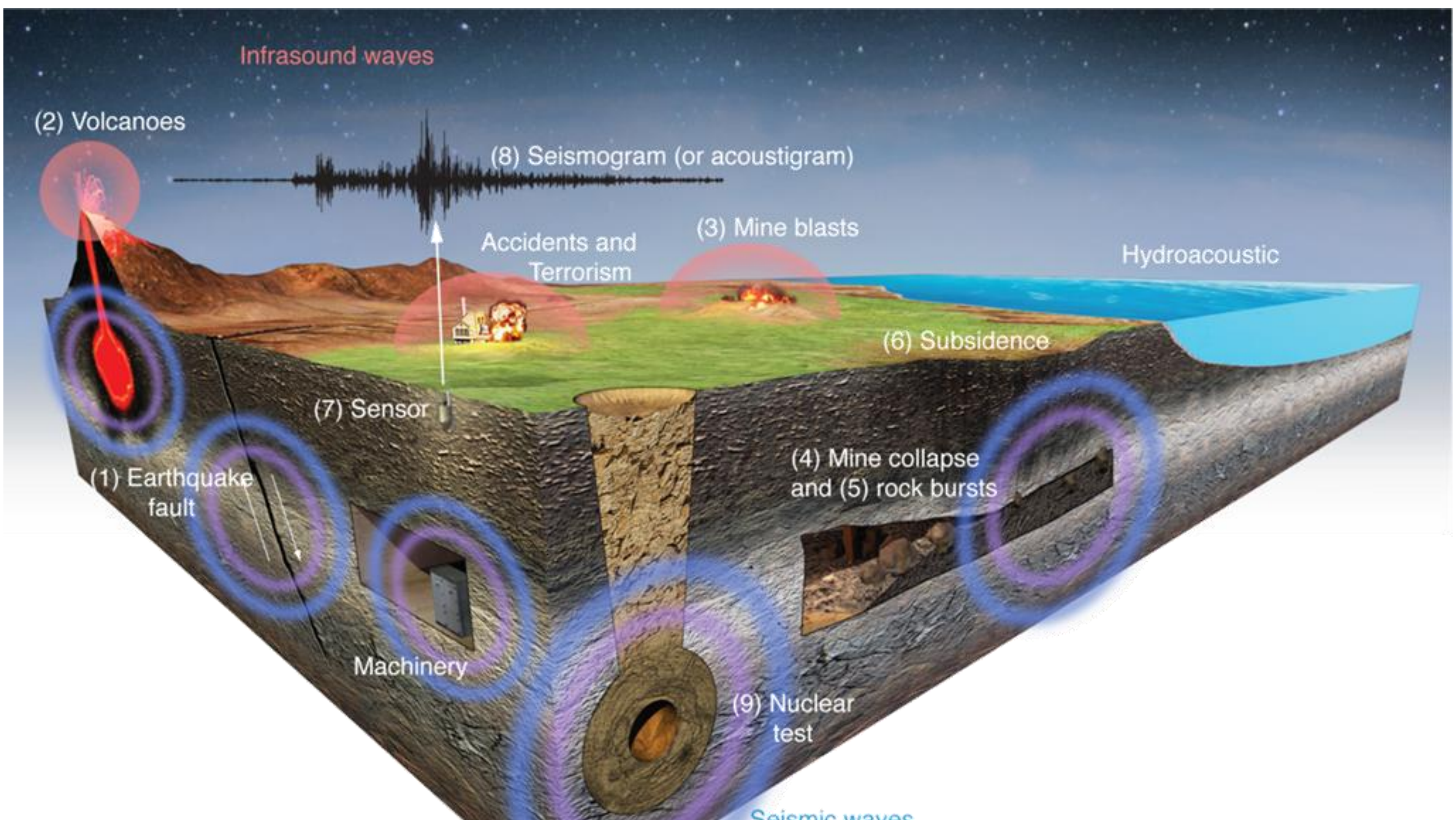
January 2014

DNN R&D

Ground-based Nuclear Detonation Detection (GNDD) Team — Goals, Objectives, and Requirements



DOE/NNSA/NA-22/GNDD-GOR-2014

Date	Version	Description	Approved
	1.0	Initial release	1/13/2014 X Dr. Rhys Williams Assistant Deputy Administrator

