Verification of the Comprehensive Nuclear Test-Ban Treaty:
(2010)

1.1 Defining the Task

The Comprehensive Nuclear Test Ban Treaty (CTBT) prohibits the test detonation of any nuclear weapon. Confirming compliance by all nations requires continuous monitoring for possible clandestine detonations that could occur under any circumstances above-ground, underground, or underwater.

The task of monitoring for clandestine nuclear weapons testing, however, is not unique to participation in the CTBT. Independent of the CTBT, the national security interests of the United States have required the monitoring of potential foreign nuclear weapons tests since the end of World War II, over 60 years ago. The US monitoring effort has been focused, and will continue to focus, on specific nations that are of high concern to the national security of the US and its allies.

In the 1950s public concern over global radioactive fallout generated international opposition to nuclear testing, which at that time was usually conducted above-ground. Concern over health risks led to the 1963 Limited Test Ban Treaty (LTBT). The LTBT prohibits nuclear testing above ground and in the oceans, or in any manner that "causes radioactive debris to be present outside the territorial limits of the State under whose jurisdiction or control such explosion is conducted."

The LTBT contains no provisions for verification. Nevertheless, the US has been monitoring compliance with this treaty successfully for almost half a century. The detection of nuclear tests aboveground has been accomplished with high confidence because of the characteristic light signal and radioactive substances that are produced by a nuclear detonation and by the disturbances they cause in the atmosphere. The detection of nuclear tests underwater has also been accomplished with high confidence because of the efficiency with which water transmits acoustic (sound) waves and the ability of such acoustic waves to be detected by the extensive networks of underwater sensors used to track submarines.

While the LTBT does not prohibit testing underground, the US and other nations have been continuously monitoring for underground tests to meet their individual national security requirements.

The monitoring challenge that has the most potential for creating uncertainty is detecting small nuclear explosions underground, and specifically, in differentiating the signals of a potential clandestine nuclear explosion from those of a naturally occurring earthquake and other events that cause ground motion.

1.2 Recent Breakthroughs

Since 1960, a comprehensive program to improve the monitoring of underground testing has been conducted by the United States and has involved the national laboratories, federal agencies, independent contractors, and the academic research community. The effort has produced major advances in all areas – the sensitivity of seismological instrumentation, the methodologies for analyzing the data collected from seismometers, and the distribution of seismological data collections systems.

With time, our monitoring capabilities have continued to improve. Within the last ten years, however, these improvements have increased dramatically due to fundamental changes in the strategies used for nuclear monitoring. Specifically, data and methodologies have expanded to include the use of "regional" waves — seismic waves that travel at higher frequencies within the Earth's crust and that travel distances up to 1500 km (1000 miles). Particularly important is the availability today of data from seismic stations throughout the Middle East, North Africa, Russia, Kazakhstan, Mongolia, China and South Korea. Access to these regions permits countries of special concern to the United States to be monitored at much closer distances and thus down to events of much smaller size.

