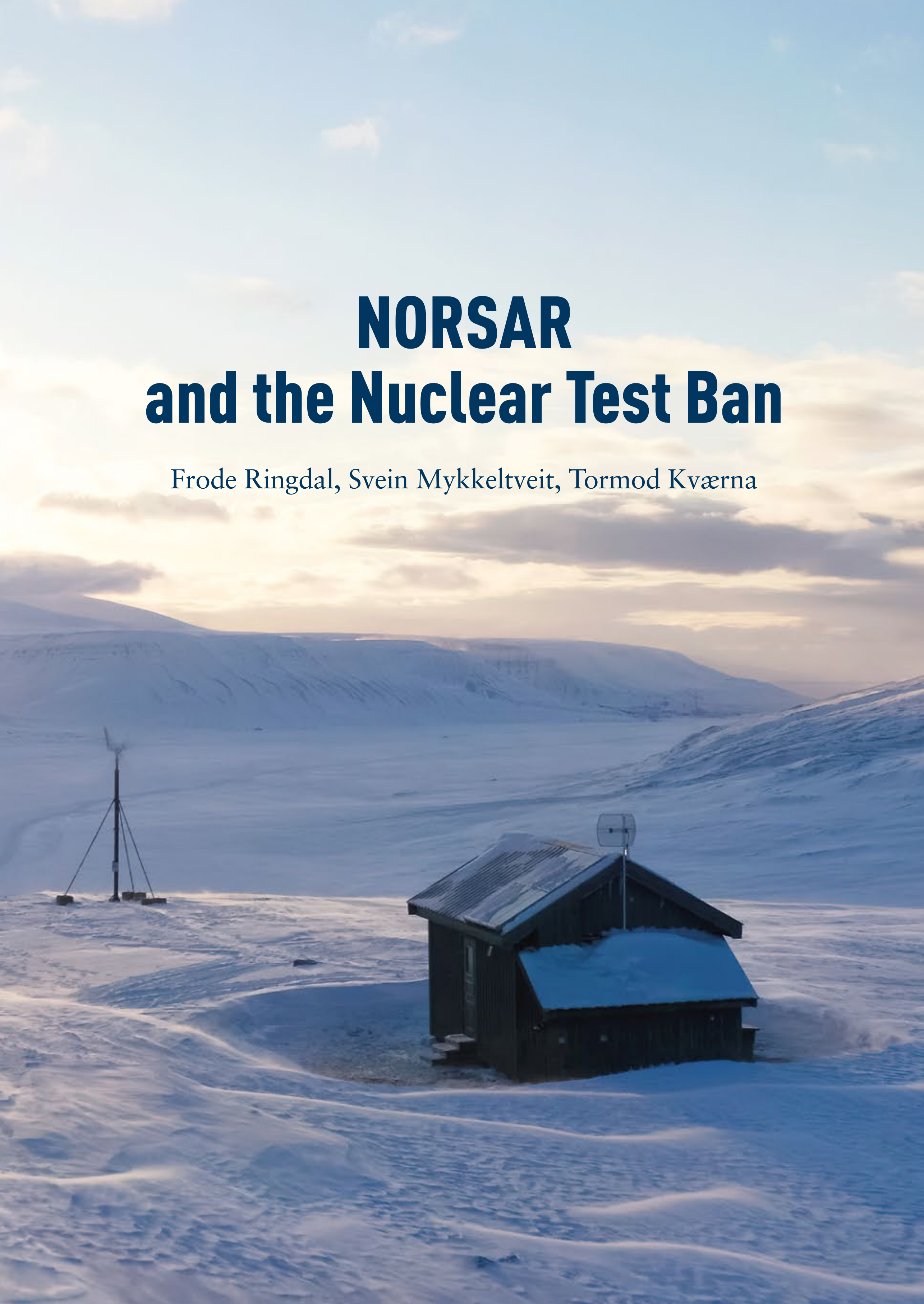
NORSAR
and the Nuclear Test Ban

Frode Ringdal, Svein Mykkeltveit, Tormod Kværna



Frode Ringdal joined NORSAR as a research scientist in 1969. He became the director of NORSAR in 1977, a position he held until 1997. He was scientific secretary of the Group of Scientific Experts during its entire twenty-year life span from 1976. Frode Ringdal served as a task leader in the Working Group on Verification of the CTBTO Preparatory Commission from 1997 to 2016. In 1999, he organized and led an international scientific effort on location calibration of the International Monitoring System, with annual seminars held over five years with the participation of specialists from about twenty countries. The results were essential for the successful calibration effort of the seismic network. Frode Ringdal has been a guest editor of the Bulletin of the Seismological Society of America, and has published numerous papers on seismology and topics relevant to nuclear test ban monitoring.

Svein Mykkeltveit was a delegate for Norway to the Group of Scientific Experts from 1986, and a convenor of the planning process for the group’s GSETT-3 experiment. He has advised Norway’s Ministry of Foreign Affairs on CTBT issues. From 1997 until 2019, he was a friend of the chair and task leader of the Working Group on Verification at the CTBTO Preparatory Commission. Since 1979, he has held research and managerial positions at NORSAR, and is currently a consultant. Svein Mykkeltveit was project leader for the design and establishment of regional seismic arrays in Norway in the 1980s and 1990s. He has authored papers on interpretation of seismic refrac-tion data, seismic array design, processing methodology for seismic data, understanding of the seismic noise field, and other topics relevant to monitoring of nuclear tests.