CONTENTS

INTRODUCTION

OVERVIEW OF DNN R&D'S OFFICE OF NUCLEAR DETONATION DETECTION

Defense Nuclear Nonproliferation Research and Development's (DNN R&D) Office of Nuclear Detonation Detection (NDD) develops technology to improve nuclear detonation detection and nuclear forensics. This Office also supports production of operational sensor payloads for the United States Nuclear Detonation Detection System (USNDS). NDD technology and systems are intended to support the nation's independent nuclear explosion detection capability, but in select cases, may also be applicable to the international monitoring regime.

The NDD leverages the unique expertise, capabilities, and resources of the National Laboratories, academia, and industry by sponsoring leading-edge research, conducting technology demonstrations, and developing prototypes to meet national nuclear security requirements. NDD works closely with other U.S. Government and international agencies.

NDD is organized into three research teams:

1. *Ground-based Nuclear Detonation Detection (GNDD)*: The GNDD Team conducts research related to seismic, infrasound, hydroacoustic, and radionuclide signals from underground, underwater, and surface nuclear explosions and provides scientifically validated research products for use in the U.S. National Data Center and U.S. Atomic Energy Detection System in support of the operational treaty monitoring mission.
2. *Forensics-based Nuclear Detonation Detection (FNDD):* The FNDD Team improves the nation's scientific and technical capability in nuclear forensics, specifically with regard to the accuracy, discriminating power, and timeliness of technical methods to help identify distinguishing characteristics and potential origins of interdicted material or collected debris. FNDD emphasizes understanding forensic evidence of near-surface nuclear detonations and interdicted bulk items related to nuclear security.
3. *Satellite-based Nuclear Detonation Detection (SNDD):* The SNDD Team produces and improves U.S. operational satellite nuclear detonation sensors[1] in support of both treaty monitoring and military missions. Projects cover on-going development and production to sustain fielded or to-be fielded systems, as well as those that seek to advance technology that might likely be incorporated into future systems.

[1] This includes the Global Burst Detector (GBD) payload for Global Positioning System (GPS) satellites and the Space and Atmospheric Burst Reporting System (SABRS) payload hosted on geosynchronous satellites.

The goal, objectives, and requirements (GOR) presented in this document define a framework for describing research directed specifically by GNDD. The intent of this document is to provide a communication tool for the GNDD Team with NNSA management and with its stakeholder community. It describes the GNDD expectation that much of the improvement in the proficiency of nuclear explosion monitoring will come from better understanding of the science behind the generation, propagation, recording, and interpretation of seismic, infrasound, hydroacoustic, and radionuclide signals and development of “game-changer” advances in science and technology.

GNDD seeks synergies and collaboration with complementary work funded elsewhere within DNN R&D, in other programs in NNSA including the Office of Nonproliferation and International Security (NIS), and those across other government agencies , such as the Department of State (DOS), and the Department of Defense (DoD). In addition, GNDD research supports improvements to the U.S. Atomic Energy Detection System (USAEDS) and the U.S. National Data Center. Where policy directs, the GNDD Team supports improving international monitoring capabilities.

MONITORING ENVIRONMENT

Figure 1 shows the physical environment where sources of interest for nuclear explosion monitoring occur, which is predominately near the Earth's surface or slightly into the crust. This environment is rich with confounding natural sources such as earthquakes (1), volcanic activity and the seismic noise caused by the pounding of the surf on shorelines (2), human-engineered events such as mine blasts (3), collapses (4), rock bursts (5), and subsidence (6).

