NORSAR

Symposium on Regional Seismic Arrays and Nuclear Test Ban Verification

Oslo, Norway, 14–17 February 1990

Royal Norwegian Ministry of Foreign Affairs
Norwegian Seismic Array (NORSAR)

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Foreword

An effective system of verification is of utmost importance in any international arms control and disarmament agreement. For a Comprehensive Nuclear Test Ban Treaty (CTBT), international cooperation in the exchange and analysis of seismic data will form a principal tool for ensuring adequate verification.

Norway has consistently supported the work of the Conference on Disarmament's Group of Scientific Experts in developing a global seismological system to assist in the verification of a CTBT. The seismological facilities in Norway today are among the most advanced in the world, incorporating the most recent scientific and technological achievements. In particular, the new seismic array technology described in this document holds promise to significantly improve the effectiveness of a global seismic verification system.

The picture on the cover page was taken at the ARCESS array site in Finnmark, northern Norway, on August 29, 1986.

Nuclear Test Ban Verification

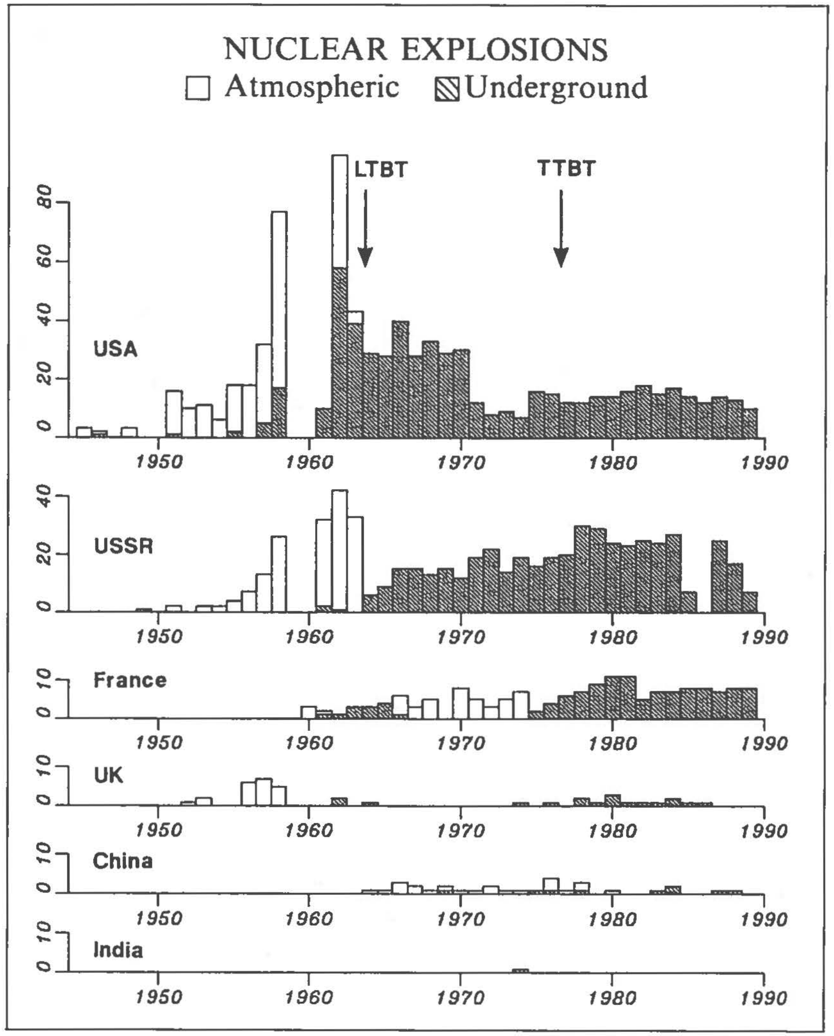
To achieve a Comprehensive Nuclear Test Ban Treaty (CTBT) has been a major aim of international disarmament negotiations for more than three decades. The Limited Test Ban Treaty of 1963 prohibited nuclear explosions in the atmosphere, in outer space and under water. The treaty did not comprise underground nuclear tests since the verification possibilities were not seen as adequate at that time.

