviations are used for the various research areas: Seismic Monitoring Research (S), Hydroacoustic Monitoring Research (O), Radionuclide Monitoring Research (R), Infrasound Monitoring Research (A), On-Site Inspection Research (I), Space-Based Monitoring Research (N), and Automated Data Processing Research (D).

and data bases of velocity structures, travel time curves, regional characteristics of wave propagation, attenuation characteristics, and evasion assessments.

Task S2. Develop Detection, Phase Identification, and Event Association (DPIEA) Techniques

The goal of this task is to develop new and/or improved regionally dependent algorithms for detection, phase identification, and event association in the Mid-East/N. Africa and southern and central Asia regions.

Task S3. Develop Empirical Location (Epicenter And Depth) Techniques

The goal of this task is to develop improved epicenter and depth estimates. These are likely to depend upon the properties of the specific regions. Significant improvements in epicenter location capability will benefit all aspects of treaty verification. More precise locations would greatly reduce the effort required in an on-site inspection. Event identification would benefit from improved depth estimates.

Task S4. Develop Empirical Discriminants in Areas of Interest

The goal of this task is to test discriminants and determine the performance of existing and potentially useful regional ones in the southern and central Asia and Mid-East/N. Africa regions. Combinations of discriminants will be studied as well as individual discriminants.

Task S5. Develop Models for Regional Propagation and Event Location

The goal of this task is to develop an understanding of the physical properties of both the regions under consideration and the recording network that control the accuracy of the location and depth estimation efforts. The empirical results of tasks S2 and S3 will be used to develop a model that embodies the important propagation features observed in the region. The model will provide a basis for the validation, refinement, extension, or redefinition of existing location and depth estimation techniques and the development of new ones.

Task S6. Develop Models for Discriminants

The goal of this task is to develop a physical understanding of the factors controlling the performance of existing event discrimination procedures. The results of Task S4 will be used to develop a model of the performance of discrimination techniques that could be generalized for all regions of interest. This task will provide a basis for the validation, refinement, extension, or redefinition of existing discrimination techniques, for the development of new techniques, and for the prediction of the performance of the discriminants in new regions.

Task S7. Perform Field Studies

The modeling undertaken in tasks S5 and S6 will generate key questions regarding regional propagation and event identification that can be addressed only by field studies. Two types of field studies are envisioned: passive and active. In a passive field study, portable instrumentation would be deployed in the vicinity of targets of opportunity where seismic activity is anticipated. These could be earthquake aftershocks or routine blasting at mines or construction sites and other geologic settings of interest. This kind of field study is adequate for calibration of propagation models used in event location but would be inadequate for the explosion phenomenology development needed for event identification. In this latter case, source location and timing are critical. Therefore, an active experiment in which the experimentalists specify the time, location, and other source parameters is required. This task will design and implement both types of experiments, but only the active ones will satisfy the requirements of both the modeling aspects of location (S5) and identification (S6) simultaneously.

Task S8. Integrate Results

This task integrates the results obtained in the various components of the seismic research project. For example, the magnitude of the mine monitoring problem for a given region will be summarized in a report drawing on the results of S1, S3, and S4.

Task Breakdown:

The task breakdown for Seismic Monitoring Research is shown in Table A1.

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
S1.			Develop Regional Characterization Methodology	Task S1 will provide geological and geophysical information for the regions of high interest for use by Tasks S2-S8. Sources of natural and man-made seismicity and cultural noise will be identified and characterized.											
	S1.1		Collect Data												
		S1.1.1	Geological and geophysical data												
			a. Collect, archive & integrate existing geological and geophysical data for southern and central Asia	a. Initial geological & geophysical data from southern and central Asia in organized archive	X					a. Preliminary geological & geophysical data to AFTAC & researchers	X				
			b. Collect, archive & integrate existing geological and geophysical data for Mid East/N. Africa	b. Initial geological & geophysical data from Mid East/N. Africa in organized archive		X			X	b. Preliminary geological & geophysical data to AFTAC & researchers		X			X
		S1.1.2	Natural seismicity												
			a. Collect, archive & integrate existing natural seismicity data for southern and central Asia	a. Initial seismicity data from southern and central Asia in organized archive	X					a. Preliminary seismicity data to AFTAC and researchers	X				
			b. Collect, archive & integrate existing natural seismicity data for Mid East/N. Africa	b. Initial seismicity data from Mid East/N. Africa in organized archive		X			X	b. Preliminary seismicity data to AFTAC and researchers		X			X
		S1.1.3	Explosions and related seismicity												
			a. Collect, archive & integrate explosion and related seismicity data for southern and central Asia	a. Initial explosion and related seismicity data from southern and central Asia in organized archive	X					a. Preliminary seismicity data to AFTAC and researchers	X				
			b. Collect, archive & integrate existing explosion and related seismicity data for Mid East/N. Africa	b. Initial explosion and related seismicity data from Mid East/N. Africa in organized archive		X			X	b. Preliminary seismicity data to AFTAC and researchers		X			X
		S1.1.4	Locations and characteristics of cultural noise sources												
			a. Collect, archive & integrate data on existing cultural noise sources in southern and central Asia	a. Initial cultural noise data from southern and central Asia in organized archive	X					a. Preliminary cultural data to AFTAC and researchers.	X				
			b. Collect, archive & integrate data on existing cultural noise sources in Mid East/N. Africa	b. Initial cultural noise data from Mid East/N. Africa in organized archive		X			X	b. Preliminary cultural data to AFTAC and researchers.		X			X
	S1.2		Analysis products.												
		S1.2.1	Velocity structure and travel times												
			a. Determine seismic velocity structure & travel time curves for southern and central Asia	a. Summary of existing travel times & velocity structure for southern and central Asia	X					a. Travel times & velocity models to AFTAC & researchers	X				
			b. Determine seismic velocity structure & travel times for Mid East/N. Africa	b. Summary of existing travel times & velocity structure for Mid East/N. Africa		X			X	b. Travel times & velocity models to AFTAC & researchers		X			X
			c. Assess uncertainties in velocity structure and travel time results							c. Travel time and velocity model uncertainty analysis			X		
		S1.2.2	Seismicity (natural and man made) maps												

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
			a. Produce seismicity maps of natural & artificial sources for southern and central Asia.	a. Initial maps of man-made & natural seismicity	X					a. Maps & report quantifying regional seismicity.	X				
			b. Produce seismicity maps of natural & artificial sources for Mid East/N. Africa	b. Initial map of man made & natural seismicity		X			X	b. Maps & report quantifying regional seismicity.		X			X
		S1.2.3	Noise statistics of regions and stations												
			a. Produce noise statistics for existing seismic stations in southern and central Asia.	a. Status report with noise plots	X					a. Final report quantifying station noise for southern and central Asia	X				
			b. Produce noise statistics for existing seismic stations in Mid East/N. Africa.	b. Status report with noise plots for station siting & detection levels.					X	b. Final report on station noise					X
			c. Assess significance of noise statistics							c. Progress report on station noise uncertainty analysis			X		
			d. Evaluate impacts of noise, station outages, propagation barriers, & other scenarios on performance.	d. Interim report on effects of noise on network performance				X							
		S1.2.4	Phase attenuation and scattering (Pn, Pg, Sn, Lg, coda, and surface waves) maps												
			a. Identify & quantify prominent regional phases for southern and central Asia.	a. Seismograms & preliminary phase identification for southern and central Asia.	X					a. Preliminary wave propagation characteristics for southern and central Asia.	X				
			b. Identify & quantify prominent regional phases for Mid East/N. Africa.	b. Seismograms & preliminary phase identification for Mid East/N. Africa.		X			X	b. Preliminary wave propagation characteristics for Mid East/N. Africa.		X			X
			c. Assess uncertainties in phase attenuation & scattering maps.							c. Preliminary wave propagation uncertainty analysis			X		
		S1.2.5	Define sites with unique geophysical properties.												
			a. Locate sites with unique properties that could affect monitoring using data for Southern and Central Asia in S1.1.1.							a. Report on and map of sites with unique properties in Southern and Central Asia.	X				
			b. Locate sites with unique properties that could affect monitoring using data for Mid East/N. Africa in S1.1.1.							b. Report on and map of sites with unique properties in the Mid East/N. Africa.		X			X
S2.			Develop detection, phase identification, and event association (DPIEA) technologies	Task S2 will develop new and/or improved regionally dependent algorithms for detection, phase identification, and event association in the Mid East/N. Africa and southern and central Asia regions.											
	S2.1		Assess capabilities and needs and develop statistical measures.												
		S2.1.1	Research and document current DPIEA techniques and summarize previous results												
			c. Develop statistical basis for DPIEA procedures.	c. Document DPIEA procedures. Final report.			X								
		S2.1.2	Determine additional needs for DPIEA.												