Tormod Kværna is a scientific advisor at NORSAR and a task leader of the Working Group on Verification at the CTBTO Preparatory Commission. He started working at NORSAR in 1984 as a seismologist and has since then held different research and management positions. He has conducted extensive research and written numerous papers on seismology and methods for monitoring of a nuclear test ban, in particular on the use of seismic arrays. Methods developed on data processing and network capability estimation have been implemented in the daily operations at the International Data Center of the CTBTO Preparatory Commission. Tormod Kværna is also a board member of the Norwegian National Seismic Network, and the Chair of the Norwegian National Committee to the International Union of Geodesy and Geophysics (IUGG).

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NORSAR

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The book covers the history until November 2021, when the first version of the manuscript was completed.

ISBN 978-82-693085-1-8

First edition December 2022 (printed)
This digital version of April 2024 includes a few corrections to the first edition.

Preface

This book represents our attempt to take the reader through the nuclear test ban history of NORSAR. This journey over more than 50 years contains many successes but also some disappointments. The story revolves around the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which was adopted by the United Nations in 1996, but still needs to enter into force. Our narrative emphasizes the activities at NORSAR in support of the CTBT, before and after its adoption, and how these activities responded to changing political and technical requirements over the years. Therefore, a major underlying theme is the interplay between NORSAR and other stakeholders in the CTBT environment, nationally and internationally.

NORSAR's original area of work focused on seismology and test ban verification, and this has remained its core business to date. However, after a few years, such disciplines as seismic risk assessment and seismic modeling for hydrocarbon exploration became substantial parts of NORSAR's activities. These and other activities which have emerged over the years are outside the scope of this book and are dealt with to a limited extent where there is a connection to test ban activities.

The narrative is mostly chronological, with most chapters covering approximately five years. However, at times we deviate from this pattern in order to improve the continuity and avoid reverting to a specific theme several times.

We have used the following source material for this book: our own notes, NORSAR's archives, proposition documents from the Norwegian Ministry of Foreign Affairs to the Norwegian Parliament (the Storting), meeting minutes and decisions of the Storting, reports and other documents issued by the Conference on Disarmament and the CTBTO Preparatory Commission, journal articles and books, newspaper articles, and more.

This book is our version of the story, colored by our experiences and emphasizing the subjects we happened to be engaged in and about which we have first-hand knowledge. Our colleagues at NORSAR may have had other experiences and observations over the years. Any errors of fact or interpretation are our sole responsibility. Views presented in this book are those of the authors and may not reflect, and do not represent, those of NORSAR nor Norwegian authorities.

We highly appreciate the careful and insightful editing by Jenifer Mackby for both substance and the English language. We would also like to thank colleagues at NORSAR for their support and advice.

Frode Ringdal
Svein Mykkeltveit
Tormod Kværna

Kjeller, Norway, November 2021

Executive summary

On 10 September 1996, the United Nations General Assembly made a historic decision. By a vote of 158 to 3, with five abstentions, it adopted the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which bans nuclear weapon test explosions and any other nuclear explosions in all environments. The text of the Treaty had been negotiated at the Conference on Disarmament (CD) in Geneva. Norwegian scientists provided key contributions to developing the treaty verification regime through NORSAR's participation in the CD Group of Scientific Experts for almost 20 years prior to the start of the CTBT negotiations.

Photo: www.ctbto.org

On 24 September 1996, the CTBT was opened for signature. The first Head of State to sign the Treaty was the United States President, William J. Clinton (shown in the picture). He characterized the CTBT as "the longest sought, hardest fought prize in the history of arms control negotiations."

Photo: Marty Lederhandler / AP Photo/ NTB

Norway's Prime Minister, Gro Harlem Brundtland (pictured), likewise signed the CTBT on 24 September 1996. Afterward, she said that it was particularly satisfying to hear the recognition of the sustained effort by Norway in the establishment of the Treaty.

Although the United Nations adopted the Treaty, its actual entry into force requires ratification by 44 specified countries. As of this writing, this has still not been achieved. Nevertheless, the Treaty has established an international norm of no nuclear testing, which contrasts with the more than 2000 nuclear tests carried out before the Treaty was adopted.

In this book, we cover the test ban history of NORSAR from the events that led to its establishment in 1968 until the present time. This story has two distinct phases: the long journey leading up to the decision by the UN to adopt the CTBT, and the now more than 25-year journey of implementing the Treaty, in anticipation of its entry into force.

We first summarize the early efforts to limit nuclear testing and address treaty verification arrangements. By the late 1950s, seismology was identified as the key technology, as it provides the means for detecting underground nuclear explosions, which represent the most difficult challenge to test ban verification. We then describe the initial experiments with temporary seismic installations in Norway in the 1960s, which resulted in a government-to-government agreement between Norway and the United States in 1968 to build and operate a large seismic array facility in southeastern Norway. According to this agreement, the purpose of the facility was to provide seismic data of earthquakes and nuclear explosions with the overall aim of developing and testing methods for verification of a future CTBT. The United States, through its Advanced Research Project Agency (ARPA), was to finance both the construction and the operation of the array. In particular, the United States was concerned about the Soviet Union's nuclear tests. Since the geological conditions in Norway were favorable for recording such tests, the U.S. took the initiative to build a large seismic facility in Norway in order to collect seismic data for research purposes.