A verification system for a CTBT must be able to ensure, at a politically acceptable level, compliance with the agreements and to provide a credible deterrence against potential violations. An important function of such a system will be to build confidence that a treaty is adhered to through extensive international consultation and cooperation.

It is no coincidence that the science of seismology has had a central position throughout the negotiations of verification procedures for a CTBT. In fact, at a distance from the source, a nuclear explosion conducted underground can only be detected by recording the pressure waves that are generated, and that propagate through the earth in the same way as seismic waves generated by earthquakes.

After the Limited Test Ban Treaty of 1963, most of the nuclear weapon states have conducted their weapons tests underground, and testing in this environment causes by far the most difficult verification problems.

This is the background for the extensive research and development being conducted at NORSAR, with the aim to obtain improved methods for detecting and identifying underground nuclear explosions.



Annual number of nuclear explosions conducted by six countries. Note that the Limited Test Ban Treaty (LTBT) of 1963 did not significantly reduce the number of tests, but merely caused the signatories to conduct their testing underground. The Treshold Treaties (TTBT and PNET) of 1976, limiting the size of nuclear explosions to 150 kilotons TNT, did contribute to reduce the yields, but not the number of nuclear explosions.

Norwegian Contributions

Norway has over the years devoted considerable resources to conducting seismological research on CTBT verification, in particular in support of the multilateral efforts within the Conference on Disarmament. Research and developments associated with the Norwegian Seismic Array (NORSAR) have formed a key element in this regard.

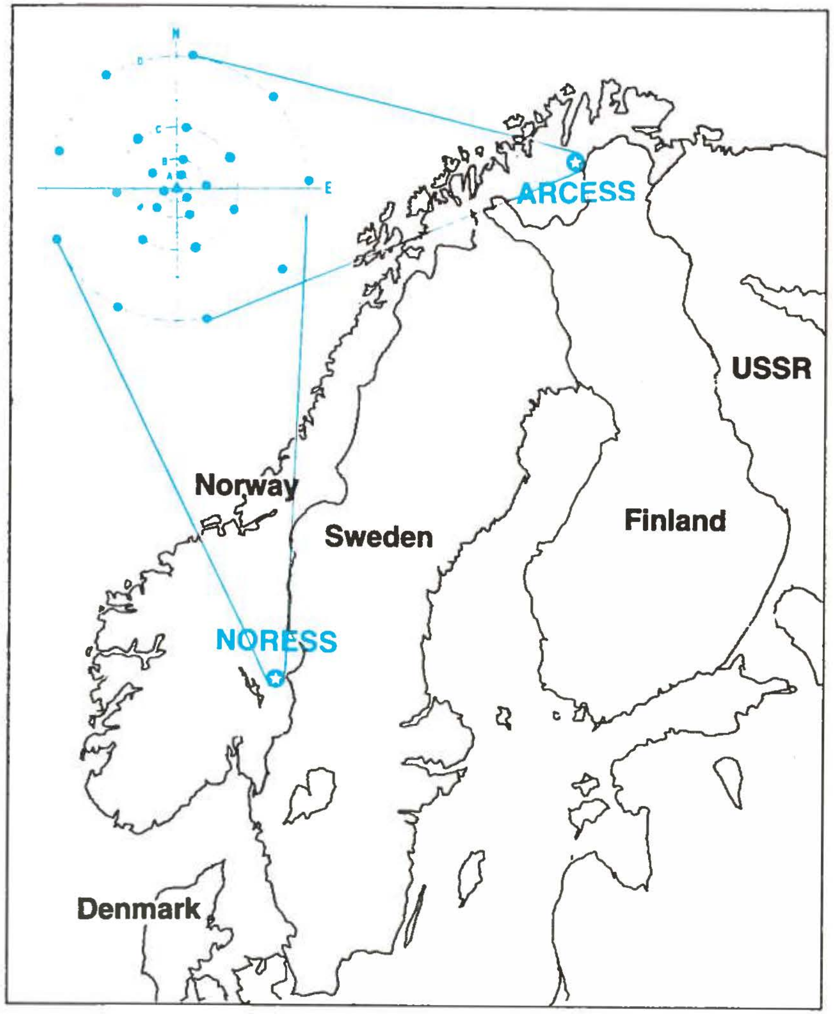
The establishment of the NORSAR observatory dates back to the signing in 1968 of a Government-to-Government agreement between Norway and the United States concerning seismological research and development. Administered by the Royal Norwegian Council for Scientific and Industrial Research (NTNF), NORSAR has over the years developed into an international center for seismological research on nuclear test ban verification.