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
			c. Develop DPIEA technical performance criteria							c. Interim report.			X		X
		S2.1.3	Develop uncertainty analysis techniques.												
			c. Develop DPIEA technical performance criteria and uncertainty analysis	c. Progress report on performance criteria and uncertainty			X		X	c. Final report on DPIEA performance criteria and uncertainty analysis			X		X
	S2.2		Evaluate current DPIEA techniques												
		S2.2.1	Compile data set												
		S2.2.2	Test algorithms on data set												
			c. With contractors, determine new data uncertainties using S2.1.3 results							c. Progress report			X		
		S2.2.3	Analyze regional dependence of algorithms												
			c. With contractors determine significance of regional differences							c. Progress report			X		X
			d. Evaluate network performance using new regional DPIEA techniques.							d. Evaluation report				X	
	S2.3		Develop and evaluate new DPIEA algorithms.												
		S2.3.1	Formulate modifications to DPIEA algorithms												
			d. Develop and evaluate new DPIEA algorithms							d. Evaluation report				X	
		S2.3.2	Test new formulations												
		S2.3.3	Re-analyze regional dependence												
	S2.4		Network performance												
			c. Investigate new DPIEA techniques & evaluate performance.							c. Progress report			X		
	S2.5		Calibration analysis												
S3.			Develop location (epicenter and depth) techniques	Task S3 will develop improved epicenter and depth estimates.											
	S3.1		Assess capabilities and needs and develop statistical measures.												
		S3.1.1	Research and develop location technologies and summarize previous results												
			c. Develop statistical basis for location procedures.	c. Final report on analysis of past performance			X								
		S3.1.2	Determine needs for event location (epicenter and depth) techniques												
		S3.1.3	Develop performance criteria and uncertainty analysis techniques.												
			c. Identify and establish performance criteria and sources of uncertainty in location algorithms	c. Progress report on performance criteria and uncertainty			X		X	c. Final report on location performance criteria and uncertainty			X		X

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
	S3.2		Evaluate current location techniques.												
		S3.2.1	Compile data set												
			b. Confirm locations of data to be used as reference base	b. Proven locations for improvement determinations		X			X	b. Proven locations for improvement determinations		X			X
		S3.2.2	Test algorithms on data set												
		S3.2.3	Analyze regional dependence												
			a. Recompute locations with new southern and central Asia models & current methods							a. Comparison of new and old locations	X				
			b. Recompute locations with new Mid East/N. Africa models & current methods							a. Comparison of new and old locations		X			
			c. Statistically assess regional location technique differences							c. Progress report on regional comparison (southern and central Asia vs Mid East/N. Africa) location techniques			X		
	S3.3		Develop and evaluate new location algorithms.												
		S3.3.1	Combine regional and teleseismic methods												
			d. Evaluate new regional location algorithms for their automation performance.							d. Interim report				X	
		S3.3.2	Multiple phase techniques.												
			a. Develop improved methodology							a. New location algorithms using multiple phases	X				
			c. Develop and document uncertainty for multiphase location algorithms							c. Progress report			X		
		S3.3.3	Waveform correlation and matching												
		S3.3.4	Network performance.												
			c. Develop statistical methods to evaluate regional location algorithms in network settings.							c. Progress report on factors influencing network performance.			X		
			d. Evaluate network performance with regional location algorithms.							d. Evaluation of network performance.				X	
		S3.3.5	Calibration analysis												
S4.			Empirically develop discriminants	Task S4 will determine the performance of existing and potentially useful regional seismic discriminants in the southern and central Asia and Mid East/N. Africa regions.											
	S4.1		Assess capabilities and requirements and develop statistical performance measures												
		S4.1.1	Research and document current discrimination techniques & summarize previous results												

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cntrct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cntrct
			a. Research current discrimination techniques used in southern and central Asia.	a. Summarize previous discrimination work in southern and central Asia.	X					a. Assess the effectiveness of current discriminants for southern and central Asia.	X				
			b. Research current discrimination techniques for Mid East/N. Africa.	b. Summarize previous discrimination work in Mid East/N. Africa		X			X	b. Assess the effectiveness of current discriminants for Mid East/N. Africa.		X			
			c. Develop statistical basis for discrimination procedures.	c. Final report on current discrimination techniques			X		X						
		S4.1.2	Determine discrimination needs												
		S4.1.3	Develop performance criteria and uncertainty analysis techniques for discrimination												
			b. Develop decision process & structure for uncertainty	b. Report with preliminary concepts		X				b. Report defining procedures		X			
			c. Identify and establish performance criteria and sources of uncertainty	c. Progress report on measure s of performance and uncertainty			X		X	c. Report			X		
	S4.2		Test current discriminants against data.												
		S4.2.1	Compile data												
			a. Collect historic and current data, including GSETT-3 data, from Mid East/N. Africa.	a. Documented data set	X					a. Report describing discrimination performance for southern and central Asia and possible improvements.	X				
			b. Collect historic and current data, including GSETT-3 data, from southern and central Asia.	b. Documented data set		X			X	b. Report describing discrimination performance for Mid East/N. Africa and possible improvements.		X			
		S4.2.2	Test algorithms on data set												
			a. Process data from southern and central Asia.	a. Preliminary report on discriminant performance in southern and central Asia.	X				X	a. Report quantifying performance of current discriminants in southern and central Asia.	X				
			b. Process data from Mid East/N. Africa.	a. Preliminary report on discriminant performance in Mid East/N. Africa		X			X	b. Report quantifying performance of current discriminants in the Mid East/N. Africa.		X			
			c. Determine GSETT data uncertainties							c. Final evaluation report on GSETT-3 data uncertainties.			X		X
		S4.2.3	Analyze regional dependence.												
			b. Participate in statistical analysis of regional dependence with PNL.	b. Status report on statistical properties of results of 4.2.2		X				b. Report on preliminary findings		X			
			c. Assess significance of regional differences	c. Progress report.			X			c. Report on preliminary findings			X		X
	S4.3		Develop and evaluate new discrimination algorithms												
		S4.3.1	Develop modified discriminants for specific regions												
			a. Modify southern and central Asia discriminants							a. Description of changes in the discriminants for southern and central Asia.	X				
			b. Modify Mid East/N. Africa discriminants							b. Description of changes in the discriminants for Mid East/N. Africa.		X			

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
		S4.3.2	Test new discriminants												
			a. Process data set from southern and central Asia and similar regions							a. Preliminary report on the performance of the discriminants for southern and central Asia	X				
			b. Process data set from Mid East/N. Africa							b. Preliminary report on the performance of the discriminants for the Mid East/N. Africa		X			
		S4.3.3	Determine the contribution of regional seismic data.												
			b. Examine value of combining regional data with data for other distances.	b. Status report on concept & preliminary results		X				b. Report on joint performance.		X			
		S4.3.4	Devise new waveform measures												
			b. Develop new discriminants using extended portions of the seismogram	b. New whole-waveform discriminants		X				b. Final report on value of combining data		X			
			d. Develop enhanced ripple-fired identification methods using high frequency data from Pinedale	d. Interim report on identifying ripple-fired conventional explosions				X		d. Final report on identifying ripple-fired conventional explosions				X	
		S4.3.5	Investigate different classification procedures												
			c. Devise new 3-component waveform measures	c. Progress report on 3-component waveform measures			X			c. Final report on 3-component waveform measures			X		
		S4.3.6	Create master event techniques (coordinate with location work).												
			b. Create master event techniques for natural and artificial seismic activity	b. Status report on concept & preliminary results		X			X	b. Final report describing technique & results		X			X
		S4.3.7	Local network comparisons												
			b. Evaluate variation with distance using dense regional networks	b. Preliminary assessment & databases.		X			X	b. Analysis of performance for discrimination as a function of distance.		X			X
	S4.4		Network performance												
			d. Evaluate new algorithms and form guidelines for modeling the network's discrimination performance	d. Interim report on network discrimination performance.				X		d. Final assessments of network discrimination performance.				X	
S5.			Develop physical basis for regional propagation and event location	Task S5 will develop an understanding of the physical properties of both the regions under consideration and the recording network that control the accuracy of the location and depth estimation efforts.											
	S5.1		Code development												
			a. Test software	a. Reports on experience and consultations on problems encountered	X					a. Reports on experience and consultations on problems encountered	X				
			b. Develop and maintain codes for wave propagation	b. State-of-the-art, efficient codes to model regional wave propagation		X				b. State-of-the-art, efficient codes		X			
	S5.2		Analyze regional wave propagation characteristics												
		S5.2.1	Amplitude and arrival time characteristics.												
			a. Examine attenuation properties.							a. Preliminary report on attenuation properties.	X				

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
			b. Examine attenuation properties.							b. Preliminary report on attenuation properties		X			X
		S5.2.2	Ray tracing.												
			a. Use rays and known sources to determine structure in southern and central Asia							a. Preliminary report on 2-D structure	X				X
			b. Use rays and known sources to determine structure in Mid East/N. Africa.							b. Preliminary report on 2-D structure		X			X
		S5.2.3	Surface wave inversions.												
			a. Invert surface waves to determine gross structure in southern and central Asia							a. Preliminary report on gross structure.	X				X
			b. Invert surface waves to determine gross structure in Mid East/N. Africa							b. Preliminary report on gross structure		X			X
		S5.2.4	Body wave inversions.												
			b. Invert body waves to determine fine structure in Mid East/N. Africa							b. Status report on feasibility of study; preliminary results		X			X
		S5.2.5	Tomography.												
	S5.3		Waveform synthesis to validate models												
			a. Develop and utilize wave propagation models for southern and central Asia	a. Current propagation models for southern and central Asia	X					a. One- and two-dimensional regional wave propagation models for southern and central Asia	X				
			b. Develop and utilize wave propagation models for the Mid East/N. Africa	b. Current propagation models for the Mid East/N. Africa		X				b. One- and two-dimensional regional wave propagation models for Mid East/N. Africa		X			
	S5.4		Assess implications for receiver array design and processing techniques.												
S6.			Develop physical basis for discrimination and characterize the different event types	Task S6 will develop an understanding of the physics controlling the performance of existing event discrimination procedures in the regions under consideration.											
	S6.1		Code Development												
			a. Test software	a. Reports on experience and consultations on problems encountered	X					a. Reports on experience and consultations on problems encountered	X				
			b. Develop and maintain codes for modeling source region phenomenology	b. State-of-the-art, efficient codes		X				b. State-of-the-art, efficient codes		X			
	S6.2		Characterize properties of various event types												
		S6.2.1	Nuclear explosions												
			a. Model nuclear explosions using non-linear physics codes	a. Controlling parameters identified	X					a. Report on range of controlling parameters	X				
			b. Model nuclear explosion data using system analysis techniques	b. Source parameters identified		X				b. Report on source parameters		X			
		S6.2.2	Earthquakes												
			a. Model earthquake data obtained from the first deployment of S7.2.4	a. Source parameters for shallow earthquakes	X				X	a. Joint report on empirical source parameters for shallow earthquakes	X				