The Norwegian Defence Research Establishment (FFI) constructed the seismic array facility (in this book referred to as NOA, its official station code, to distinguish it from the institution NORSAR) in 1968-1970. After detailed studies, it was concluded that an optimum cost-performance tradeoff would be obtained by constructing 22 subarrays, each consisting of 6 vertical short period seismometers and one three-component long period seismometer. The diameter of each subarray was about 8 km, and the array diameter was 110 km.

The Royal Norwegian Council for Scientific and Industrial Research (NTNF) was chosen in 1970 to manage the operation of the array and support the associated research. In line with this decision, NTNF established NORSAR on 1 July as a project with its own facilities, including a data center, at Kjeller. A small group of Norwegian scientists and invited specialists began working with the array data. The NOA array became well known internationally through several workshops with wide expert participation from many countries. In particular, a Nordic cooperation (Denmark, Finland, Iceland, Norway, Sweden) in detection seismology was established and is still active.

A significant change occurred after the NOA facility's first five years of full-scale operation. On 1 April 1976, ARPA informed NTNF that they planned a reduction of the size of the array. ARPA explained that it had changed its priorities regarding seismic monitoring research, focusing on a world-wide network of single-site Seismic Research Observatories rather than large arrays. ARPA would continue funding operations at the reduced level. This marked the end of the operation of the NOA array in its original size.

The new situation, however, led to an important new initiative that turned out to be a game changer in seismic monitoring. The staff at NORSAR, in cooperation with American scientists, began to develop a new small seismic array concept, focusing on processing high signal frequencies for events at the regional distance range of up to 3,000 km. The new array was named NORESS (Norwegian Regional Seismic Array System). It was dedicated at a ceremony in Oslo in 1985. At the dedication ceremony, the United States Ambassador to Norway, Robert D. Stuart, delivered a congratulatory message from the President of the United States, Ronald Reagan, to the Director of NORSAR on the construction of the most advanced regional seismic array in the world! NORESS became the model for many other small array stations in different countries.

Following the NORESS dedication, the NORSAR organization hosted a workshop for the entire Conference on Disarmament (CD), attended by 84 participants from 41 countries. The workshop aimed to shed further light on seismological verification aspects of a future CTBT through briefings and demonstrations of the seismological facilities in Norway. Similar workshops hosted by NORSAR before and after 1985 placed NORSAR at the forefront of CTBT verification work.

The workshop provided renewed inspiration for the work of the CD Group of Scientific Experts (GSE). The GSE had been meeting regularly in Geneva since 1976 to develop and test the framework for the seismic verification regime of a CTBT. From the beginning, representatives of NORSAR had participated actively in the GSE and provided substantial contributions to its work and reports. The GSE conducted three global tests on international seismic data exchange and processing (1984, 1991, and 1995-2000). The experience and knowledge gained from these tests formed the basis for the CTBT global monitoring system.

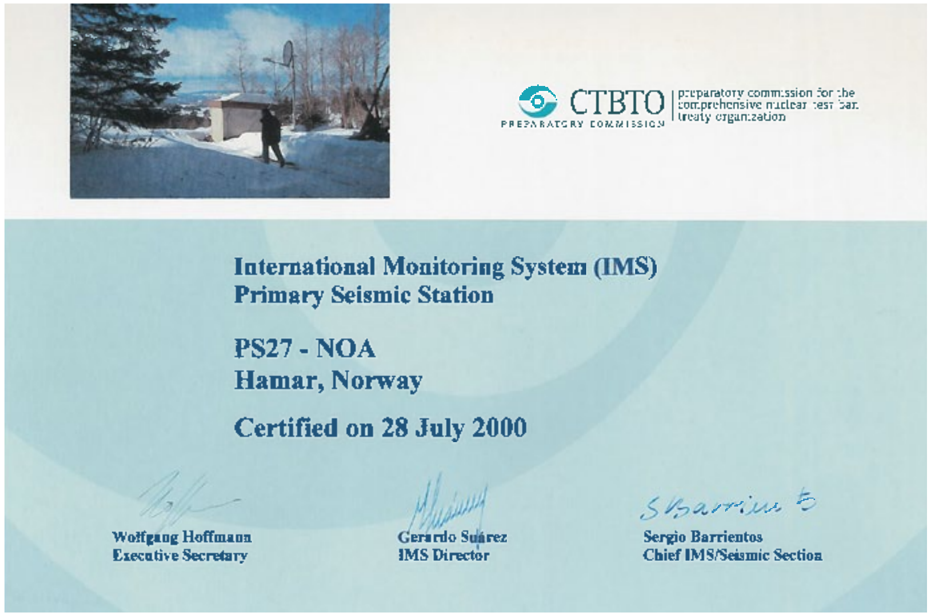
The Soviet Union/Russia conducted its final nuclear explosion at Novaya Zemlya on 24 October 1990. This explosion prompted a question in the Norwegian Parliament about what the government would do to promote a CTBT. The Minister of Foreign Affairs responded that he would initiate an expert study on technical questions related to a CTBT. NORSAR became a key participant in this expert study and contributed substantially to the report of the expert group, along with internationally well-known experts in the field. The Ministry of Foreign Affairs issued the report in May 1992, which anchored Norway politically and technically at the forefront of the process that led to the adoption of the CTBT in 1996.