The Regional Array Concept

The regional array concept represents one of the major advances in recent years in the field of seismological verification. Norwegian and United States scientists have collaborated to develop the most advanced system in the world for remotely detecting, identifying and characterizing underground nuclear explosions.

The NORESS array (Norwegian Regional Seismic Array System), comprising advanced field installations as well as sophisticated data processing techniques, was established in southern Norway in early 1985. In June of that year, the Norwegian Ministry of Foreign Affairs hosted a Workshop in Oslo presenting the NORESS facilities in the context of seismological CTBT verification.

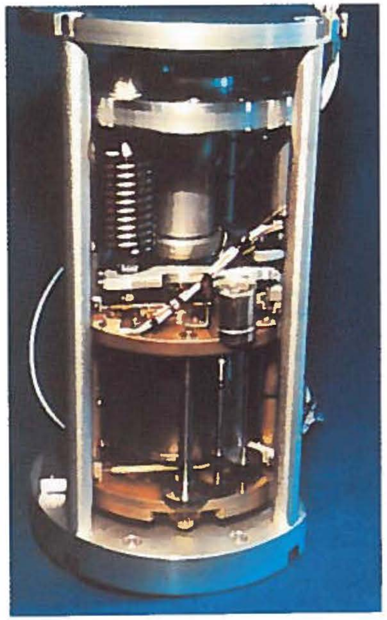
A new dimension was added to the seismological facilities in Norway with the deployment in 1987/88 of a second regional array, termed ARCESS, in the arctic region of Finnmark, northern Norway. In combination with NORESS, this second array today provides excellent seismological detection of small events over large parts of the northern hemisphere.



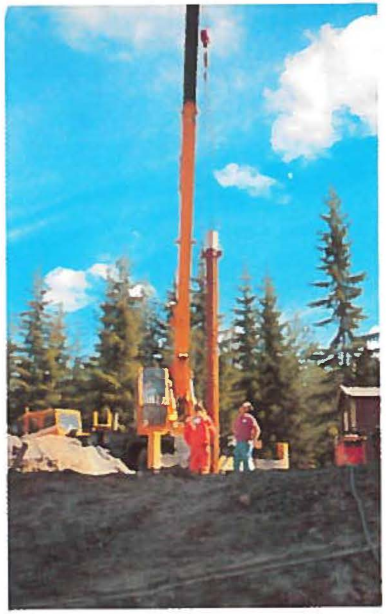
The two Norwegian regional arrays, NORESS and ARCESS, are situated approximately 1100 km apart. Their geometric patterns are identical, each comprising 25 seismometer sites deployed in concentric rings over an area of approximately 3 km in diameter.

The Field Systems

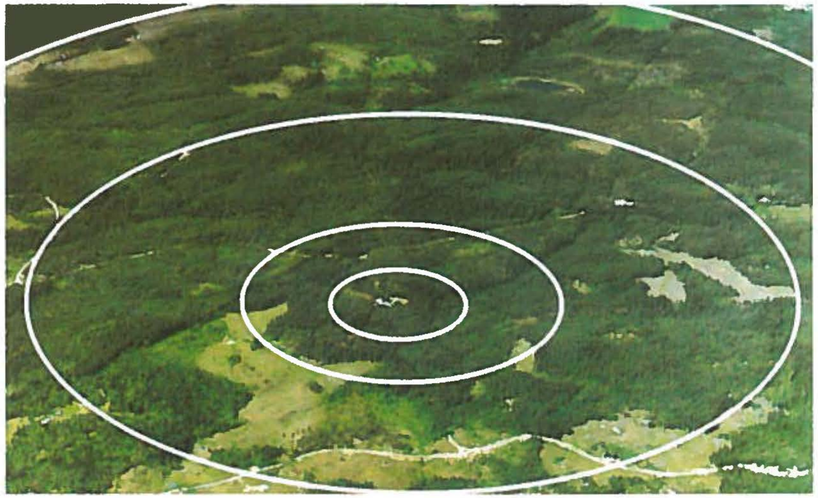
Among the features that make the NORESS/ARCESS arrays exceptional are their automatic field operation, requiring only occasional visits for maintenance; the transmission of seismic information to distant receiving stations in real time; automatic self-calibration; exceptional reliability and high quality of the data; and automated signal processing methods.