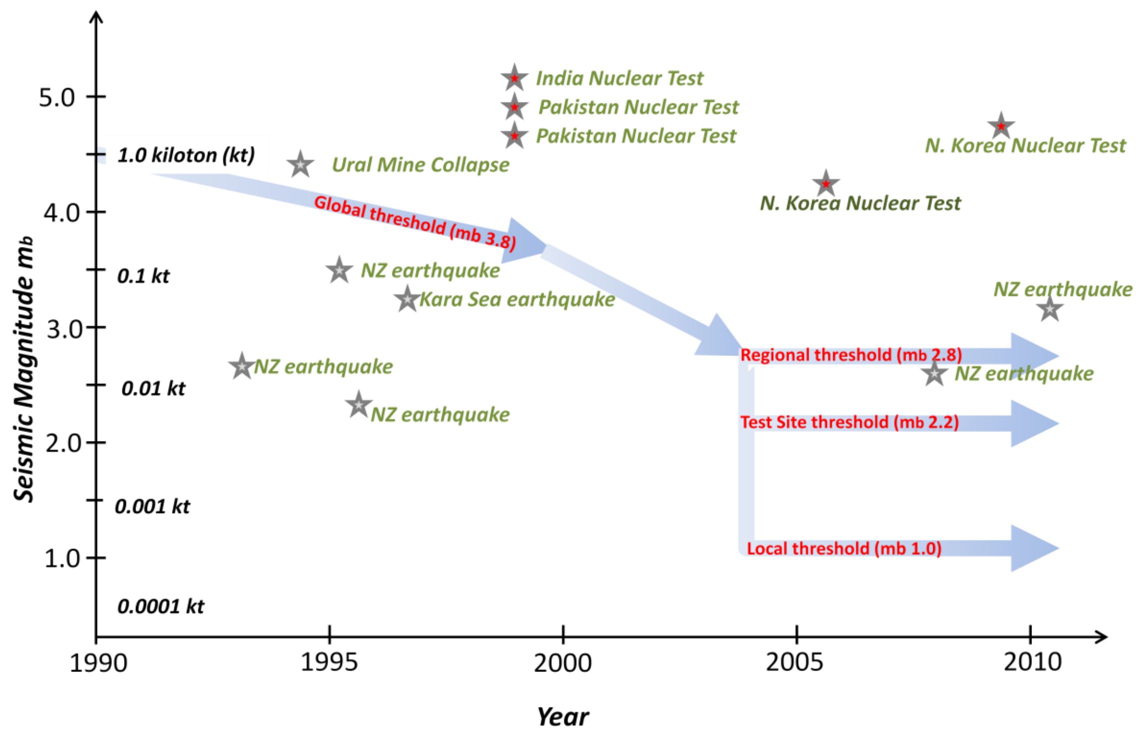


Figure 1: Improvement in Seismic Monitoring Over the Last 20 Years

Since 2000, the capabilities of the US and its allies to detect a clandestine nuclear weapons test has improved greatly due to the implementation of regional monitoring methods and increases in data availability and quality. Specifically, the expansion of seismic networks has allowed for the use of high-frequency regional seismic waves. Regional seismic waves provide additional methods for distinguishing the seismic signals produced from an explosion from those produced by a occurring earthquakes. The number of problem events that occur, fewer than about one per year, is now small enough that on-site inspections are feasible under the verification provisions of the treaty.

Fundamental improvements in our ability to monitor underground nuclear testing have occurred in the following three areas:

1) Use of Regional Seismic Waves

While research into regional seismic methods was underway at the time of the CTBT signing more than a decade ago, it was not until 2004/2005 that many of these new research products began to be implemented into the routine operational systems that continue today. Regional seismic waves travel through the Earth's crust and uppermost mantle (the top few tens of kilometers of the Earth's interior) at high frequencies. Regional seismic waves provide new methods for distinguishing the seismic signals produced from a small underground nuclear explosion from those produced by a naturally occurring earthquake.