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
			b. Model earthquake data obtained from the second deployment of S7.2.4	b. Source parameters for shallow earthquakes		X			X	b. Joint report on empirical source parameters for shallow earthquakes		X			
		S6.2.3	Industrial explosions (mining and construction blasts)												
			a. Model explosion data obtained from the second deployment of S7.2.2	a. Source parameters for near surface mine blasts	X					a. Joint report on empirical source parameters for shallow earthquakes	X				
			b. Model explosion data obtained from the first deployment of S7.2.2	b. Source parameters for near source mine blasts		X				b. Joint report on empirical source parameters for shallow earthquakes		X			
		S6.2.4	Induced seismicity (rockbursts, oil field subsidence, etc.)												
			b. Model induced seismicity data obtained from the deployment of S7.2.3	b. Source parameters for earthquakes induced by mining and other activities		X				b. Report on source parameters for earthquakes induced by mining and other activities		X			
		S6.2.5	Model discriminants using the source information gained in S6.2.1 – S6.2.4												
			a. Apply results to modeling southern and central Asia data	a. Qualitative assessment of models and determination of outlier events for southern and central Asia	X										
			b. Apply results to modeling Mid East/N. Africa data	b. Qualitative assessment of models and determination of outlier events for Mid East/N. Africa		X									
	S6.3		Study special events (e.g. outliers, explosions, earthquakes, rock bursts).												
			a. Identify and explain outliers from discrimination studies in southern and central Asia, et al	a. Summary of the outlier population to be used in assessment	X				X	a. Physical description of possible source processes for discrimination outliers in southern and central Asia	X				X
			b. Identify and explain outliers from discrimination studies in Mid East/N. Africa, et al	b. Summary of the outlier population to be used in assessment		X			X	b. Physical description of possible source processes for discrimination outliers in Mid East/N. Africa		X			X
			c. Provide statistical guidance for studies	c. Input to reports on special events			X								
	S6.4		Determine effects of regional propagation on discrimination.												
			a. Determine propagation effects on southern and central Asia discrimination	a. Preliminary wave propagation & source models for testing.	X				X	a. Assessment of propagation effects on discrimination in southern and central Asia.	X				
			b. Determine propagation effects on Mid East/N. Africa discrimination	b. Preliminary wave propagation & source models for testing		X			X	b. Assessment of propagation effects on discrimination in Mid East/N. Africa		X			
	S6.5		Perform evasion studies.												
			a. Model evasion potential in southern and central Asia	a. Preliminary report on evasion potential for southern and central Asia	X					a. Quantified evasion potential for southern and central Asia including locations of possible evasion sites	X				
			b. Model evasion potential in Mid East/N. Africa and evasion involving chemical explosions and rockbursts	b. Preliminary report on evasion potential in the Mid East/N. Africa		X			X	b. Quantified evasion potential in the Mid East/N. Africa including locations of possible evasion sites		X			

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
S7.			Perform field studies	Task S7 will design and execute experiments that satisfy requirements of both the location (S5) and identification (S6) tasks.											
	S7.1		Active experiments for calibration and phenomenology.												
		S7.1.1	Design controlled experiments.												
			a. Plan small conventional explosions and close-in & local measurements to address source geometry effects.	a. Plan small conventional explosions and close-in & local field measurements to address source geometry effects.	X				X	a. Analysis of cylindrical source studies. Quantification of implications on P/Sv wave generation.	X				
			b. Plan mid-size conventional explosions and local & regional measurements to address depth effects & decoupling.	b. Plan mid-size conventional explosions and local & regional field measurements to address depth effects & decoupling.		X			X	b. Analysis of data and description of effects of depth and blasting practices on regional seismic signals		X			
		S7.1.2	Deploy instrumentation on experiment												
			a. Emplace close-in and local seismic sensors to measure ground motion.	a. Data from close-in & local experiments.	X				X	a. Assessment of coupling/discrimination of US mining explosions & regional magnitude utilizing experimental data.	X				X
			b. Emplace local and regional seismic sensors to measure ground motion.	b. Data from local and regional experiments.		X				b. Analysis of data collected for depth & decoupling effects on magnitude and discrimination.		X			
		S7.1.3	Execute experiment												
			b. Execute experiment and coordinate activities among contractors, Laboratories and others	b. Oversight of safe, effective detonation of explosive and collection of local and regional measurements		X			X	b. Report on the experiment and assessment of the value of a sequel		X			
			d. Provide fuzing and firing, system design, safety & instrumentation support	d. Fuzing & firing system design. Safety analysis report				X		d. Instrumentation report				X	
	S7.2		Passive experiments for calibration and phenomenology												
		S7.2.1	Design measurements for industrial explosions of opportunity.												
			a. Plan close-in & local measurements at mines with representative blasting practices.	a. Plan for close-in & local field measurements of conventional explosions & rockbursts.	X					a. Plan for close-in & local field measurements of conventional explosions.	X				
			b. Plan local & regional measurements at mines with representative blasting practices.	b. Plan for field measurements of conventional explosions & rockbursts.		X				b. Plan for local & regional field measurements of conventional explosions.		X			
			c. Plan data collection/processing for multiple targets of opportunity in Washington state.	c. Plan for field measurements of conventional explosions.			X			c. Plan for field measurements of conventional explosions			X		
		S7.2.2	Deploy instrumentation on experiments; collect data on routine explosions.												
			a. Local data on large mine blasts	a. Close-in & local data on large mine blasts.	X					a. Local data on large mine blasts	X				

Table A1: Seismic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
			b. Regional data on large mine blasts	b. Regional data on large mine blasts		X				b. Regional data on large mine blasts		X			
			c. Collect local/regional data on multiple historic and current explosions of opportunity in Washington State	c. Database of local and regional explosion data			X			c. Database of local and regional explosion data			X		
		S7.2.3	Direct comparison of explosion and earthquakes from deep mines												
			b. Deploy seismic network in the vicinity of deep mines to record both explosions and induced seismicity	b. Data for earthquakes and explosions in the same geologic formation		X				b. Data for earthquakes and explosions in the same geologic formation		X			
			c. Collect local/regional data on historic and current earthquakes in Washington State	c. Database of local and regional earhquake data			X			c. Database of local and regional earhquake data			X		
		S7.2.4	Aftershock studies on shallow earthquakes												
			a. Joint laboratory effort to record local and regional data from shallow earthquakes	a. Data from shallow earthquakes	X					a. Data from shallow earthquakes	X				
			b. Joint laboratory effort to record local and regional data from shallow earthquakes	b. Data from shallow earthquakes		X				b. Data from shallow earthquakes		X			
S8			Integrate results	Task S8 will combine the results from the two regionalization studies with the phenomenology studies to provide algorithms for designing the monitoring systems in regions in which we have little experience											
	S8.1.		Compare DPIEA, location, propagation, and discrimination results from the regions	Documentation of workshop findings											
			Joint Laboratory and Phillips Laboratory effort/workshop to compare results from different regions	a. & b. Workshop/proceedings.	X	X									
	S8.2		Assess monitoring challenges posed by mining activities and shallow earthquakes												
			Joint Laboratory and Phillips Laboratory effort/workshop to compare results from different regions	a. & b. Workshop/proceedings.	X	X									

2. RADIONUCLIDE MONITORING RESEARCH

Goal: The radionuclide monitoring research element's goal is to develop and demonstrate real-time (or near real-time) measurement capabilities for detecting noble gas and particulate fission products that may be released from subsurface detonations in the earth or the ocean or released directly to the atmosphere from surface or near-surface events. The technical requirements for real-time analysis are a collection/analysis time ranging from 24-72 hours for the particulate sampler and 6 hours for the xenon sampler. The noble gas radionuclides, including ^{133}Xe (5-day half-life) and ^{135}Xe (9-hour half-life) are most likely to be promptly vented, and their unique ratio could permit both confirmation of the nuclear detonation and its time of occurrence. Because of the short life of ^{135}Xe, it is essential that it be collected and measured on a real-time basis, since its transport to a remote location would result in unacceptable decay losses.

The objective of this R&D element includes the development of collection and analysis systems that will permit real-time collection and analysis of radioactive gases and particulates to provide the sensitivities needed to meet USG monitoring goals.

Products: The primary products of this element will be rugged, low-maintenance systems, including hardware and software for field operations capable of automatically collecting radioactive particulates and gases from the atmosphere and measuring the concentrations of each specific radionuclide by coincidence gamma-ray spectrometry; retaining the samples for future reference where applicable; and transmitting absolute concentration and spectral information to the National and the International Data Centers. The feasibility for conducting the key elements of this task has been demonstrated in the laboratory. However, the actual operation of such real-time analysis systems has yet to be demonstrated. The products of greatest importance in this task may be the extremely sensitive counting systems that will improve measurement sensitivity for the noble gas and particulate radionuclides by as much as 100-fold over conventional radioassay techniques. These systems could permit worldwide or regional monitoring of specified releases with fewer monitoring stations.