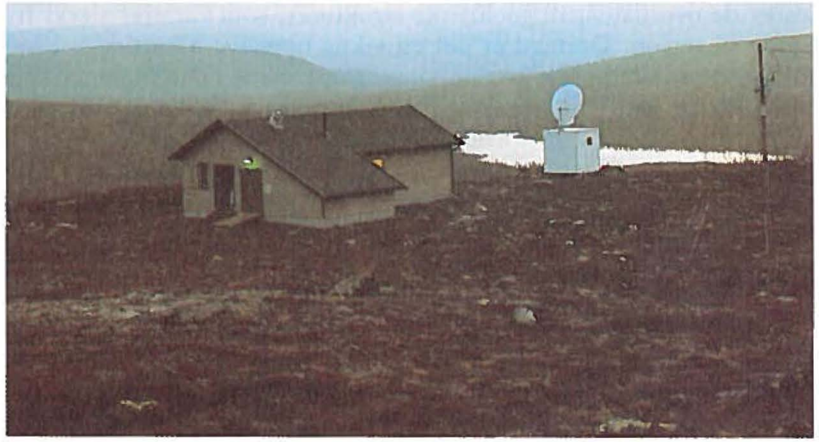
Short period seismometer designed to respond to the most detectable signals from underground explosions. The instrument is approximately 38 cm long.



Borehole instruments being installed at the array center site to record ground motions in the east-west, north-south, and vertical directions.



Site of the NORESS array. Seismometers are deployed on concentric circles. Data from all seismometers are cabled to the central site, where they are transmitted to a data processing center at Kjeller, Norway.

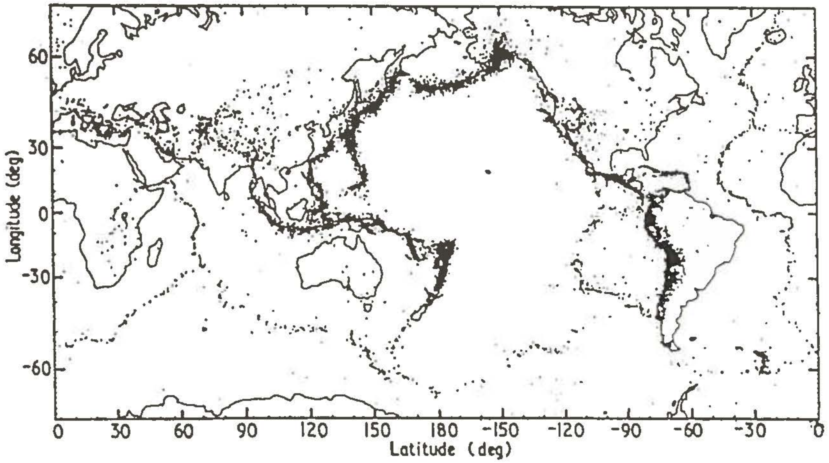


The ARCESS central field station houses instruments that provide power, timing signals and calibration commands to all instruments in the array. Data from the array seismometers are collected and transmitted by satellite to the NORSAR Data Center at Kjeller.