2) Increased data coverage, quality, and availability

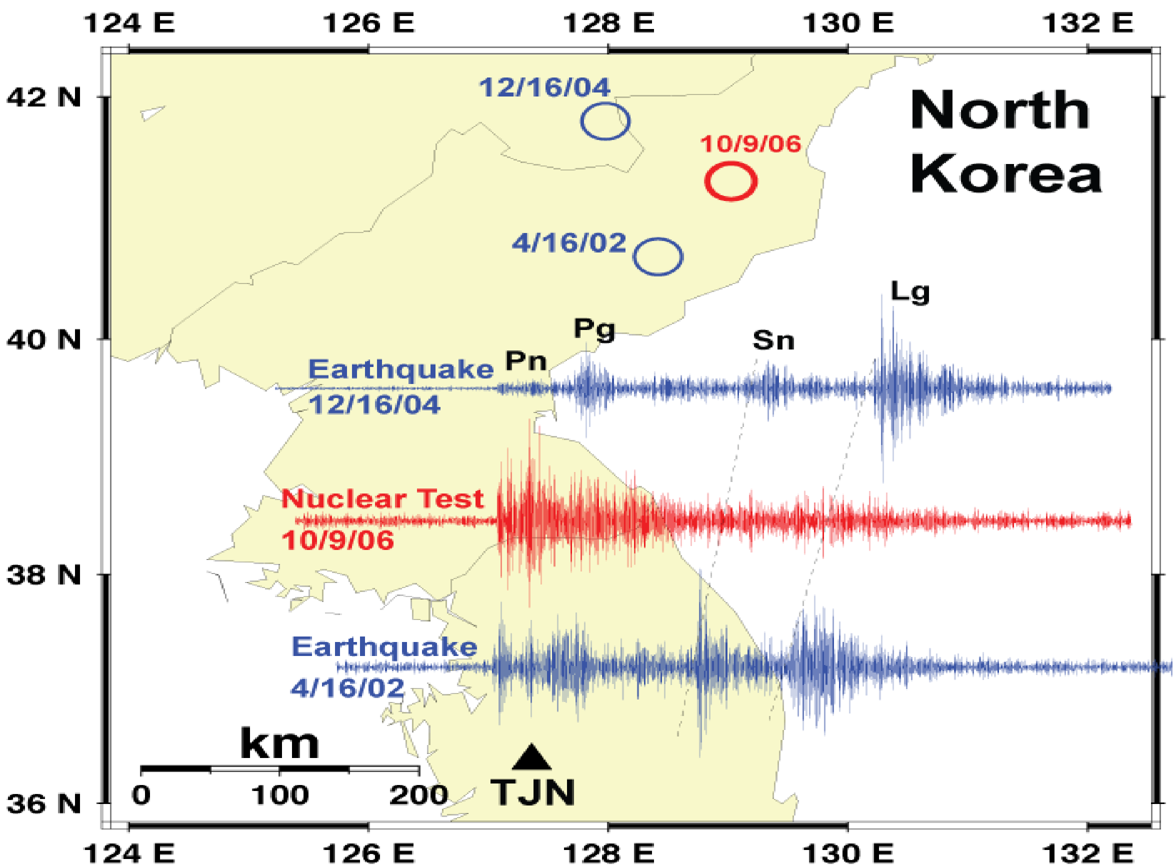
Over the last decade the amount of seismological data that is available to detect a potential clandestine nuclear weapons test has increased approximately 10-fold. Improvements in global digital communication networks have increased the capacity to transmit these large amounts of data from around the world in real or near-real time by approximately 100-fold. Computer power, data storage and retrieval increased approximately 10-fold. Furthermore, much of this newly available data is coming from nations and areas which were previously inaccessible.

3) Improvements in our ability to distinguish the seismic signals of a small nuclear explosion from those of naturally occurring earthquakes.

The use of digital data now provides for ground motion to be recorded continuously with high sampling rates over broad frequency ranges. This has led to new methodologies that use the characteristics of the ground motion that are recorded at various frequencies to distinguish potential small explosions from naturally occurring earthquakes. Access to high-frequency seismic data has allowed for applications of new discriminants that have improved by about a factor of 10 or more our capability to distinguish explosions from naturally occurring earthquakes.

Box 1: Example: North Korea:

The recent nuclear weapon test conducted by North Korea provides an illustration of the improvements in all three of these areas.



Several of the major improvements in our ability to monitor potential clandestine nuclear explosions are illustrated in these seismic recordings of earthquakes and explosions of a size that corresponds to less than one kiloton. These capabilities also extend to many other areas of interest to the US and down to sizes that are equivalent to explosions well below one-tenth of a kiloton using openly available real-time data. In fact, nearby explosions in China that release approximately one one-thousandth (1/1,000) the energy of the events shown have seismic signals that can be recorded with quality that allows them to be distinguished from those of a naturally occurring earthquake. Note the relatively strong *P*-waves from the nuclear explosion compared to the earthquake, and the relatively strong *S*-waves (*Lg* in this case) of the earthquake. The surface wave has a relatively long-period nature (compared to the body waves) and is an indication of the shallow depth of the nuclear explosion. This type of surface wave is not generated by earthquakes. *(Walter et al., 2007).*

1.3 Statement by Professional Organizations

In 1999, the American Geophysical Union (AGU) and the Seismological Society of America (SSA) produced a joint statement on the verifiability of the CTBT. The position statement was approved in 1999 and was reaffirmed in 2003 and again in 2007 by AGU. AGU is one of the largest professional scientific societies in the United States. These two organizations represent over 50,000 geoscientists.