Approach: The approach for developing radionuclide monitoring systems is to acquire real-time or near real-time measurements so that the natural variations in the background are understood and can be accounted for. The design and operation of the counting systems will be based on these considerations within the limitations of space, weight, and power. The monitoring effectiveness for airborne "signature" particulates and gaseous radionuclides will depend on several factors, including the distribution of the monitoring sites in the regions of interest; the background of the signature radionuclides, if any, at these sites; the volume of air from which the signature radionuclides are extracted; the rate of extraction; the counting efficiency of the detector system; the delay time between sample collection and analysis, if any; and the counter backgrounds.

The tasks to be carried out in this element involve design, development, testing, and optimization of laboratory prototype instruments with user organizations as indicated in tasks R1.7 and R2.7.

Task Overview:

Task R1. Real-Time Noble Gas Radionuclide Measurement Technology

The goal of this task is to develop a near real-time (6- or 8-hours-old samples) analyzer that automatically and continuously separates Xenon from the atmosphere, measures concentrations of the ^{133}Xe and ^{135}Xe, and reports these concentrations to the National and International Data Centers. These measurements are to be made at levels specified by the United States Government (USG). This will represent a new technology with specific applications to CTB monitoring and will emphasize high detection capability so as to minimize the number of monitoring stations required in a given region and on a worldwide scale.

Task R2. Real-Time Particulate Radionuclide Measurement Technology.

The goal of this task is to develop a real-time analyzer that automatically and continuously separates particulate material from the atmosphere, measures the concentrations of airborne radionuclides with particular emphasis on short-lived fission products, and reports these concentrations to the National and International Data Centers. These measurements are to be made at levels specified by the USG. This will represent a new technology with specific applications to CTB monitoring. It will emphasize high detection sensitivity, which is accomplished by beta-gamma, and gamma-gamma coincidence counting techniques, so as to minimize the required number of monitoring stations within a specific region and on a worldwide scale. The practicality of these systems for maintenance-free operations over periods of months will be compared with single gamma-ray spectrometry systems.

Task Breakdown:

The Task Breakdown for Radionuclide Monitoring Research is shown in Table A2.

Table A2: Radionuclide Atmospheric Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
R1.			Develop real-time noble gas radionuclide measurement technology	Task R1 will develop instrumentation for the automatic, real-time analysis of xenon radionuclides.											
	R1.1		c. Construct an initial laboratory prototype unit	c. Design drawings of a laboratory prototype unit			X								
	R1.2		Test an initial laboratory prototype unit												
		R1.2.1	c. Conduct parametric studies of xenon radionuclide collection/release	c. Performance document			X								
		R1.2.2	c. Acquire/test a beta-gamma xenon radionuclide counting system	c. Technical description			X								
	R1.3		c. Document the performance of the laboratory prototype	c. Performance document			X								
	R1.4		c. Design a rugged field prototype	c. System design			X								
	R1.5		c. Prepare the engineering drawings for and construct a rugged field prototype	c. Drawings and rugged field unit			X								
	R1.6		c. Test a field prototype and optimize in coordination with user organizations							c. Field prototype and field tests			X		
	R1.7		c. Establish natural background, assist installation and test at potential monitoring sites							c. Report on field performance			X		
R2.			Develop real-time radionuclide measurement technology	Task R2 will develop instrumentation for the automatic, real-time analysis of short-lived particulate fission products.											
	R2.1		c. Construct initial laboratory prototype	c. Laboratory prototype unit			X								
	R2.2		Test initial laboratory prototype												
		R2.2.1	c. Conduct parametric studies of collection/counting methodologies	c. Performance description			X								
		R2.2.2	c. Acquire and test beta-gamma-gamma coincidence counting systems	c. Instrument design and performance description			X								
	R2.3		c. Document Laboratory instrument performance	c. Documentation describing instrument design and performance			X								
	R2.4		c. Design rugged field prototype	c. Preliminary instrument design			X								
	R2.5		c. Prepare engineering drawings and construct rugged field prototype	c. Engineering drawings and field instrument			X								
	R2.6		c. Test field prototype and optimize it based on user input	c. Report on installations and operational results						c. Field prototype and field test			X		
	R2.7		c. Establish natural background, assist installation and test at potential monitoring sites							c. Report on field performance			X		

3. HYDROACOUSTIC MONITORING RESEARCH

Goal: The hydroacoustic monitoring research element's goal is to develop techniques, specifications, and (possibly) prototype hardware for a hydroacoustic system that detects, locates, and identifies nuclear detonations in, on, or above the oceans at performance levels that meet the US national requirements.

Products: This element will characterize the hydroacoustic signature of oceanic nuclear tests and the properties of acoustic propagation in the oceans that affect observations of explosions. In addition, it will develop, as needed, hardware and software to detect, locate, and identify explosions at sea. The basic physics of acoustic coupling between low-atmospheric and shallow bursts and the ocean sound (SOFAR) channel will be characterized theoretically and, if possible, by comparisons with historic data. The coordinated use of satellite, atmospheric acoustic, seismic, and debris sampling assets with hydroacoustic assets will be documented. A census of available hydroacoustic assets will provide a basis for an informed decision about whether to proceed to development of assets for CTB monitoring. The task will develop options (e.g., hydrophone arrays suspended from floating or moored buoys or fixed arrays cabled to shore), specifications and, if required, prototypes of new systems.

Approach: This element has three major components: (1) a numerical modeling effort to determine nuclear test signatures, estimate worldwide hydroacoustic coverage, and examine interactions with other technologies; (2) an empirical effort to verify the calculations, and (3) an engineering effort to specify and, if necessary, prototype a low-cost hydroacoustic system. These three components are described below in more detail.

1. DOE proposes to assemble the necessary modeling capability to characterize the generation and propagation of explosion-induced hydroacoustic waves in the world's oceans. DOE proposes to calculate estimates of the long-range nuclear signature and of propagation loss in areas of interest. The calculations will be conducted by linking existing codes for the nuclear source and strong shock regions (DOE nuclear device software) with weak shock propagation models (Navy nonlinear acoustics code) and long-range linear acoustic and elastic propagation models (using finite difference, normal mode, reflectivity, and parabolic options). These combined codes will be used to estimate location accuracy for regions of interest (travel time variability) and investigate discriminant performance (channel stability, multipath effects). DOE plans, in addition, to study the coupling of near-surface and deep explosion energy to seismic paths and the combined use of hydroacoustic and seismic assets for event discrimination.

2. DOE proposes an empirical effort to validate the propagation codes by comparing the results of calculations with recordings of explosions of opportunity and historical data. DOE may use the pattern of observed/ missed T phases from undersea earthquakes and other sources of opportunity to validate computer codes.

3. DOE plans to specify the desired hydroacoustic system characteristics and, if warranted, proceed to prototype development. DOE will evaluate vertical hydrophone arrays suspended beneath free-drifting and moored buoys, bottom-mounted hydrophone arrays cabled to shore, and other configurations for possible modification for the nuclear test surveillance task. DOE may select an existing system, perform engineering modifications, test the prototype, and develop a deployment plan for the numbers and locations of sensors needed to complete coverage.

Task Overview:

Task O1. Acquire Oceanographic Data and Network Propagation Modeling Software

This task acquires and links the oceanographic data and propagation models (strong shock, weak shock, and linear) necessary for assessing and predicting the performance of hydroacoustic sensor networks. The US Navy and NOAA have already assembled most of the oceanographic data and developed appropriate propagation codes for modeling network performance (DOE has developed the strong shock codes). Acoustic network models are also available from the ATOC consortium (Acoustic Thermometry of the Ocean's Climate). Academic and foreign sources may have data that will fill gaps in oceanographic databases in remote regions. All of these sources will be evaluated and integrated to permit modeling of the nuclear test monitoring problem. In addition, this task will obtain such historic hydroacoustic observations of nuclear tests at sea as can be found.

Task O2. Hydroacoustic Signature Characterization

This task uses the capabilities developed in Task O1 to predict the hydroacoustic signature of nuclear detonations above and below the water surface. It attempts to model the historic observations of oceanic nuclear tests and of other explosive tests of opportunity. The task characterizes acoustic propagation in areas of interest, such as regions with high attenuation or having potential to shadow sensors in a hydroacoustic network. It recommends sensor locations and estimates system performance.

Task O3. Determine Hydroacoustic Technologies Required for Oceanic CTBT Monitoring

As warranted, the task will examine low-cost assets for CTBT monitoring: single hydrophones or hydrophone arrays suspended beneath drifting or moored buoy systems and bottom-mounted hydrophone arrays cabled to shore or telemetered to buoyed transmitters. The task generates specifications for platforms and, if necessary, constructs and tests a prototype. The task will consider communication and processing bandwidth issues, power and logistical constraints, and installation vs. maintenance cost tradeoffs.

Task O4. Signal Processing Methods for Detection, Location, and Discrimination of Oceanic Tests

This task exploits the unique explosion signature and the properties of SOFAR propagation to develop detection, location, and identification algorithms for events conducted both above and below the water surface. It includes automated detection of the bubble pulse and an examination of the effects of channel uncertainty and reverberation on discrimination at long ranges. This task will adapt existing transient location methods and provide software for detection and location to responsible agencies. It develops joint hydroacoustic and seismic discriminants and catalogues the potential sources of false alarms, such as subsea earthquakes and volcanoes, and conventional chemical explosions at sea.

Task Breakdown:

The Task Breakdown for Hydroacoustic Monitoring Research is shown in Table A3.