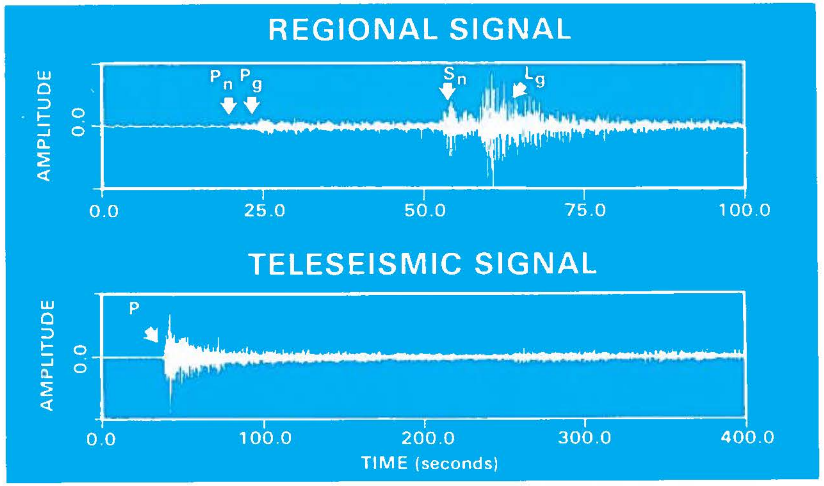
Detecting Nuclear Explosions

An important attribute of seismic arrays is their ability to detect very weak seismic signals that are submerged in background noise. This is done by computer processing the data with advanced algorithms. Signals from all seismometers are combined in ways that enhance the seismic signals of interest, while suppressing the noise. This is especially important for verifying a comprehensive test ban treaty because the ability to detect signals from low-yield tests, or tests conducted under conditions that muffle the signals, often has been cited as a main difficulty in ensuring reliable verification.

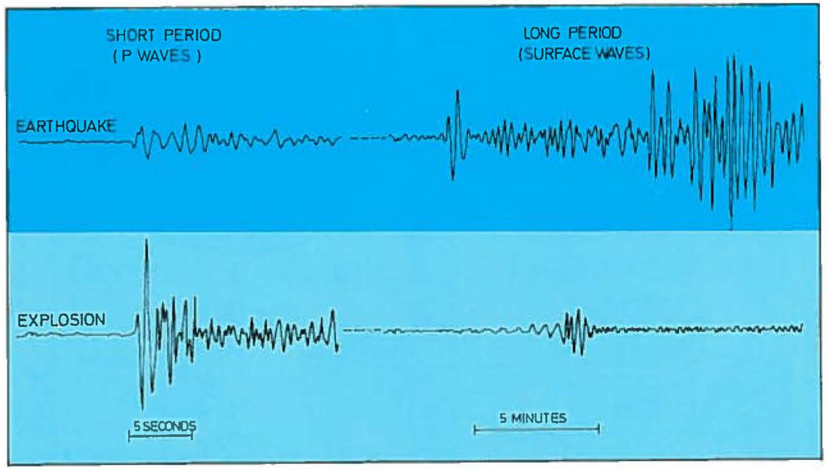
Another key problem in seismic verification is to reliably distinguish the seismic recordings originating from underground nuclear explosions from those produced by other sources, especially earthquakes. The many thousands of earthquakes occurring world-wide each year pose a formidable problem in this regard, and reliable source identification becomes particularly difficult as the size of the event decreases. Again, seismic arrays are especially well suited to handle these small events, and thus become essential also in a source identification context.



Earthquake occurrence world-wide (above magnitude 4.5) for a seven-year period.



The signals recorded at a seismograph station show different characteristics depending upon the distance from the source. At regional distances (less than 3000 km), the signals are complex in nature, whereas teleseismic signals (distance 3000–9000 km) are much simpler.



Seismic signals are recorded both from earthquakes and underground explosions. As shown on the figure, a typical earthquake signal (top) and an explosion signal (bottom) have different characteristic features, which may be used to discriminate between these two types of sources.