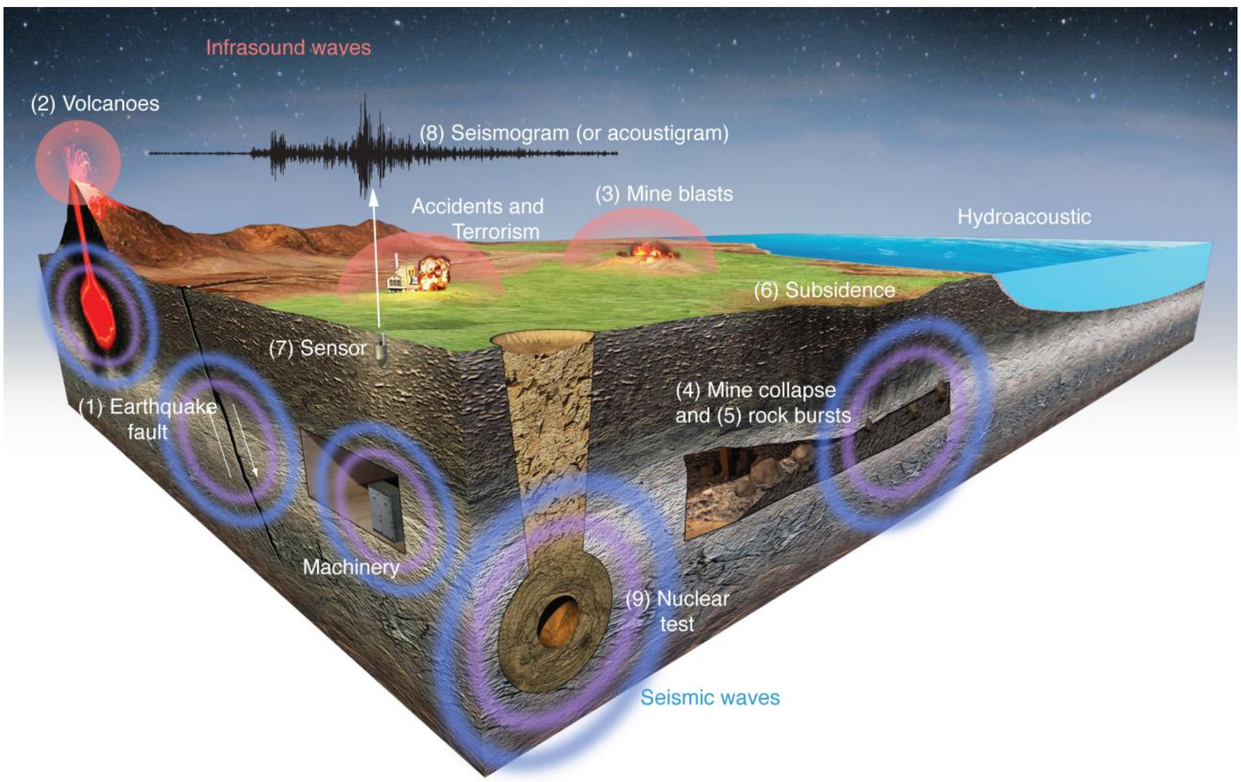


Figure 1. The physical environment near the Earth's surface within which nuclear explosion monitoring must operate.

All these sources generate signals in the form of seismic waves, and infrasonic (including acoustic waves along the surface of the earth) and hydroacoustic waves that can be detected at large distances with today's ultra-sensitive sensors (7). Each individual event recorded at a particular station has a unique signature (8). Advanced signal analysis seeks to distinguish the signature of a nuclear test from this background noise and other non-nuclear events.

Since 1980, all declared nuclear tests (9) have been conducted underground, and seismic waves have become the principal means for prompt detection, location, identification of source type (e.g., earthquake, explosion, etc.) and yield estimation. Radionuclide monitoring is predominantly focused on capturing the noble gases that seep or vent from an underground triggering event or the particulates from an atmospheric explosion, and is the principal means in establishing whether or not an explosion is nuclear.

GOAL

The GNDD Team conducts research to drive the state-of-the-art in waveform and radionuclide technologies providing science tools and validated geophysics datasets that enable improved analyses of real-world nuclear explosion monitoring.

The goal of the GNDD Team is to:

> ***Advance the U.S. ground-based nuclear explosion monitoring capabilities to detect, locate, identify, and determine yield of events associated with foreign nuclear weapons development.***

GNDD supports the DOE strategic goal[2] to "enhance nuclear security through defense, nonproliferation, and environmental efforts" and the NNSA strategic goal[3] to provide "technical and policy expertise to advise policymakers and to develop technologies to monitor compliance with arms control and nonproliferation commitments." Finally, GNDD supports DNN R&D's overall strategic direction[4] to develop technologies that support the next generation of emerging arms control and nonproliferation treaties and agreements. The GNDD goal is a natural follow-on to prior[5,6,7] plans.