Table A3: Hydroacoustic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
O1.			Acquire oceanographic data & network propagation software	Task O1 will develop the oceanographic data and propagation models for networks of hydroacoustic sensors that are necessary for performance assessments.											
	O1.1		Augment oceanographic data from US Navy and NOAA with data from other sources.												
			b. Acquire southern Hemisphere and other oceanographic data as needed.	b. Comprehensive bathymetry, sound speed and bottom loss data necessary for network performance prediction		X			X						
	O1.2		Adapt existing long-range propagation models (software) to assess network performance												
			b. Link parabolic, ray and normal mode codes to oceanographic database & strong/weak shock codes	b. Complete propagation simulation capability to predict attenuation and path variability worldwide.		X			X						
	O1.3		Acquire Historic Explosion Data												
			a. Acquire hydroacoustic and seismic observations of oceanic nuclear tests	a. Database of fully and partially coupled nuclear explosions to validate theoretical predictions	X				X						
O2.			Hydroacoustic signature characterization.	Task O2 will provide a detailed examination of the nuclear source, both theoretically and empirically.											
	O2.1		Review existing hydroacoustic signature information.												
	O2.2		Determine signature and source level of oceanic nuclear detonations and network detection requirements												
		O2.2.1	Model coupled and evasively tested nuclear sources including SOFAR coupling												
			a. Analyze historic observations through simulation	a. Ground truth of hydroacoustic signal character and strength, source coupling.	X					a. Seismic observations of coupled and decoupled events: seismic decoupling factor computed.	X				
			b. Simulate strong shock coupling to long-range SOFAR and seismic paths; explosions in/above water surface	b. Theoretical estimate of long-range acoustic signature and strength		X			X	b. Theoretical estimate of long-range seismic signature and strength: seismic decoupling estimated.		X			
		O2.2.2	Perform empirical study of decoupling through scaled field experiments												
	O2.3		Determine hydroacoustic coverage in remote regions.	b. Map of acoustic coverage.					X	b. Map of acoustic coverage.		X			X
O3.			Determine hydroacoustic network required for complete coverage for fully coupled and evasive tests	Task O3 will generate specifications for the modified systems, construct prototypes if required, and consider the communication and processing bandwidth issues.											
	O3.1		Examine relevant buoy and cable technology.												

Table A3: Hydroacoustic Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
	O3.2		Develop prototype asset from existing technology and evaluate												
		O3.2.1	Develop technical specifications for the platform, the sensors, the signal processing and communications.												
			b. Recommend platform (buoy or other), determine sensor and signal processing requirements	b. Recommend platform, technical specifications for sensors, and on-board processor.		X			X						
			d. Determine communication and GPS localization requirements.	d. Choice of satellite communication link and GPS receiver											
		O3.2.2	Develop prototype asset from existing technology and evaluate												
			b. Develop platform, sensor, onboard processor software							b. Prototype hardware delivered. Field test of mechanical and acoustic characteristics, signal processing.		X			X
			d. Develop communication and GPS location systems							d. Prototype communication system delivered. Field test of communication links.				X	X
O4.			Develop detection, location and discrimination algorithms for hydroacoustic oceanic monitoring	Task O4 will exploit the unique explosion signature and the properties of waveguide propagation to develop enhanced detection, location, and discrimination algorithms.											
	O4.1		Develop algorithms (detection, location and discrimination) for hydroacoustic nuclear test monitoring												
			b. Examine triangulation and modal ranging methods for oceanic nuclear explosions.							b. Location software package delivered to responsible USG hydroacoustic monitoring agencies.		X			X
	O4.2		Automate detection of bubble pulse signature (fully-coupled explosion)												
			b. Develop automatic detection software. Validate with data from existing assets.	b. Detection software delivered to agencies responsible for hydroacoustic monitoring.		X									
	O4.3		Develop joint discriminants using seismic and hydroacoustic observations.												
			b. Develop discriminants empirically, verify physics with propagation codes, test multipath sensitivity							b. Discriminant documentation and software delivered to USG hydroacoustic monitoring agencies.		X			X

4. INFRASOUND MONITORING RESEARCH

Goal: The goal of this task is to resolve research issues related to detection of the low-frequency acoustic signal from atmospheric, shallow buried, or moderately shielded explosions. These signals are to be detected by a global network of arrays of microbarographs and infrasound microphones that are assumed to be designed for detection of kiloton-type explosions out to 3000 to 5000 km. Using available propagation information, global detection capability will be estimated as a function of source size and location, number of stations, false alarm rate, and background level. These results will help determine the operational characteristics of an acoustic monitoring system applicable to both international monitoring and space-based monitoring systems.

Products: The products of this research area will be a prototype monitoring station design; detection estimates as functions of source size and location, number of stations, false alarm rate, and background noise level; and performance estimates for evasive tests. A specific concept for acoustic signal detection will be evaluated using an array of seismic sensors.

Approach: Using data from USG acoustic arrays deployed for atmospheric nuclear explosion detection and more recent data from higher frequency infrasound arrays, a system design will be proposed for monitoring for explosions underground, near the earth's surface, or in the atmosphere. The low yields of interest to a CTBT are expected to have signal energy at higher frequency than previous tests. Recent DOE-supported research in infrasound has allowed propagation issues to be studied, modeling capability to be developed, and measurements to be made for large surface explosions. The detection estimates will be based on past and current measured data on explosions, current understanding of propagation, and waveform modeling.

Task Overview:

Task A1: Evaluation of Non-DOE Proposal

This task provides an evaluation of a non-DOE proposal for using deeply buried seismometers to detect low-frequency acoustic signals. DOE will serve as a liaison as the proposed work is performed in field tests, if appropriate.

Task A2: Generate Detection Estimates

Based on current infrasound experience in propagation physics, explosion measurements, and global wind data, generate detection estimates (or detection contour maps) as a function of source size, number of array sites, and background level.

Task A3: Evaluate Performance

Evaluate performance of acoustic techniques for the detection of evasive tests, i.e., tests that involve shallow burial and/or moderate amounts of shielding. Examine new beam-forming techniques for acoustic arrays in low signal-to-noise environments.

Task Breakdown:

The Task Breakdown for the Infrasound Monitoring Research Area is shown in Table A4.

Table A4: Infrasound Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
A1.			Evaluation of seismic/acoustic technology	Task A1 will evaluate the utility of deeply buried seismometers for detecting low frequency acoustic signals											
			a. Assist in assessment of proposed seismic/acoustic technology	a. Report on the use of seismometers to detect low frequency acoustic signals	X										
A2.			Generate detection estimates	Task A2 will generate detection estimates as a function of source size, number of array sites and background level											
			a. Estimate detection capability	a. Report and maps describing detection capability for various parameters	X										
A3.			Evaluate performance	Task A3 will estimate acoustic monitoring performance in the presence of evasion											
			a. Estimate performance in evasion context	a. Report on acoustic techniques for detecting evasive tests	X										

5. ON-SITE INSPECTION RESEARCH

Goal: The on-site inspection (OSI) research element's goal is to develop forensic technologies to be deployed on-site near the source region to identify a localized energy release whose remotely observed characteristics are similar to those expected from nuclear explosions. This effort includes both pre- and post-detonation observation technologies for confidence-building-associated measures and OSIs, respectively.

Products: The OSI element will produce algorithms and specifications for an integrated system to meet the CTBT requirements. The element is intended to provide the basis for production of a standard version of equipment to be used by the international organization.

Approach: On-site inspections could be appropriate in certain monitored testing environments. The retrieval of a radioactive fission product is definitive evidence of a test. Since an evasive underground test has the best chance of preventing the detection of these diagnostic radionuclides, OSI efforts are focused on this environment. An OSI system will consist of a combination of monitoring technologies that include but are not necessarily limited to systems to detect aftershocks and identify their triggering event, soil gases, and the residual subsurface effects of an explosion. In addition, the task encompasses techniques for a rapid large-area search to determine likely targets for detailed inspection. These technologies include but are not limited to analysis of imagery from low-flying aircraft and airborne geophysical techniques. One of the first deliverables will be an overview that will summarize what is known and identify knowledge gaps in the OSI area.

Relevant phenomena (for example, aftershock discrimination, gas sampling, and ground surface alteration) induced by natural and man-made sources will be considered, and associated diagnostic signatures will be identified. Existing data and research results will be supplemented with existing computer models to define the range of variability of these signatures and their utility as diagnostics. The program task will identify tradeoffs between the utility of the information obtained by various methods and the effort required to acquire it (e.g., development cost, fielding difficulty, vulnerability to evasion and intrusiveness). Input from policy experts will be sought as these tradeoffs are evaluated. To the extent possible, the system recommended will be based on available technology, with additional development requirements determined from conditions unique to the CTBT context.

Task Overview:

Task I1. Refine the Understanding of the Phenomenology

This task will focus on refining the description of the aftershock signatures expected from localized high-energy-release events, including evasively tested nuclear explosions, earthquakes, chemical explosions, and mine collapses. It will consider signatures that might be recorded at the zero-time of the event and those recorded after the event.

Task I2. Determine the Appropriate Instrumentation

This task will examine the ability of existing instrumentation to record the signatures identified in the previous task (see I1 above) and make recommendations of the performance criteria and equipment for OSIs. It will consider the contributions of individual measurements and explore the gains that can be obtained by combining measurements. Both data-acquisition and data-processing functions will be considered.

Task Breakdown:

The Task Breakdown for On-Site Inspection Research is shown in Table A5.