The Intelligent Array System (IAS)

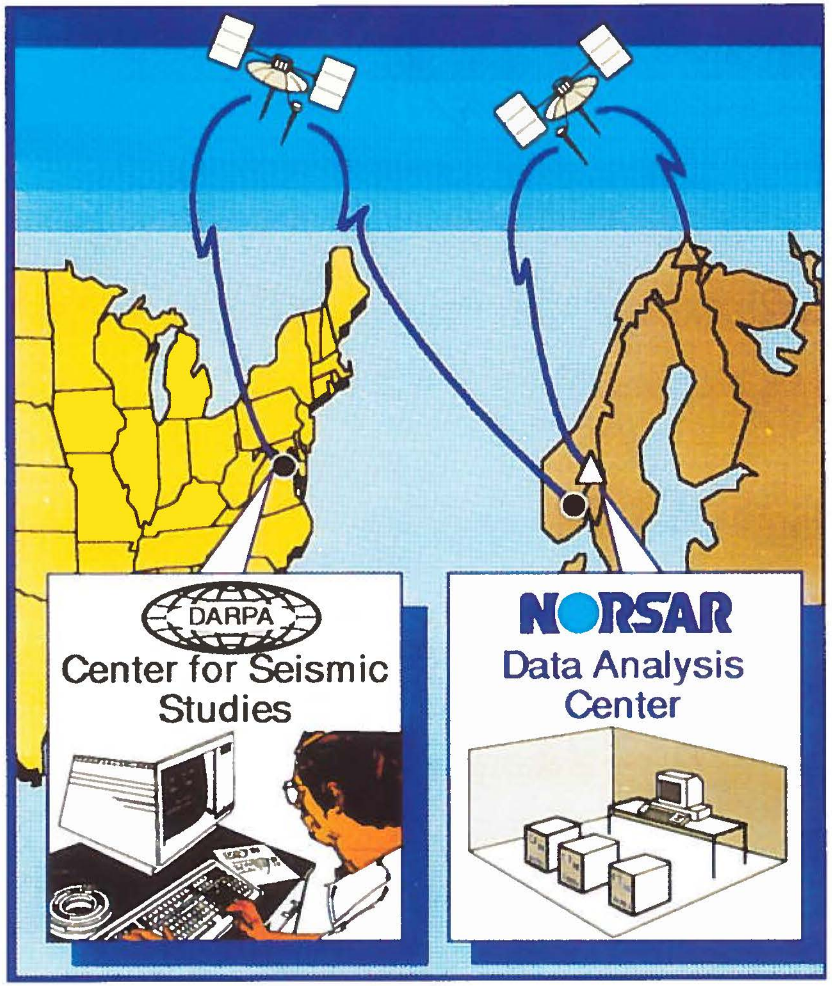
The Intelligent Array System represents a new generation of seismic data analysis technology designed to exploit the full potential of a network of sensitive regional arrays.

Each array produces an extremely large volume of data. Further, these new arrays are far more sensitive than traditional seismic stations and thus detect many more signals. Consequently, the analysis task is much greater and more complex, requiring a new approach to seismic data processing, analysis and management.

The IAS is a fully automated computer hardware and software system which analyzes the data from a network of arrays to locate and identify detected seismic events. The system has several elements distributed between the NORSAR Data Analysis Center, and the DARPA Center for Seismic Studies near Washington, D.C. Although the two analysis centers are separated by the Atlantic Ocean, their computers are connected by a direct high speed satellite link, and they are in constant communication across this link as if they were in the same location.

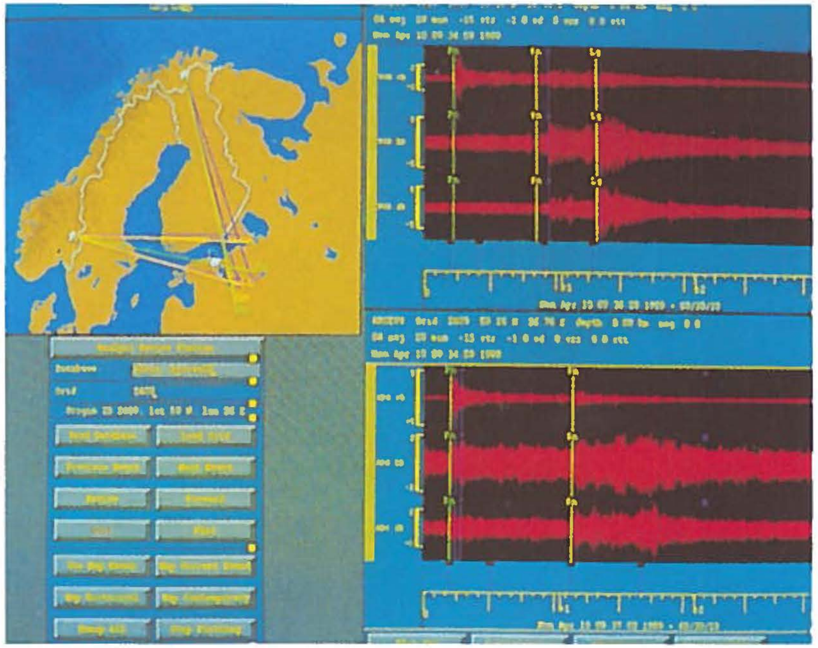
In this way, each of the two centers has identical capabilities to analyze the recorded data and access the data base for research purposes. Through international seismic data exchange, the data and results of this research will be available also to scientists from other countries.