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[2] *U.S. Department of Energy Strategic Plan,* DOE/CF-0067, May 2011. Available at http://energy.gov/sites/prod/files/2011_DOE_Strategic_Plan_.pdf.

[3] *The National Nuclear Security Administration Strategic Plan,* U.S. Department of Energy National Nuclear Security Administration May 2011. Available at http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/2011_NNSA_Strat_Plan.pdf.

[4] *Office of Nonproliferation and Verification Research and Development Strategic Implementation Plan FY 2013–2017,* U.S. Department of Energy National Nuclear Security Administration, Office of Nonproliferation and Verification Research and Development, April 9, 2012.

[5] National Nuclear Security Administration Nuclear Explosion Monitoring Research and Engineering Program Strategic Plan, DOE/NNSA/NA-22-NEMRE-2004, September 2004. Available at http://www.osti.gov/scitech/biblio/1095112

[6] *U.S. Department of Energy Comprehensive Test Ban Treaty Research and Development Plans and Accomplishments…from Signature to Entry into Force, DOE/NN-98001802, June 1998. Available at http://www.osti.gov/scitech/biblio/2779*

[7] *U.S. Department of Energy, Comprehensive Test Ban Treaty Research and Development FY95-96 Program Plan*, DOE/NN-0003, November 1994. Available at http://www.osti.gov/scitech/servlets/purl/10116434

OBJECTIVES AND REQUIREMENTS

To meet its goal, GNDD has established technical objectives for waveform and radionuclide technologies that are appropriately flexible for supporting a dynamic policy environment. For requirements the GNDD program has adopted four essential elements for innovative scientific research, including a better understanding of the physics of 1) the source signal (including seismic, hydroacoustic, infrasound, or radionuclide), 2) signal propagation, 3) sensors that detect these signals, and 4) signal analyses.

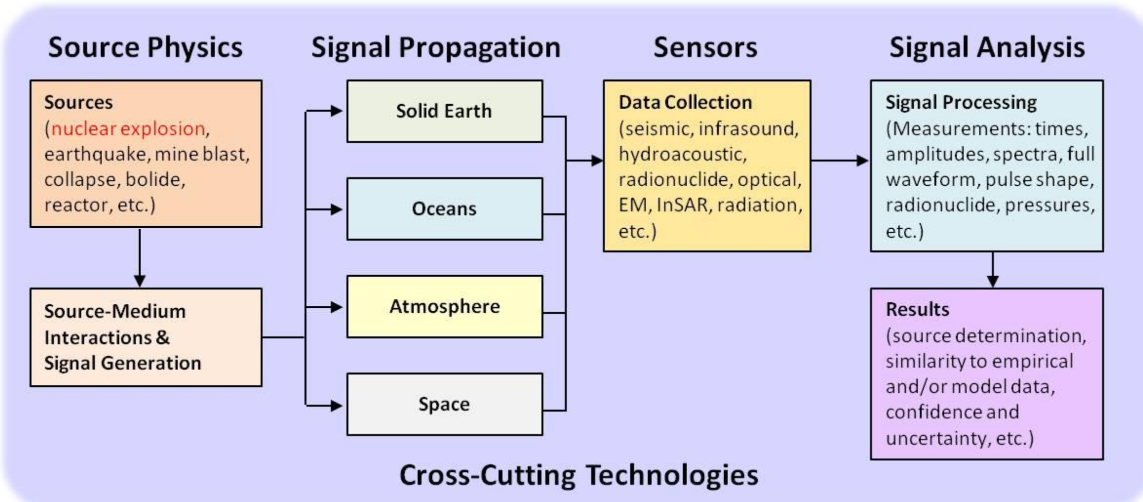

Figure 2. Representation of ground-based nuclear explosion monitoring elements.

Figure 2 shows these four elements as a requirements framework for understanding the nuclear explosion monitoring physical environment and associated operational systems. Starting from the left, the figure shows an event occurring on or within the Earth (Source Physics), its signals emanating from that source through a physical medium (Signal Propagation), the means for detecting, measuring, and storing these data (Sensors), and the processing of these data by the monitoring authority to meet its mission objectives (Signal Analysis).