Exploiting a window of political opportunity, the CD negotiated the CTBT in Geneva from 1994 to 1996, with representatives of NORSAR taking part in the technical deliberations related to treaty verification. Norway's diplomats also participated actively in the negotiations on legal and institutional issues. The negotiators drew heavily on the results of the GSE's work on seismic monitoring and the expertise of the GSE delegations to successfully develop the verification regime specified in the CTBT and its protocol. It is noteworthy that the CTBT prescribes that member states must make assessments about potential violations of the Treaty rather than relying on the Technical Secretariat (as is the case in the IAEA). The member states must therefore develop and maintain the competence needed to draw conclusions about suspicious events from data received from the CTBT verification regime and other data available to them from national technical means.

Since the United Nations' adoption of the CTBT in 1996, NORSAR staff members have participated in key positions in the CTBTO Preparatory Commission (PrepCom) in Vienna. The main technical task of the PrepCom and its Provisional Technical Secretariat (PTS) has been to develop and complete the International Monitoring System (IMS), which consists of networks of seismic, hydroacoustic, infrasound, and radionuclide monitoring stations, as well as the processing of data from the IMS at the CTBT International Data Center (IDC). Additionally, NORSAR hosted a sequence of five annual workshops on IMS location calibration in Oslo, with the participation of internationally acknowledged experts.

PrepCom created two working groups in 1997: Working Group A (WGA) for administrative matters and Working Group B (WGB) for verification. NORSAR represents Norway in WGB and assumed important roles in organizing the work in this group from the beginning; it has retained these roles to date. In addition, NORSAR's participation in WGB ensures that Norway's interests in all technical aspects of CTBT implementation are considered.

A proud moment for the NORSAR staff occurred when the PTS in the year 2000 selected the station NOA to be the first of 337 technical facilities of the International Monitoring System to be officially certified (pictured). This selection represented a recognition of Norway's substantial contributions over the years leading up to the Treaty. All six IMS monitoring stations on Norwegian territory were officially certified by 2013. As of this writing, 303 IMS facilities have been certified.



CTBTO
PREPARATORY COMMISSION
preparatory commission for the comprehensive nuclear test ban treaty organization

International Monitoring System (IMS)
Primary Seismic Station

PS27 - NOA
Hamar, Norway

Certified on 28 July 2000

Wolfgang Hoffmann
Executive Secretary

Gerardo Suárez
IMS Director

Sergio Barrientos
Chief IMS/Seismic Section

The CTBT verification regime convincingly demonstrated its capabilities on several occasions. India and Pakistan (neither of which have signed the Treaty) carried out nuclear explosions in 1998. North Korea, which likewise has not signed the Treaty, conducted six nuclear tests of increasing explosive yields from 2006 through 2017. All of these tests were detected by the IMS network, analyzed at the IDC, and reported expeditiously to the CTBT signatory states in special sessions of the CTBTO PrepCom, thereby confirming the adequacy of the verification provisions of the Treaty. In addition, the IMS network provided important seismic and radionuclide data during several natural disasters. These include, most notably, the tsunami catastrophe in the Indian Ocean in 2004, which caused the loss of more than 200,000 lives and the earthquake in Japan in 2011, which triggered the Fukushima catastrophic nuclear power plant accident.

As part of the parliament's decision in 1999 to consent to Norway's ratification of the CTBT, NORSAR was designated as the National Data Center (NDC) for Norway for CTBT verification matters. The NDC's role includes responsibility for establishing and operating IMS stations on Norwegian territory. The NDC also advises Norwegian authorities on CTBT compliance and other technical matters related to the CTBT. The parliament emphasized that Norway should act as if the Treaty had entered into force. Following this directive, NORSAR has actively provided its assessments, as it will do after entry into force of the Treaty, to Norwegian authorities on nuclear and other events. These assessments contain details that the PTS is not mandated to provide to its member states. Such detailed assessments have been provided, for example, on the Indian and Pakistani nuclear tests in 1998 and the six nuclear tests conducted by North Korea since 2006.

The Nordic cooperation in seismology has continued with annual meetings and celebrated its 50th anniversary in 2019. In addition, NORSAR has established close ties to other seismological institutions in many countries and provided technical assistance to developing countries to support their operations and research, as needed. In particular, NORSAR has contributed substantially to capacity building in CTBT verification in Central Asia. Many of these international projects were arranged through contracts financed by the Norwegian Ministry of Foreign Affairs.

After many years of reductions in NORSAR's funding from the Ministry of Foreign Affairs, NORSAR's management has, over the last 3-4 years, succeeded in restoring the annual funding to become comparable to the 1999 level in real terms. This increase, in combination with some additional, non-recurring funding for specific purposes, has enabled recruiting of a new generation of professional staff, standardization and quality assurance of procedures, modernization of data analysis software, and assignment of personnel on duty around the clock to ensure the provision of timely advice to the Ministry of Foreign Affairs of events of interest in the context of the CTBT.

Norway remains a strong supporter of the CTBT. NORSAR has provided a new generation of experts and continues to be active in various aspects of nuclear disarmament. With continued adequate support from the Ministry of Foreign Affairs, NORSAR has a solid basis in the years to come to continue to play an important role in advancing CTBT verification and hopefully contribute substantially to a process that will eventually bring the Treaty into force.

Contents

Chapter 1

The birth of NORSAR

1.1 Oslo 21 June 1967, in the parliament

A remarkable event occurred in Oslo on 21 June 1967. The Norwegian parliament's Extended Foreign Affairs and Constitution Committee met on that date. On the agenda, along with two other topics, was an innocuous item with the heading "Cooperation with the United States on a seismological station."