Intelligent Array System
(IAS)



Automatic Signal Processing

The interpretation of the seismic data by the automated processing in IAS is presented to a seismic analyst for review and validation in the form of standard displays for consistency of event review. The signals are presented as filtered beams with the detections marked and labeled with their seismic interpretation (i.e., Pn, Lg, etc.). A map showing the seismic location and the error bounds of the automated event solution is provided with an estimate of the direction of arrival for each signal detected from this event.



Interactive Event Analysis

After the automatic IAS solution has been produced, the analyst can review this solution in detail and change any aspect by manipulating the waveform and map displays. All the results, including changes made by the analyst, are automatically updated into a database and monitored to make improvements to the automated and interactive processing as experience grows and new research results become available.

Fusion With Other Information

In addition to access to all the results of the automated processing, IAS incorporates the ability for an anlyst to view high quality satellite images from the SPOT Image Corporation. In combination with the raw and processed data, the analyst is able to review satellite imagery around the event locations. The 20 by 20 km area shown is in Estonia, and the small circle encloses a quarry which is the probable source of the detected seismic event. The ellipse marks the 95 per cent confidence limits for the location based on seismic data alone.

The Data Centers

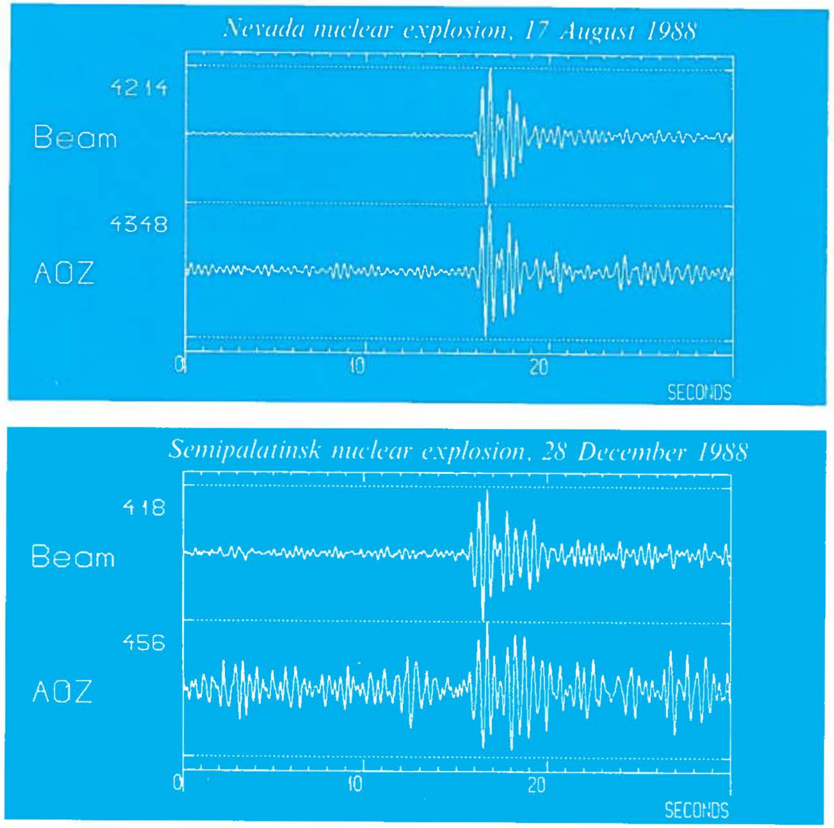
The high-speed transatlantic link enables coordination of the data analysis and interpretation between the data centers in Norway and the United States. Pictures from these two centers are shown below.