Table A5: On-Site Inspection Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
I1.			Refine the understanding of the phenomenology	Task I1 will use on-site data to describe shot time and post-shot explosion phenomenology and develop the means to discriminate evasive nuclear tests from other events.											
	I1.1		Discuss gaps between present capabilities and requirements												
	I1.2		Aftershocks												
		I1.2.1	Characterize aftershock types												
			a. Identify events and provide data to determine factors that affect aftershock distributions	a. Identification and processing of selected LANL aftershock data from NTS	X					a. Provide geological and emplacement data for characterization of NTS aftershocks	X				
			b. Examine LLNL aftershock data and characterize event types	b. Preliminary characterization of aftershock types		X				b. Report on source types found in LLNL data		X			
		I1.2.2	Develop discriminants												
			b. Develop discrimination algorithms that can be used with aftershock data	b. Preliminary aftershock discriminants developed		X				b. Report on aftershock discriminants		X			
		I1.2.3	Take data on events of opportunity to test discriminants												
			b. Collect aftershock data on events of opportunity (earthquake & chemical explosion)							b. Report on effectiveness of aftershock discriminants on actual data		X			
	I1.3		Radionuclides												
		I1.3.1	Model concentration, localization, and time constants under diverse conditions												
			a. Study available data and code capabilities and model cavity pressure driven flow	a. Report on status of data and previous comparisons of code results with data	X					a. Report on parameter study of effects of site permeability, cavity pressure, stemming, etc.	X				
			b. Study physical processes in and model measurements of barometric, pumping-assisted surface arrival of gas	b.Preliminary calibration of codes with experimental results		X				b. Report on capability to characterize gas transport in diverse environments		X			
		I1.3.2	Collect data on events of opportunity to validate models												
			b. Tracer field experiments on events of opportunity. Analyze results							b. Report on analysis of field data		X			
	I1.4		Disturbed ground												
		I1.4.1	Work with aircraft overhead imagery data to study changes in the spall zone												
			b. Develop methods to detect disturbed ground using OH imagery	b. Report on the use of imagery to detect disturbed ground and plant stress		X									
		I1.4.2	Compare contributions of satellites and overflight												
			b. Compare resolution of satellite and low-fly-over data							b. Report describing when flyovers are needed to supplement satellite observations		X			
		I1.4.3	Collect overhead imagery data on events of opportunity												
			b. Collect low level flyover data and test detection algorithms on them							b. Report on data collected from field survey and results of algorithm tests		X			X

Table A5: On-Site Inspection Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
	I1.5		Residual underground effects												
	I1.6		Visual inspection. Determine observables for visual inspection												
			a. Determine observables and procedures for visual inspections of suspect sites	a. Annotated list of observables and evaluation of procedures for visual inspections	X					a. Guidelines for visual inspection	X				
	I1.7		EM monitoring												
		I1.7.1	Develop theoretical understanding of EMP												
			a. Understand mechanisms for EMP generation at all frequencies for conventional and nuclear explosions	a. Initial theoretical framework developed	X					a. Requirements for EMP monitoring and analysis of system capabilities	X				
		I1.7.2	Carry out measurements on events of opportunity												
			b. Make EM measurements on events of opportunity and analyze data	b. Report on field efforts and preliminary analysis of EM discrimination capability		X				b. Report on E-M discrimination value for event of opportunity		X			
	I1.8		Near field ground motion												
			a. Determine OSI potential of surface and free field ground motion measurements	a. Review of NTS experience and evaluation of technologies to counter evasion scenarios	X					a. Acquisition and analysis of data from events of opportunity and development of source discriminants	X				
			b. Take data on events of opportunity							b. Provide data for interlaboratory analysis		X			
I2.			Determine appropriate instrumentation	Task I2 will examine the ability of existing instrumentation to record the signatures identified in the previous task. It will consider the contributions of individual measurements and explore the gains that can be obtained by combining measurements											
	I2.1		Identify equipment for recording signatures (seismic, gas sampling, etc.)												
			a. Provide input on overall equipment requirements	b. Provide input on preliminary identification of equipment requirements	X					b. Review final equipment requirements and performance criteria	X				
			b. Develop overall equipment requirements	b. Preliminary identification of equipment requirements		X				b. Final equipment requirements and performance criteria		X			
			d. Determine appropriate seismic monitoring equipment and evaluate commercially available equipment	d. List of required equipment. Evaluation reports of commercial equipment.						d. Input to final report					
	I2.2		Develop preliminary requirements document												
	I2.3		Select and procure equipment												
	I2.4		Add required modifications to commercial equipment												
	I2.5		Field test components and begin developing operating procedures												
	I2.6		Carry out vulnerability assessment. Consider both hardware and procedures												

6. SPACE-BASED MONITORING RESEARCH

Goal: The goal of space-based monitoring research is to develop sensors to detect, locate, identify, and characterize nuclear explosions in the atmosphere and in space. The genesis of this program was the requirement to verify the Limited Test Ban Treaty (LTBT) and later the Treaty on the Nonproliferation of Nuclear Weapons (NPT). In the future, this research could contribute key elements for verifying compliance with the CTBT and worldwide nonproliferation obligations.

Products: The space-based monitoring program element will supply nuclear explosion monitoring sensors for spaceborne deployment aboard the Defense Support Program (DSP), the Global Positioning System (GPS), and possibly future high-Earth-orbit platforms. Sensors are provided for monitoring the atmosphere, the upper atmosphere, and space.

Approach: The Defense Support Program performs a primary mission of early warning of missile attack and a secondary mission of treaty verification. Early attack warning is provided by using large infrared sensors to detect and track ballistic missiles in flight. Detection, location, identification, and characterization of nuclear detonations (NUDETs) is provided by radiation and optical sensors carried by the DSP satellites. The DSP system is based on a constellation of satellites deployed in synchronous, equatorial, geostationary orbits. The satellites are stabilized in positions and orientations that permit constant surveillance of the Earth (except the polar regions) and surrounding space. Unfortunately for the treaty verification mission, the DSP system is scheduled to be phased out, starting approximately in the year 2007.

The Global Positioning System is a constellation of satellites whose primary mission is to provide accurate navigational data and whose secondary mission is treaty verification. Now that it is fully deployed, GPS consists of 24 crosslinked, Earth-facing, half-synchronous-altitude, 55-degree-inclination satellites, at least 4 of which are above the horizon with respect to any point on the Earth at all times. Navigational signals from the GPS satellites provide accurate, continuous, three-dimensional radio-navigational positioning information for civilian and military applications worldwide. Due to spacecraft weight and power constraints, GPS NUDET capabilities have been considerably more limited than those of DSP, although they are worldwide and continuous. It is planned to direct future R&D principally toward enhancements to these GPS capabilities.

Task Overview:

Task N1. Develop Space-Based Atmospheric Monitoring Technology

Task N1.1 Optical

The optical sensor (BDY) currently flown on GPS is one variant of optical sensor designs used on many satellites. It uses a two- or three-segment photodiode sensor with a non-imaging optical system. The whole Earth's background is incident on each segment in these older instruments. In the usual mode, all segments are active, and the output from the segments is added together in the electronics. When an event occurs, the signal is amplified by the electronics and the information is provided to the ground for analysis.

The Enhanced Bhangmeter (BDYE) is being developed as a major upgrade to BDY. Candidate design concepts for BDYE are now being considered, and various candidate parts are under development.

The present BDYE concepts involve using a larger array of photodiode elements with an imaging optical system. Each element will observe only a small part of the Earth's surface. Each element in this array will have its own amplifier electronics, and, since it has only a small part of the Earth as background, the noise level on each of the segments is lower. As a result, the signal-to-noise ratio is improved and lower level events can be discriminated by intelligent processing within the BDYE. This increased sensitivity will require an increase in dynamic range. Otherwise, the system will saturate on larger events, especially for events occurring at higher altitudes.

Our goal in the design of this next-generation instrument is to effect an order of magnitude improvement in minimum detectable signal levels without the need for significant increase in physical size. The increased sensitivity achievable with such an instrument will improve identification and characterization of otherwise weak or obscured NUDET signals.

Task N1.2 Electromagnetic Pulse (EMP)

The Fast On-orbit Recording of Transient Events (FORTÉ) project is directed toward the development and flight test of an advanced radio frequency (RF) detection and characterization system aboard a small spacecraft. Emphasis is on proliferation detection technology for discovery of covert nuclear weapons tests. RF and optical signals will be exploited simultaneously. Major developments in RF and optical capabilities will be pursued to increase detectability and improve false signal discrimination for GPS Block-II, allowing all-weather coverage, true dual phenomenology, and detection of low-technology explosions.

The FORTÉ experiment will demonstrate advanced electromagnetic pulse (EMP) detection methods in space. Optical sensors will augment the RF system in order to develop robust discrimination algorithms (principally against lightning) for reliable operation in a weak signal environment. Such methods are needed to improve our future capability to detect atmospheric nuclear explosions. Recognizing the dual utility, mission science data will be made available to researchers who are studying lightning and the ionosphere. The extensive database on the global distribution of lightning, as seen from a satellite platform, can be used in studying, for example, the correlation of global precipitation rates with lightning flash rates and location. It is also planned to combine these data with those from simultaneous ground-based measurements as part of lightning physics studies.

FORTÉ will also conduct ionospheric physics experiments. The effects of large-scale structures within the ionosphere (such as traveling ionospheric disturbances and horizontal gradients in the total electron content, or TEC) on the propagation of broad bandwidth signals will be studied. For example, using well-characterized broad bandwidth pulsed RF sources, the ionosphere will be probed during a FORTÉ pass to retrieve a tomographic description of the variation in TEC.