The topic seemed puzzling since it was well known that the United States already was operating 125 existing or planned conventional seismic stations in various countries, including three stations in Norway near Kongsberg, Kirkenes, and Ny-Ålesund, as well as a small experimental seismic array installed at Ringsaker to the southeast of Lillehammer in 1963, all in cooperation with the University of Bergen. One may have wondered why this subject needed to be taken up again.

In fact, this was an initiative that would have great ramifications. It would eventually lead to Norwegian scientists assuming a key role in developing the global verification regime for the Comprehensive Nuclear-Test-Ban Treaty!

When Norway's Minister of Foreign Affairs, John Lyng, took the floor to introduce this agenda item, he had to admit that leaked information had appeared in the premier newspaper in Norway, "Aftenposten." This newspaper had provided the day before a detailed description of the American proposal forwarded to Norwegian authorities in May 1967, so he assumed that some of the Committee members were already informed about the plans. The proposal was to establish an advanced seismic array in two stages, one stage to include an expanded small array with about 20 connected array elements at Øyer to the north of Lillehammer for testing purposes and, if the result was positive, a much larger array in the second stage. The installation costs for both the first small array and the large main array would be borne by the Americans through a scientific institution that was to be designated for this cooperation.

The foreign minister added that this area of Norway was suitable from a geological perspective, with favorable conditions for recording seismic events in the Soviet Union.

He also noted that for some time, preparatory work on a joint Nordic project in this field had been conducted and that an agreement in principle to pursue this initiative had been reached during a meeting of the Nordic foreign ministers in August 1965. This work had continued since then. Mr. Lyng said that potential cooperation between Norway and the United States on a new array project would not hinder the Nordic plan. On the contrary, it would be an excellent supplement to a Nordic seismic network.

BOX 1.1.1

Why seismology?

The most difficult problem in verifying adherence to the CTBT has always been to detect and identify a clandestine underground nuclear explosion.

The main technical tools for monitoring underground nuclear explosions come from the field of seismology, which is the study of earthquakes and related phenomena.

Seismology makes use of seismic stations, which sense and record the ground vibrations from seismic waves generated by sources at various distances from the station. Such seismic sources are typically earthquakes but can also be underground explosions, including nuclear detonations, as well as various phenomena in water and on the surface of the Earth. The analysis of data from seismic stations sheds light on the nature of the sources. It can indicate whether a specific vibration - a seismic signal - originates from an earthquake or an explosion. Seismic waves are also used to map the inner structure of the Earth, from the crust to the core.

The United States was naturally concerned with the Soviet Union's nuclear tests. The geological conditions in Norway were favorable for recording such tests, which is why the U.S. took the initiative to build a large seismic facility in Norway to collect seismic data for research purposes.

BOX 1.1.2

Seismic arrays

A seismic array is a group of seismometers distributed over an area and connected to a central site, where the signals are processed jointly.

By adding the individual traces from the seismometers with various time delays, one can make the array act as a large antenna, which can be steered in any given direction and at various wave propagation speeds. This process of adding the individual traces (called "beamforming," resulting in a trace called a "beam") also serves to amplify signals propagating across the array because the signals tend to be fairly well correlated from trace to trace, while the ever-present seismic background noise is generally uncorrelated. Seismic arrays provide an estimate of the location of the source and a lower signal detection threshold than that of a single seismic station.

Seismologists identify specific seismic "phases" in the seismograms. Some of the most important phases are the short-period P (primary), S (secondary), and Lg waves and the long-period surface waves (Rayleigh and Love waves). Seismic phases propagate at different speeds and modes (compressional or shear waves) and through different parts of the Earth's interior. Examples of a seismologist's identification of various phases are shown in Fig. 1.1.1.

The NOA array in Norway is in the class of large-aperture arrays (more than 50 km in diameter) designed for optimum detection of signals from sources at long distances from the station, while the NORESS-type small arrays are typically 5 km or less in diameter, with a geometry aiming at best performance for sources at shorter distances.

The foreign minister finally noted that a number of institutions in Norway had been informed about the two-stage approach proposed by the United States: among others, the Norwegian Ministry of Defence, the Norwegian Defence Research Establishment (FFI), the Seismological Observatory of the University of Bergen, and the Royal Norwegian Council for Scientific and Industrial Research

(NTNF). None had expressed any reservations about either stage 1 or stage 2. The Seismological Observatory in Bergen, in particular, emphasized that such an undertaking would have great scientific merit.

After a short discussion, the foreign minister concluded that the Committee agreed to the first stage in the plan and would await the result of this stage before deciding upon the second stage.