These objectives and requirements are elaborated below.

OBJECTIVE A: DEVELOP ADVANCED METHODS TO DETECT, LOCATE, DETERMINE YIELD, AND SUPPORT IDENTIFICATION OF FOREIGN NUCLEAR EVENTS USING WAVEFORM TECHNOLOGIES

Requirement a: Waveform source physics

This requirement focuses on providing a physical basis for predicting the seismic signals emitted by all source types (e.g., earthquakes, explosions, mining blasts, etc.) in a variety of geologic, tectonic, and human-engineered emplacement settings. For explosions, the complexity of the source and the need for far more sophisticated models, especially for shear-wave (S-wave) generation, drives future R&D in mathematical representations of physical source models, numerical simulations, geologic models containing fracture networks, and yield estimation, with underlying theoretical work supporting the overall development.

The R&D themes for waveform source physics are:

- Determine new and more effective methods to identify sources of waveform signals
- Predict nuclear explosion seismic S-wave amplitudes near the source for all emplacements
- Tune earthquake waveform amplitude models to their tectonic setting
- Predict industrial explosion local and regional waveform amplitudes
- Predict local and regional waveform signals from the collapse of underground cavities
- Calculate energy partitioning for sources near earth-water-air interfaces.

Requirement b: Waveform signal propagation

This requirement focuses on improved waveform signal prediction with impacts for event detection, location, identification, and magnitude/yield estimation. Many factors control the timing, amplitude, and frequency content of propagating waveform signals. Foremost among these is the heterogeneity of the Earth's velocity and attenuation structure. In real application, other factors arise and must be considered. For seismic waveforms, this includes improved understanding of the subsurface density, wave velocities, and associated attenuation.

For infrasound, this includes understanding the velocity profile and dynamics of the atmosphere, which is in constant motion and has daily and seasonal variations (requiring stochastic methods).

For hydroacoustic, this includes improved understanding of the velocity profile of the oceans, which undergoes seasonal variations, as well as the bathymetry.

The R&D themes for Waveform Signal Propagation are:

- Improve travel time predictions
- Improve amplitude modeling
- Predict travel-time, amplitude and full waveform signals from these models.

Requirement c: Waveform sensors

This requirement focuses on sensor development, network configuration analyses, and testing facility support. Current Waveform Sensor R&D is focused on regional and local environments, the areas (local in particular) where data collection must occur to record the small events that have increasingly become the focus of explosion monitoring. Specific technology areas include micro-seismometers, micro-acoustic sensors, and seismo-acoustic integration. Local seismic monitoring will require a new breed of small sensors able to operate in the short-period regime.

Deploying local networks has several troublesome issues: optimal spatial distribution, inter-sensor and station communications, on-board processing, and long-term power, weight, and size constraints.

Therefore, the R&D themes for waveform sensors are:

- New short-period (SP) micro seismometers and micro acoustic sensors
- Prototype local monitoring sensor systems
- Sensor network deployment software
- Sensor testing and evaluation facility maintenance.

Requirement d: Waveform signal analysis

This requirement focuses on signal enhancement (filtering, beaming, rotation, principal component analysis, waveform correlation, etc.), signal detection, parameter measurement, signal association, event location, magnitude/yield determination, and event identification. Enhancement can use parameters derived from waveforms or the waveforms themselves. The desired product is a high-quality, comprehensive list of well-described, possible nuclear events. Because direct evidence is seldom available and all measurements have error, a further challenge is to research and develop uncertainty estimates for GNDD analyses. Also, because earthquakes are so much more common than explosions and thus dominate the typical set of signals on any given day, a large proportion of signal analysis work focuses on identifying and screening the signals from earthquakes.

The R&D themes for waveform signal analysis are:

- Improve the robustness and accuracy of parameter estimation
- Develop new waveform parameters
- Improve parameter-based methods for monitoring
- Improve waveform-based methods for monitoring.