The FORTÉ payload consists of three instruments: an RF system, an optical system, and an "event classifier." The RF system incorporates three broad bandwidth RF receivers covering the frequency range 30–300 MHz, a polarization-selective antenna, and high-speed waveform digitizers. As part of the RF system, an Adaptive PreWhitening Filter processor module will continuously reduce the interference caused by narrow band noise sources such as commercial broadcast stations and communication transmitters. The optical system consists of a coarse imager (10-km x 10-km ground resolution) for lightning flash location (500 frames/sec) and a fast photodetector (50k samples/sec) for recording individual light curves. The event classifier, based on digital signal processing technology, will provide on-orbit characterization of impulsive RF events that have satisfied trigger criteria.

The complete FORTÉ project includes a small spacecraft and a satellite operations center at SNL, Albuquerque, New Mexico. The satellite will be nadir pointing and three-axis stabilized. Body-mounted solar cells will provide a daily averaged 55 W of power. The target orbit is 800 km altitude at 65° inclination. Baseline designs specify a minimum mission duration of one year, with the capability to operate for up to three years. Launch aboard a Pegasus vehicle is planned for November or December 1995.

Task N1.3 Infrasound

The Active Radio Interferometer for Explosion Surveillance (ARIES) subsystem is being designed by DOE to monitor NUDET phenomenology that is not exploited by existing NUDET sensors. It will serve as a global monitoring system to detect and locate nuclear and conventional explosions, particularly those that are conducted evasively (e.g., concealed, low-yield explosions). The system uses radio interferometry to detect the acoustic waves that are characteristically produced in the atmosphere when an explosion occurs. Such waves collisionally couple to the ionosphere to produce fluctuations in the electron density. These ionospheric perturbations can then be detected by measuring the relative phase shifts between quasi-parallel VHF signals propagating through the disturbed region of the ionosphere.

This program includes only an initial demonstrate of the ARIES system. However, a fully operational ARIES system to detect such waves would consist of ground-based VHF transmitters and satellite-based ARIES receivers. The VHF transmitters are arranged as an array of 8–10 transmitter pods, each pod consisting of 4–5 individual transmitters spaced about 10 km apart. Each transmitter within each pod transmits VHF CW signals (100–165 MHz, pending frequency allocation proposal review) up to a constellation of GPS-based ARIES receivers. The signals are received at the satellite via the existing W-sensor high-band antenna. These signals are then transmitted back down to the ground via the GVLS C-band downlink for processing and display. For global coverage, preliminary computer modeling efforts indicate that the pods should generally be positioned around the Earth in a $\pm 20°$ alternating fashion about the geomagnetic equator. Pods placed at existing GPS ground stations should be sufficient for global coverage. Additional or alternate sites might be located at various seismic stations, existing satellite ground stations, or military installations.

Task N1.4 Sensor Data Downlink

In addition to other treaty verification functions, the Global Verification and Location System's Nuclear Detonation Detection System (NDS) Augmentation Payload (NAP) will provide capability to enhance detection of nuclear testing in the Earth's atmosphere through implementation of a fast data downlink from the NDS-optical and electromagnetic pulse detection sensors. This will make it possible to bring down data that are not presently downlinked due to NDS crosslink capacity limitations.

Task N1.5 Code Upgrades

The optical emissions code upgrade task will (1) update and improve the numerical algorithms, (2) document the physics algorithms, and (3) provide user friendly versions of the two fireball simulation codes RADFLO and MODEL 3. Examples of improvements include modern hydrodynamics and flexible spectral binning. Existing versions utilize older programming styles and have had many modifications that are not well documented. The new documentation will consolidate the modifications made since the early 1970s. User friendly versions will be designed for UNIX-based computers.

The electromagnetic pulse-code upgrade task will advance the detection and discrimination of NUDET EMP to support the government's CTBT verification requirements. A variety of computer codes on fireball formation, EMP generation, RF propagation, RF detection, and analysis will be extended and augmented.

Task N1.6 GPS Operational System Development and Support

This task provides for the design and development of GPS satellite payloads for detecting and characterizing events within the Earth's atmosphere and in space. It includes new system designs and studies, component development/evaluation, payload/subsystem tester development, procurement of prototype and qualification hardware, flight system software development, CAE/CAD design activities, development of prototypes, evaluation of system performance, anomaly resolution, launch support, on-orbit analysis, and LAZAP and RZAP collections.

Task N2. Develop Space-Based Upper-Atmosphere and Space Monitoring Technology

Task N2.1 X-ray

Present GPS satellites carry either a Burst Detector X-ray (BDX) sensor or a Burst Detector Dosimeter (BDD) sensor. The function of the BDX instrument is to detect exoatmospheric nuclear detonations or detonations in the upper reaches of the atmosphere. The function of the BDD instrument is to monitor the natural or disturbed particle environment in order to properly interpret NDS mission data.

This task will design a new instrument that will combine both of these functions in one box and extend the X-ray energy-range capability in both directions. The merger of these functions will reduce the impact on the spacecraft private sector partner of integrating two separate boxes, either of which could be flown in the same slot on a given spacecraft. It will further reduce the impact of keeping configuration control for which box should be flown on a particular launch. The extended energy range X-ray sensors will provide increased sensitivity and spectral coverage to allow (a) detection of low-performance devices, such as entry-level weapons, and (2) detection of events deeper in the atmosphere.

Task N2.2 Gamma and Neutron

This task is developing a Space and Atmospheric Burst Reporting System (SABRS) proposed for deployment on future generations of the GPS satellites (or perhaps for deployment on some other platforms of opportunity). SABRS will provide a multiphenomenological system to detect, identify, characterize, and attribute NUDETs occurring in the atmospheric transition (30 km-100 km) and exoatmospheric (100 km and up) regions. It comprises detectors that measure the primary radiations from NUDETs in these regions. It also carries an environmental monitoring capability to provide (a) dosimetry for the satellite and (b) environmental conditions information for the SABRS radiation sensors.

SABRS could bring to GPS Block IIF a combined prompt and delayed gamma-ray detector (BPD), and a neutron detector (BDN). Delayed gammas and neutrons are unambiguous signatures of a NUDET, and their signatures contain certain critical nuclear weapon characterization information. Prompt gammas provide other critical nuclear weapon characterization information. The delayed gamma detector capability also includes a very energetic particle monitor, which is important for understanding the background environment.

Task N2.3 DSP Operational System Support

This task provides launch support and technical support for users of the nuclear detonation detection payloads carried aboard Defense Support Program (DSP) satellites. The work involves testing, data analysis, detector characterization, and interpretation of sensor outputs to meet mission requirements. Also included are prelaunch testing, hardware/software maintenance contracts for the Test Unit, maintenance of data links from remote sites, the collection, processing and archiving of selected test data, analysis of on-orbit data, anomaly resolution, and design assessments.

Task Breakdown:

The Task Breakdown for the Space-Based Monitoring Research is shown in Table A6.

Table A6: Space- Based Monitoring Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
N1.			Develop space-based atmospheric monitoring technologies	Task N1 will develop space-based optical, electromagnetic pulse, and infrasound atmospheric monitoring technologies; associated modeling codes and data down-links; and support the Global Positioning System's satellites											
	N1.1		Optical												
			d. Develop an imaging optical radiometer	d. Enhanced bhangmeter (BDYE)				X		d. BDYE				X	
	N1.2		Electromagnetic pulse (EMP)												
			a. Develop and flight test an advanced RF detection and characterization system aboard a small spacecraft	a. Fast on-orbit recording of transient events (FORTE)	X					a. FORTE	X				
			d. Develop an optical lightning locater system and an adaptive pre-whitening filter	d. Fast on-orbit recording of transient events (FORTE)				X		d. FORTE				X	
	N1.3		Infrasound												
			a. Develop a means of globally monitoring ionospheric disturbances created by infrasound from explosions	a. Demonstration of Active Radio Interferometer for Explosion Surveillance (ARIES)	X					a. Demonstration of ARIES.	X				
	N1.4		Sensor Data Downlink (NDS)												
			d. Develop a high-speed data downlink for optical and RF sensors on Global Positioning System (GPS) satellites	d. NDS augmentation payload (NAP)				X		d. NAP				X	
	N1.5		Code upgrades												
			a. Update and improve existing NUDET modeling codes	a. Optical and EMP codes	X					a. Optical codes	X				
	N1.6		Develop and support GPS operational system												
			a. Develop and support direct radiation sensors	a. Global Burst Detector (GBD) support	X					a. GBD support	X				
			c. Provide statistical analysis of flight data	c. GBD support			X			c. GBD support			X		
			d. Develop and support optical sensors and data processing systems	d. GBD support				X		d. GBD support				X	
N2.			Develop space-based upper-atmospheric and space monitoring technology	Task N2 will develop direct radiation sensor technologies and support the Defense Satellite Support Program											
	N2.1		X-ray												
			a. Combine existing sensors in a single box and extend their capabilities	a. Burst Detector X-ray/Dosimeter (BDX/BDD)	X					a. BDX/BDD	X				
	N2.2		Gamma and neutron												
			a. Develop new direct radiation sensors for GPS or other satellites	a. Space and Atmospheric Burst Reporting System (SABRS).	X					a. Space and Atmospheric Burst Reporting System (SABRS).	X				
	N2.3		DSP operational system support												
			a. Support existing direct radiation sensors.	a. Radiation Detection Capability support	X					a. Radiation Detection Capability support	X				
			d. Support existing optical sensors.	d. Radiation Detection Capability support				X		d. Radiation Detection Capability support				X	

7. AUTOMATED DATA PROCESSING RESEARCH

Goal: The goal of this task is to develop, demonstrate, and validate improvements to the existing and planned information system technologies that are necessary to provide the capability for highly automated, high-confidence processing of data in support of CTBT monitoring. These technologies will support integration of algorithms and knowledge.