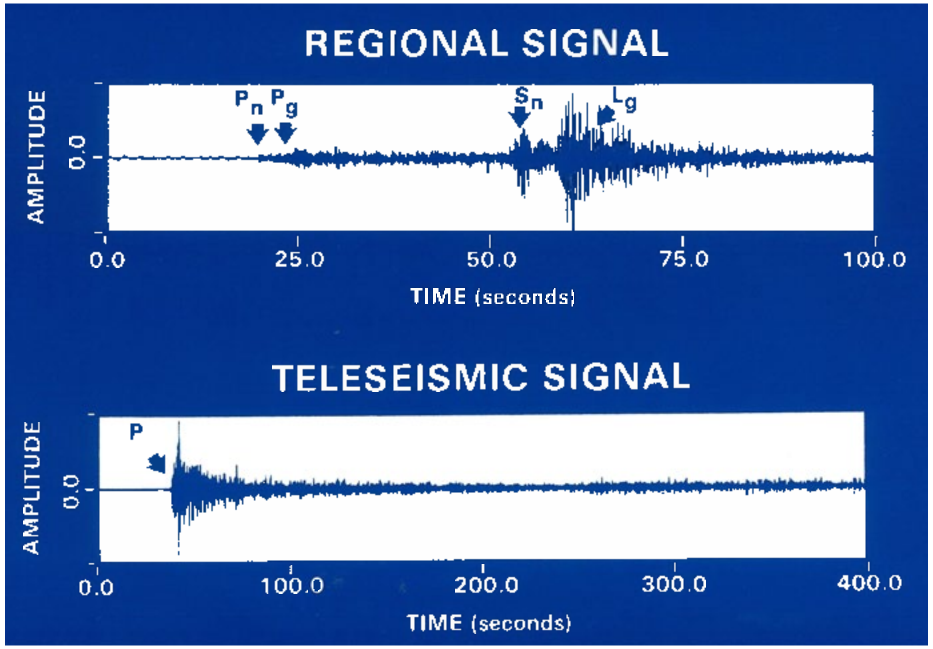


Fig. 1.1.1 For short-period waves, it is often practical to classify the distance from the source to the receiver as either regional (0-3,000 km) or teleseismic (3,000-10,000 km). However, it can be difficult to identify the regional phases, and there are many borderline cases. This figure was prepared on the occasion of the inauguration of the NORESS array in 1985.

1.2 Political and scientific background

It would be useful here to briefly review the developments in both the political and technical arenas that had taken place in the years preceding 1967. The United States conducted the first nuclear test explosion in July 1945, and the Soviet Union followed suit in 1949. By 1964, the United Kingdom, France, and China also had tested a nuclear device. Public concern over nuclear weapons and nuclear test explosions was growing steadily, including in Norway, which suffered from radioactive fallout from atmospheric testing at the Soviet test site at Novaya Zemlya. The first international initiative to address limitations to nuclear testing was taken by Prime Minister Jawaharlal Nehru of India in 1954 when he called for a “Standstill agreement.” Other attempts at achieving bans or limitations on testing followed this initiative. During 1959-60 negotiating partners, the Soviet Union, the United Kingdom, and the United States, even observed a moratorium on tests. However, none of the attempts prior to 1963 resulted in an agreement.

The cooperation between Norway and the United States described above was by no means the first initiative to address the science of seismology in detecting nuclear explosions. A goal of the United States had been to negotiate a halt of nuclear tests on the condition that a reliable verification regime could be established. The most difficult verification problem was related to underground nuclear explosions, so the research focused on seismology.

The first scientific meeting on the verification of underground explosions was held in Geneva in 1958. It included experts from Canada, Czechoslovakia, France, Poland, Romania, the Soviet Union, the United Kingdom, and the United States. They discussed detection methods and defined the capabilities of a network of 180 “Control Posts” to verify compliance with a possible treaty.

In 1959, the so-called Berkner Panel in the United States followed up on the Geneva experts’ work. It proposed a comprehensive research program in seismology and systems development aiming at a worldwide seismic system for monitoring underground nuclear explosions. Following the recommendations of the Berkner Panel, President Dwight D. Eisenhower initiated a United States seismic research and development program named Vela Uniform and assigned it to the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense. By 1970, about 450 million U.S. dollars had been spent on this program.

Several initiatives were taken under Vela Uniform. The United States established inter alia the previously mentioned global network of 125 single seismic stations in more than 60 countries, known as the World-Wide Standardized Seismograph Network (WWSSN), and five small array stations named the Vela arrays on the U.S. mainland. Whereas WWSSN gave the science of seismology a great push forward, it became clear that a network of single seismic stations was not sufficient for satisfactory detection and identification of underground nuclear tests. On the other hand, seismic arrays were considered to have the potential for an adequate treaty monitoring system. Such arrays, composed of a number of seismic sensors placed in a geometrical pattern, have, as noted in Box 1.2, the ability to enhance weak seismic signals and provide an estimate of the geographical location of the source of the signal.

In 1963, the United States, the United Kingdom, and the Soviet Union negotiated the Treaty Banning Nuclear Tests in the Atmosphere, in Outer Space and Under Water – the Partial Test Ban Treaty – which confined testing to underground but did not include a verification regime. France and China were not parties to the Treaty and continued to carry out nuclear tests in the atmosphere until 1974 (France) and 1980 (China). Nevertheless, the majority of nuclear testing was conducted underground at that time, and this largely eliminated the problem of nuclear radiation fallout, which had been a major concern for many countries.

The size also referred to as the yield of a nuclear explosion, is typically specified in kilotons (1000 tons) or megatons (1 million tons) of chemical explosive equivalent. The United States carried out its largest *atmospheric* test, named Castle Bravo, measuring 15 megatons, on 1 March 1954 at the Bikini atoll in the Pacific Ocean. This yield is about 1000 times the size of the Hiroshima bomb. The Soviet Union conducted its largest atmospheric test, Tsar Bomba, on 30 October 1961 at Novaya Zemlya, and it measured as much as 50 megatons, according to Soviet sources.

The United States detonated its largest *underground* nuclear test on 6 November 1971 on Amchitka Island, Alaska, with a yield of nearly five megatons. The largest Soviet *underground* nuclear test, on 27 October 1973, was carried out at their test site on Novaya Zemlya and had a yield of four megatons. Thus, the Partial Test Ban Treaty did not, to any great degree, restrict the continuation of nuclear testing. Fig. 1.2.1 illustrates the large span in the yields of nuclear explosions.