Capability to Monitor the Comprehensive Nuclear-Test-Ban Treaty

Adopted by Council September, 1999; Reaffirmed December 2003; Reaffirmed December 2007

In September 1996, the United States was the first country to sign the Comprehensive Nuclear-Test-Ban Treaty (CTBT), an international agreement to ban all nuclear test explosions, now signed by 177 nations. The treaty is intended to impede the development of nuclear weapons as part of the international nonproliferation regime. The treaty is not yet in effect because it has not been ratified by enough countries—including the United States. As a result, many of its verification provisions have not yet been fully implemented. When implemented, the American Geophysical Union (AGU) and the Seismological Society of America (SSA) are confident that the combined worldwide monitoring resources will meet the verification goals of the CTBT.

The CTBT will be monitored by: 1) the national intelligence means of various countries, 2) the International Monitoring System (IMS) negotiated under the CTBT that consists of seismic, hydroacoustic, radionuclide, and infrasound networks, along with on-site inspections, and 3) the efforts of numerous independent scientists and institutions worldwide. It is this combination of resources that gives confidence in the ability to uncover CTBT violations. AGU and SSA expect that this overall monitoring capability will continue to strengthen as more data are collected, more research is performed, and as global communications networks expand.

The seismic component of the International Monitoring System is to consist of 170 seismic stations. This network (which in 2007 was more than half built) will be able to detect all seismic events of about magnitude 4 or larger and to locate those events within 1000 square kilometers (a circle with a diameter of approximately 35 km), which is the maximum area permitted by the treaty for an on-site inspection. A seismic magnitude of 4 corresponds to an explosive yield of approximately 1 kiloton (the explosive yield of 1,000 tons of TNT). AGU and SSA are confident that the verification system, if built as planned, can be relied upon to meet that goal.

One of the biggest challenges to monitoring the CTBT is the possibility that testing could be successfully hidden by conducting nuclear explosions in an evasive manner. The concern is partly based on U.S. and Russian experiments which have demonstrated that seismic signals can be muffled, or decoupled, if a nuclear explosion is detonated in a large underground cavity. The decoupling scenario, however, as well as other evasion scenarios demand extraordinary technical expertise and the likelihood of detection is high. AGU and SSA consider such technical scenarios credible only for nations with extensive practical testing experience and only for yields of at most a few (that is, 1 or 2) kilotons. Furthermore, no nation could rely upon successfully concealing a program of nuclear testing, even at low yields.

Data from the treaty's monitoring system will also contribute to our scientific understanding of the Earth and efforts to mitigate earthquake hazards. Article IV.A.10 of the treaty states "The provisions of this treaty shall not be interpreted as restricting the international exchange of data for scientific purposes". AGU and SSA support a broad interpretation of this article and strongly urge that all data from the International Monitoring System be made openly available without any restriction or delay.

1.4 Seismic Monitoring Resources

A common misconception is that the US will rely on the CTBT international monitoring system for verification of compliance. The discovery of a clandestine nuclear weapon test is the responsibility of each nation's national authority (per treaty language). The international monitoring system is simply the "tip of the iceberg" in terms of potential sensor networks that are capable of detecting evidence of a clandestine nuclear test. Anyone attempting to undertake a clandestine nuclear weapons test would have to consider the continually evolving and inherently unpredictable array of sensors (the majority of which are not designed for nuclear monitoring) that are capable of providing evidence of a clandestine nuclear weapons test. The AGU and SSA based their assessment on the integrated capability of all the resources that were available to detect a potential clandestine nuclear explosion. This consists of:

1) The monitoring systems of the US and its allies that includes the US Atomic Energy Detection System operated by the Air Force Technical Applications Center, the expertise of the DoD and DOE laboratories, the US Geological Survey and government-contracted consultants and US academic experts;

2) The international monitoring system established by the treaty that allows for additional enhancements such as on-site inspections, and;

3) The international Geoscience research community which has many thousands of seismometers deployed around the world for earthquake hazard or academic research purposes, and innumerable other sensor networks that are capable of detecting the atmospheric, hydroacoustic, or radiological signals that are characteristic of a nuclear explosion.