OBJECTIVE B: DEVELOP ADVANCED METHODS TO DETECT, IDENTIFY, AND SUPPORT DETERMINATION OF YIELD AND LOCATION OF FOREIGN NUCLEAR EVENTS USING RADIONUCLIDE TECHNOLOGIES

Requirement a: Radionuclide source physics

Quite different from seismic signals, which begin as a release of energy within the environment, a radionuclide event is the release of radioactive atoms. Radionuclide sources include nuclear explosions, normal or anomalous reactor operations, and release from the nuclear industry, particularly medical isotope production. These overlay on natural radioactivity such as primordial isotopes (e.g., potassium, uranium, thorium, and their decay products) and isotopes produced from the interactions of cosmic rays with the atmosphere (e.g., Be-7 and Na-24).

The R&D themes for radionuclide source physics are:

- Determine the risk of innocuous background false alarms
- Improve knowledge of subsurface gas transport
- Determine the amount of radionuclides produced in various nuclear testing conditions.

Requirement b: Radionuclide signal propagation

This requirement focuses on integrating local source input (e.g., location and radioisotopic detail of known sources) into atmospheric models because, while radionuclides can move in subterranean water, the dominant source propagation for radioactive atoms in the treaty monitoring context is atmospheric transport. By combining atmospheric and/or subsurface transport of radionuclides, rough determinations of nuclear yield can be performed. Atmospheric Transport Modeling (ATM) is central to weather prediction and therefore has large national and international academic research support. The excellent state of ATM, the existing R&D support by other agencies like NOAA and NASA, and the highly capable operational CTBT ATM capability are reasons that GNDD R&D is a user of ATM rather than a supplier. Understanding signal propagation from known sources is a necessary input to signal analysis.

Requirement c: Radionuclide sensors

This requirement focuses on operational considerations for sensor development. Key metrics in the past have been to push the limits of automated capabilities, sensitivity, accuracy and precision. These will continue to be important metrics, but ruggedness/uptime, power and complexity per cubic centimeter of Xe separations, processing speed, and sample throughput will grow in importance as the CTBT on-site inspection challenge and International Noble Gas Experiment results mount.

The R&D themes for radionuclide sensors are:

- Increase sensitivity to aerosols and short-lived xenons
- Increase xenon yield while reducing complexity
- Improve transfer of collected radionuclides into the radiation detector
- Improve operation uptime
- Solving near-field radionuclide measurement and operations problems, including On-Site Inspection.

Requirement d: Radionuclide signal analysis

This requirement focuses on understanding both aerosol and radioxenon data. Detailed analyses of fission products and other radionuclides have a role in determining the yield of explosions. This requirement also includes 'network analysis,' in which many stations' results on many days are combined with the source-receptor strength fields to determine the maximum release possible from a suspected site as a function of time. This was a key result of analysis of the DPRK 2009 event.

The R&D themes for radionuclide signal analysis are:

- Develop methods and techniques to increase the sensitivity and selectivity of radionuclide detection
- Improve discrimination of detected signals from background with algorithms
- Evaluate intra-station dependencies in an effort to maximize network capabilities.

GNDD TECHNOLOGY ROADMAP

This GOR defines the goal, objectives and requirements against which the GNDD Team applies resources to develop technologies and methods. To fully develop the research portfolio, the GNDD Team considers how these requirements can be met in terms of Source Physics, Signal Propagation, Sensors and Signal Analysis while also weighing U.S. Government (stakeholders) priorities and capability gaps.

This result is documented in the GNDD Technology Roadmap. In this roadmap, the GNDD Team provides guidance to direct Principal Investigator efforts, to help laboratory management understand future priorities, and to ultimately determine GNDD Team funding priorities.

The GNDD Technology Roadmap illuminates probing science questions and charts the past, present, and future technology advances for nuclear explosion monitoring science. The roadmap is also intended to help guide the substance of the GNDD calls-for-proposals to National Laboratories, the Small Business Innovation Research (SBIR) program, and Broad Agency Announcements (BAA).

CONCLUSION

The goal, objectives, and requirements discussed in this document define the thrust of research directed by DNN R&D and specifically by the GNDD Team. This document is a communication tool for the GNDD with NNSA management and with its stakeholder community. The GNDD Technology Roadmap provides the communication between DNN R&D and its performer base—the DOE National Laboratory system. While periodic updates to this GOR document may be necessary, the intent is to provide a stable vision and guidance needed to build and sustain a long-term R&D program.