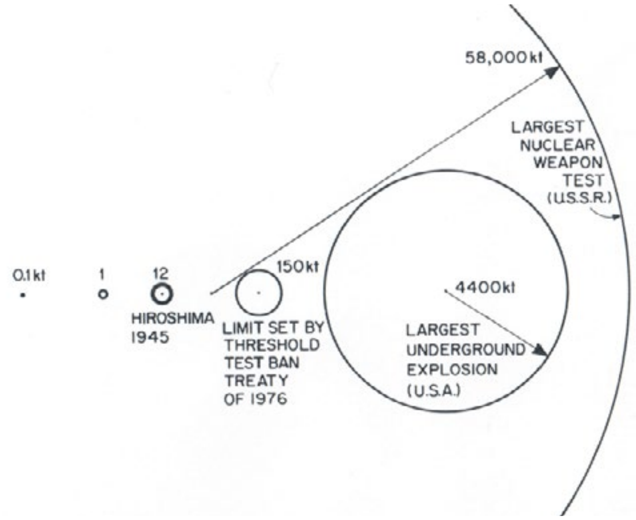


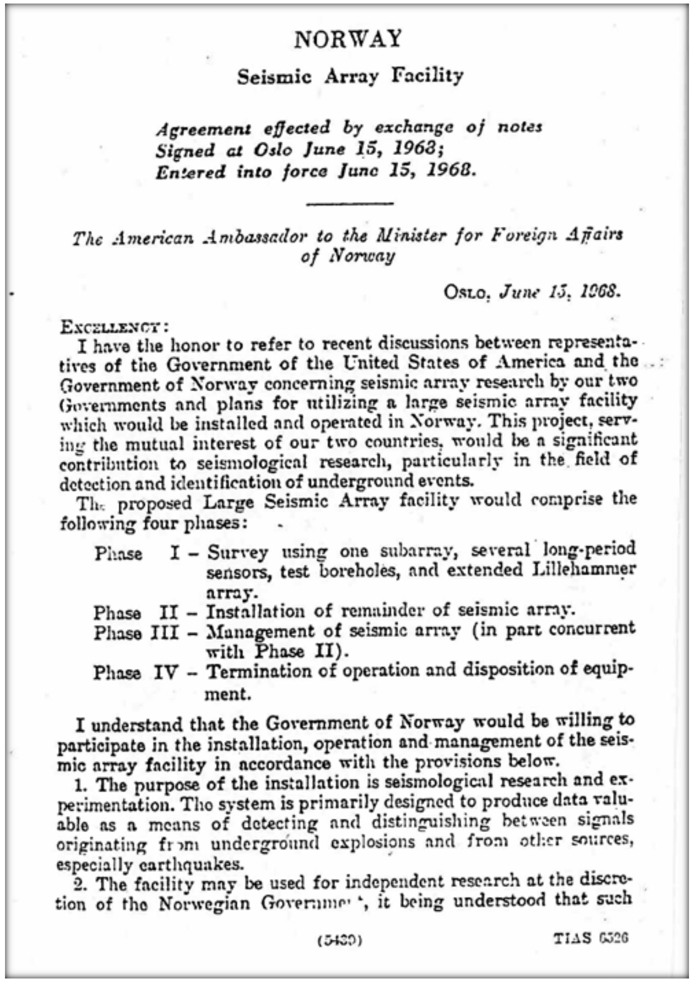
Fig. 1.2.1 *Yields in kilotons (kt) for various nuclear explosions, as illustrated by Sykes (1988). The size of the area within the circles is proportional to the yields of the explosions. Note that the yields shown in this figure may deviate slightly from the yields provided in the text in this book.*

As noted previously, the Partial Test Ban Treaty of 1963 did not ban underground nuclear tests because the scientific basis for a satisfactory verification regime for such tests was not available at that time. The focus on seismological verification research, therefore, continued and intensified. The United Kingdom had an independent program for seismic arrays and established medium-size array stations in the U.K., Canada, India, and Australia. The Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense built a gigantic seismic array (525 sensors within an aperture of 200 km) in Montana named LASA, together with an array in Alaska (ALPA), and the assumption was that a few such arrays would be capable of monitoring the entire globe. The proposed large array in Norway was to be built on the experience gained from LASA, assuming that the planned approach presented in the meeting in the Norwegian parliament on 21 June 1967 was successful.

1.3 Agreement with the United States signed on 15 June 1968

The plans from 1967 came to fruition. Almost exactly one year after the June 1967 meeting in the parliament, on 15 June 1968, the Norwegian Minister of Foreign Affairs, John Lyng, and the United States ambassador to Norway, Margaret Joy Tibbetts, signed the exchange of notes that established “the Large Seismic Array facility,” as it was initially called. Two weeks earlier, the parliament unanimously and without debate had consented to the government's proposition to enter into the agreement with the United States. Even the two representatives of the Socialist People's Party in the parliament were in favor of establishing the array and welcomed it as a promising initiative, even though this party, in general, was more reluctant to cooperate with the United States than the other parties in the parliament.

The full text of the government's proposition for cooperation with the United States in detection seismology (St. Prp. 128 (1967/68)) is found in Appendix 1. The first page of the American text is shown in Fig. 1.3.1.



NORWAY

Seismic Array Facility

Agreement effected by exchange of notes
Signed at Oslo June 15, 1968;
Entered into force June 15, 1968.