Table 1: Summary of Seismic Monitoring Capabilities:

Capabilities to monitor for potential clandestine nuclear weapons tests are largely dependent on the amount of resources invested for the task and the willingness of various nations to undertake confidence-building measures in areas of high interest.

Monitoring Objectives	Maximum Credible Yield of Nuclear Device to be Tested *(1)*
Local network *low-probability* (~10%) detection threshold.*(2)*	Max. explosive yield: 0.0002 kilotons *(seismic magnitude: 0.7)* Potential with evasions scenarios: 0.01 kilotons.*(3)*
Local network *high-probability* (~90%) detection threshold.*(2)*	Max. explosive yield: 0.0004 kilotons *(seismic magnitude: 1.0)* Potential with evasions scenarios: 0.02 kilotons.*(3)*
Regional network *low-probability* (~10%) detection threshold.*(4)*	Max. explosive yield: 0.006 kilotons *(seismic magnitude: 2.2)* Potential with evasions scenarios: 0.4 kilotons.*(3)*
Regional network *high-probability* (~90%) detection threshold.*(4)*	Max. explosive yield: 0.02 kilotons *(seismic magnitude: 2.8)* Potential with evasions scenarios: less 1 kiloton.*(3)*
Global network *low-probability* (~10%) detection threshold for Asia, Europe, N. Africa and N. America. *(5)*	Max. explosive yield: 0.04 kilotons *(seismic magnitude: 3.0)* Potential with evasions scenarios: less 1 kiloton.*(3)*
Global network *high-probability* (~90%) detection threshold for Asia, Europe, N. Africa and N. America. *(5)*	Max. explosive yield: 0.09 kilotons *(seismic magnitude:3.4)* Potential with evasions scenarios: less 1 kiloton.*(3)*
Global network *low-probability* (~10%) detection threshold. *(5)*	Max. explosive yield: 0.06 kilotons *(seismic magnitude:3.2)* Potential with evasions scenarios: less 1 kiloton.*(3)*
Global network *low-probability* (~90%) detection threshold. *(5)*	Max. explosive yield: 0.2 kilotons *(seismic magnitude:3.8)*

	Potential with evasions scenarios: less 1 kiloton.*(3)*

(1) Explosive yields are determined from the relationship mb = 4.45 + 1.0 log Y (kt) for a tectonically stable area. In regions that are tectonically active, a comparable sized explosion could produce a seismic signal with a smaller magnitude.
(2) Based on local networks such as the Southern California Network and the Southern Great Basin Digital Seismographic Network
(3) Potential for evasion is computed using a maximum decoupling factor of 70 for yields less than one kiloton. Larger decoupled explosions are limited by technical factors discussed in Chapter 5a.
(4) Based on regional networks such as the Kirgiz Network in Central Asia.
(5) See Chapter 3.2.

1.5 Key Findings:

1. Independent of the CTBT, the national security interests of the United States and its allies require the monitoring of potential foreign nuclear weapons tests. The verification provisions of the CTBT allow for improved capability to meet this national security requirements by providing the potential for additional resources such as on-site inspections.

2. A common misconception is that the US and its allies will rely on the CTBT international monitoring system for verification of compliance. This is not correct. The identification of seismic events as potential clandestine nuclear tests is the responsibility of each nation's national authority (per treaty language). The international monitoring system is simply the tip of the iceberg in terms of potential sensor networks that are capable of detecting evidence of a clandestine nuclear test. Anyone attempting to undertake a clandestine nuclear weapons test would have to consider the continually evolving and inherently unpredictable array of sensors (the majority of which are not designed for nuclear monitoring) that are capable of providing evidence of a clandestine nuclear weapons test.

3. Our monitoring capabilities have improved. Within the last ten years, these improvements have increased our ability to detect a clandestine nuclear weapons test by approximately 10 times (1,000%). Much of this improvement is due to the use of "regional" waves — seismic waves that travel at higher frequencies within the Earth's crust and travel distances of less than 1500 km (1000 miles).