Product: This task will produce prototype software and hardware technologies that are suitable for inclusion in an operational monitoring system. Near-term demonstration activities (e.g., GSETT-3) as well as mid- and long-term demonstrations of subsequent developments are also included. Development and documentation of system and data-quality requirements plus evaluation and assessment of performance will be important elements of each task.

Approach: Existing and emerging technologies will be investigated and enhanced as necessary to meet the larger data loads expected under the anticipated monitoring network. Existing algorithms for processing data will be examined in light of new computational techniques and/or computing hardware capabilities. New algorithms will be prototyped, developed, and validated for use in the monitoring system. Techniques for establishing and increasing confidence in the automated system will be explored as a method of reducing the amount of data reviewed by human analysts. Methods for increasing and validating system and data integrity will be evaluated and developed. In all cases, the thrust of this research will be to build upon the existing base of technologies and systems. Rather than repeat existing efforts, this task will be directed toward identifying gaps in the existing systems and then correcting the shortfalls or extending capabilities. All work will be done cooperatively with AFTAC, ARPA, and other members of the research community (including the private sector).

This work will be conducted in five tasks. Advanced Processing Technology will investigate advanced computing and signal processing methods for extracting information from data in an automated fashion. Computer-Human Interface Technology will emphasize techniques for improving the ability of the user to extract knowledge from the increasingly large volumes and diverse types of data. Information System Technology will work to improve capabilities for handling large volumes of data in a high-fidelity manner. Instrumentation Technology will focus on developing and demonstrating affordable, deployable seismic equipment in support of future station upgrades. Finally, the Management Support task will provide support for program planning and symposia review.

Task Overview:

Task D1. Develop Advanced Processing Technology

This task is primarily focused on improvements to the automated "engines" that extract information from raw data. It will develop and implement new algorithms, improve current methods using new computational techniques, and expand the capabilities of automated processing of data generated by monitoring activities.

Task D2. Develop Computer-Human Interface Technology

This task will emphasize techniques that allow analysts to extract knowledge from the increasingly large volumes and types of data available in the monitoring regime. It will explore next-generation techniques to improve the productivity of current tasks and expand the capabilities of the user.

Task D3. Develop Information System Technology

This task will focus on the information-handling and management techniques needed to process with high-fidelity the large volumes of data expected from the monitoring system. It will emphasize new methods for high-volume data management, system surety, and metrics for monitoring system performance.

Task D4. Develop Instrumentation Technology

This task will focus on technologies that will enable the production of the next generation of affordable, deployable, high-quality seismic equipment.

Task D5. Provide Management Support

This task will provide for Laboratory participation in program planning, program reviews, symposia, and interagency coordination as necessary.

Task Breakdown:

The Task Breakdown for the Automated Data Processing element is shown in Table A7.

Table A7: Automated Data Processing Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
D1.			Advanced Processing	Task D1 will put the data and products from other CTBT research tasks into forms that are accessible to researchers.											
	D1.1		Improve (capacity) association/location procedures												
		D1.1.1	Handle GSETT-3 volumes of data							.					
			b. Determine source depth using neural networks on spectrograms of multiple phases from regional seismograms							b. Improved depth determination method based on the properties of multiple phases		X			X
		D1.1.2	Long-term prototypes												
			b. Develop a neural network-based event detection system applied to multiple filters from low SNR events	b. Improved event detection algorithm for use on low SNR events		X			X	b. Documented software appropriate for inclusion in an operating system		X			
			d. Prototype new techniques for high - volume data association	d. Prototype of event detection software using waveform correlation & parallel processing techniques				X		d. Documented software and performance evaluation				X	X
	D1.2		Automate signal detection & discrimination												
		D1.2.1	Automate existing algorithms												
			c. Work with SNL to provide statistical input and uncertainty algorithms	c. Progress report on implementation of algorithm			X			c. Final report			X		
			d. Prototype automated solutions of currently non-automated algorithms in coordination with AFTAC & ARPA	d. Prototype of automated long period processing software				X		d. Demonstration of teleseismic/regional processing				X	
		D1.2.2	Develop prototypes of new ADP algorithms												
			b. Develop a discrimination algorithm using wavelet transforms and neural networks on the full waveform	b. Report on results of initial application to actual data						b. Report on performance of algorithm on data from sources and stations in various geographic regions		X			
			d. Validate research concepts with demonstration prototypes	d. Demonstration of environment for rapid development of prototypes				X		d. Prototypes of new algorithms from seismic research area.				X	X
		D1.2.3	Research applications of new techniques and technologies												
			b. Develop a multichannel processing environment using neural network and other processing methods	b. Prototype computer program in C++		X			X	b. Documented computer program suitable for inclusion in automated operational environment		X			
			d. Explore application of different signal processing technologies to seismic arena.	d. Report on application of techniques from non-seismic areas				X		d. Prototype of application software using non-traditional techniques				X	
	D1.3		Multisource data integration (Hydro, ...)												
			b. Develop a conceptual framework for fusion of data from multiple, dissimilar sensors	b. Preliminary design of the framework for integrating multiple dissimilar data sources		X				b. Documented software package for integrating multi-source data in an operational environment		X			
			c. Statistical techniques for multisource data integration	c. Progress report			X			c. Progress report			X		

Table A7: Automated Data Processing Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
			d. Investigate and develop prototypes for integrating multiple data sources	d. Progress demo (Seismic/Hydro)				X		d. Progress demo (Other sources)				X	
	D1.4		Review paper on state of automated processing												
D2.			Computer - human interface	Task D2 will provide new algorithms, computational methods and visualization tools that the analysts will need to handle the large amount of CTBT monitoring data.											
	D2.1		Prototype improvements in the analysts' data visualization												
			c. Explore use of animated and multidimensional displays (e.g., P1000)	c. Report on application of display technology			X			c. Algorithms and final report			X		
			d. Improve analyst ability to quickly visualize event information.	d. Review and demonstrate applications of emerging visualization technologies to monitoring problems				X		d. Prototype application of event visualization tool				X	
	D2.2		Improve analysis environment to handle CTBT data volumes.												
		D2.2.1	d. Develop enhanced integrated analysis environment to improve analyst ability to review data	d. Prototype of enhanced analyst environment											
	D2.3		Assisted environment												
			b. Develop improved signal processing tool for analysts & community	b. Improved signal processing tool for analysts' & community work stations		X			X	b. Improved graphical output, portability, and documentation		X			
			d. Prototype improved assisted analysis workstation	d. Environment design document				X		b. Prototype design				X	
D3.			Information technology	Task D3 will emphasize new methods for high-volume data management, system surety, and metrics for monitoring system performance.											
	D3.1		Surety												
		D3.1.1	Authentication												
			d. R&D prototypes for robust and reliable authentication technology and system analysis	d. System design and analysis report				X		d. Demonstration and initial prototypes				X	
		D3.1.2	Security												
			d. Investigate improved system security with easy authorized access	d. Recommendations report & demo software				X		d. Prototype software				X	X
		D3.1.3	"Red Team" GSETT-3 system surety												
			c. Provide statistical expertise to evaluate significance of vulnerabilities							c. Statistical description of vulnerability issues			X		
			d. Provide "red team" evaluation of GSETT-3 system security against hackers.							d. Final report				X	
	D3.2		Compress												
			d. Explore advanced technologies for storing and processing compressed digital data							d. Demonstration				X	

Table A7: Automated Data Processing Research Task Breakdown

Task	Sub task	Sub2 task	Work Statement	FY95 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct	FY96 Product	lanl (a)	llnl (b)	pnl (c)	snl (d)	cnt rct
	D3.3		Research data base												
		D3.3.1	Data base technology												
			d. R&D technologies to handle increased volume, access, & diversity of data in IMS							d. Demonstration				X	
		D3.3.2	Data storage and retrieval												
			d. Prototype handling large volume of waveform data using existing technologies							d. Demonstration				X	
		D3.3.3	Support research data base												
			d. Develop information base to support CTBT R&D activities	d. Prototype of initial research database				X		d. Demonstration of improved and enhanced research database				X	
	D3.4		Characterize performance (reliability, robustness, imbedded metrics)												
		D3.4.1	Embedded metrics												
			c. Provide statistical input for development of embedded metrics in IMS-type system	c. Report on statistical issues of embedded metrics			X			c. Final report on embedded metrics			X		
			d. Develop embedded metrics for evaluation of system performance.	d. Report				X		d. Demonstration				X	
		D3.4.2	Distributed system control												
			d. Demonstrate R&D technologies for highly distributed software systems.	d. Report and Concepts Demonstration						d. Capability demonstration				X	
	D3.5		Review paper on information technology												
D4.			Instrument development	Task D4 will focus on technologies that will enable the production of the next generation of affordable, deployable, high-quality seismic equipment.											
	D4.1		Miniaturization												
			d. Continue to develop rugged, light-weight, inexpensive seismic sensors to reduce costs of new alpha arrays	d. Interim report on prototype sensor performance.				X		d. Prototype				X	
	D4.2		Field technologies (Power, communications, deployment,...)												
			d. R&D of technologies required for new and retrofit arrays in harsh environments and remote locations.	d. System designs and analysis. Prototype hardware				X		d. Prototype sources integrated with systems				X	
D5.			Community management support	Task D5 will provide support for topical symposia and for Phillips Laboratory's efforts.											
	D5.1		Symposia												
			c. Coordinate topical symposium	c. Symposium and proceedings			X								
			d. Coordinate topical symposium							d. Symposium and proceedings				X	
	D5.2		Phillips Laboratory management costs	See Memorandum of Agreement					X	See Memorandum of Agreement					X