DARPA
Center for Seismic Studies

NORSAR
Data Analysis Center

Examples of Teleseismic Recordings

Although primarily designed to record weak seismic events at distances less than 3000 km, regional arrays have also demonstrated a great capability to detect seismic events in the teleseismic distance range (3000–10000 km), as shown below:

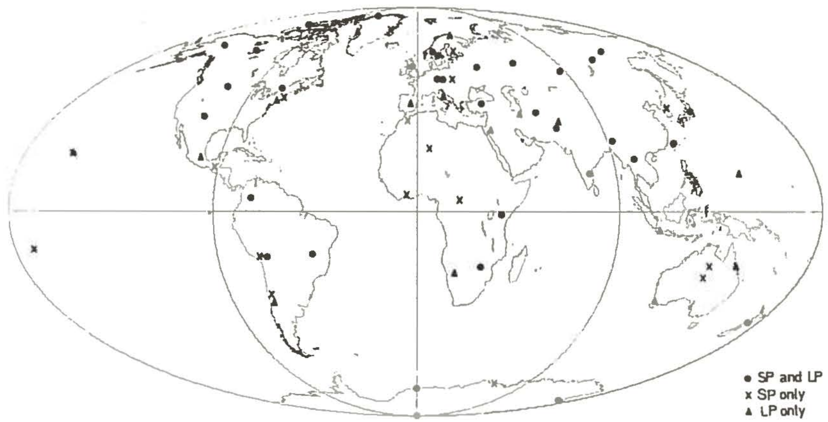


Nuclear explosions from Nevada, USA (distance 8100 km), and Semipalatinsk, USSR (distance 4200 km), recorded by the NORESS array. For each explosion, both the beam trace (i.e., the sum of all array sensors) and a typical single seismometer recording are shown. Note the significant improvement in signal-to-noise ratio on the NORESS beams compared to the single seismometer traces.

International Cooperation

Cooperative international efforts in the exchange and analysis of seismic data will form a vital part of CTBT verification. A key contribution in this regard has been the work of the Group of Scientific Experts (GSE) of the Conference on Disarmament. Since 1976, the GSE has conducted extensive studies and data exchange experiments regarding international cooperative measures to detect and identify seismic events.

Norway has consistently supported these efforts, both through active participation in the work of the Conference on the nuclear test ban issue and through significant contributions by Norwegian scientists to the GSE. In 1986, Norway formally proposed to the Conference on Disarmament that the global seismological network envisaged by the GSE should incorporate the establishment of small-aperture seismic arrays conforming to the NORESS concept earlier described.



The seismic expert group established by the Conference on Disarmament has proposed a global seismic network to assist in verifying a comprehensive test ban treaty. The stations in this network are shown on the figure.

Future Perspectives

A global seismological network would represent the cornerstone of a verification system for a comprehensive nuclear test ban. Great importance should therefore be attached to the continued efforts of the Group of Scientific Experts to develop a global system for the international exchange of seismic data, and the most recent technological developments should be utilized for this purpose.

In order to ensure adherence to such a future treaty, a global system will have to include high-quality seismic stations which are capable of detecting and identifying very weak seismic events. The NORESS and ARCESS seismic arrays in Norway represent some of the most significant recent advances in this regard, and should be taken into account when developing standards for the global network.

At the present time, two new regional arrays based on the NORESS/ARCESS concept are being deployed: The FINESA array in Finland and the GERESS array in the Federal Republic of Germany. Thus in the near future, a regional network of four highly sensitive seismic arrays will be available for joint analysis and research purposes. Data from all four arrays will be collected at NORSAR and made available for the IAS system.

Norway has made a commitment to make the seismic installations in Norway available for the global seismological network. Norway will furthermore continue to support the Group of Scientific Experts in its work toward developing reliable verification measures for a comprehensive nuclear test ban treaty.

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