The American Ambassador to the Minister for Foreign Affairs of Norway

OSLO, *June 15, 1968.*

EXCELLENCY:

I have the honor to refer to recent discussions between representatives of the Government of the United States of America and the Government of Norway concerning seismic array research by our two Governments and plans for utilizing a large seismic array facility which would be installed and operated in Norway. This project, serving the mutual interest of our two countries, would be a significant contribution to seismological research, particularly in the field of detection and identification of underground events.

The proposed Large Seismic Array facility would comprise the following four phases:

Phase I – Survey using one subarray, several long-period sensors, test boreholes, and extended Lillehammer array.
Phase II – Installation of remainder of seismic array.
Phase III – Management of seismic array (in part concurrent with Phase II).
Phase IV – Termination of operation and disposition of equipment.

I understand that the Government of Norway would be willing to participate in the installation, operation and management of the seismic array facility in accordance with the provisions below.

1. The purpose of the installation is seismological research and experimentation. The system is primarily designed to produce data valuable as a means of detecting and distinguishing between signals originating from underground explosions and from other sources, especially earthquakes.

2. The facility may be used for independent research at the discretion of the Norwegian Government, it being understood that such

(5439) TIAS 6526

Fig. 1.3.1. *The first page of the American text of the agreement.*

The agreement stated that *"the proposed Large Seismic Array facility would comprise the following four phases:*

Phase I – Survey using one subarray, several long-period sensors, test boreholes, and extended Lillehammer array.
Phase II – Installation of remainder of seismic array.
Phase III – Management of seismic array (in part concurrent with Phase II).
Phase IV – Termination of operation and disposition of equipment."

One of the provisions of the agreement states that data from the array facility can be shared openly. The agreement specified the cooperating agencies on each side: ARPA for the United States and FFI and NTNF for Norway. FFI would be responsible for the planning, procurement, installation, and testing of the array, whereas NTNF or another appropriate agency to be agreed upon would undertake the future operation and management of the array. The Institute of Seismology of the University of Bergen would serve as an advisory body and be an independent user for its own research of the data supplied by the array. It became clear early on during the negotiations leading to the agreement with the United States that the Institute of Seismology, due to its limited resources, would not be able to take responsibility for establishing and operating the large array facility (see Sellevoll and Sundvor, 2001).

Phase IV was further addressed in provision 9 of the agreement:
"9. This agreement shall remain in force until terminated by either Government after giving one year's written notice to the other Government of its intention to terminate the agreement. Such notice may be given at any time on or after June 30, 1971."

When the agreement was signed, Phase I was more or less completed. The design of the small array at Øyer was in part based on analysis of data from the small array installed at Ringsaker in 1963. The array at Øyer was then established with 12 elements in the fall of 1967. The goal of 20 elements had to be abandoned due to harsh winter conditions beginning already in November. A small array was simultaneously installed at Falldalen, southeast of Hamar, with boreholes to investigate whether placing sensors at depth rather than at or near the surface would improve the ability to detect weak signals.

The United States and Norway wanted to sign the agreement and start Phase II as quickly as possible. There was thus little time to digest the results from Phase I before the plans for Phase II needed to be completed. However, the data from Øyer at least helped to confirm the suitability of the general area selected for the envisaged array.

During January and February 1968, Norway and the United States embarked on hectic work to meet an early deadline to determine the layout of the sensors of the array to be installed in Phase II. In this work, the experts drew on the experience from the LASA array. They tried through computer simulations to find an optimum configuration for the array within an area of approximately 100 km diameter and within the envisaged funding available for the project. During this design phase, the array geometry changed drastically several times until a final configuration was settled on in March. This settlement allowed preparation for Phase II to proceed so that the agreement could be signed in June, as noted previously, and construction work could start in the field shortly after that. Chapter 2 contains a description of the field systems installed during 1968-1970 by FFI.

1.4 Terminology and organizational matters

The agreement with the United States did not use the term "NORSAR." This term first appeared in the reports issued by FFI on their construction of the new large seismic array facility as a short version of "Norwegian Seismic Array." Upon completion of the array installation in 1970, a research institution affiliated with NTNF was created that, over the years, also has been referred to as "NORSAR." The research institution was first a project and later a department of NTNF and, since 1999, an independent foundation with various formal names over the years, such as "NTNF/NORSAR" (until 1993) and "NORSAR (Norwegian Seismic Array)," and since 1999 "Stiftelsen NORSAR." Thus, the term "NORSAR" has had several meanings. For clarity in this book, "NORSAR" will denote the research institution created in 1970, whereas we will refer to the large seismic array facility installed during 1968-1970 as "NOA" or the "NOA array." "NOA" is the official station code registered in the International Registry of Seismograph Stations maintained by the International Seismological Centre.

On the organizational side, FFI took the first steps in Norway in the execution of the 1968 agreement, under a contract with the U.S. Government, to prepare for and install the new seismic array in the field and to establish the data processing center at Kjeller. For these activities, FFI hired the necessary personnel. Many of them were later employed by NORSAR when this new facility took over the operations on 1 July 1970. FFI's engagement ended on that same date. Details on these developments are provided in Chapters 2 and 3.

Chapter 2

1968 - 1970
The start-up years

2.1 The field systems of the NOA array are constructed. IBM develops the computer software

FFI organized the establishment of the NOA array as a special project directly under its director since this effort was not related to the FFI's portfolio of R&D projects. FFI managed the construction work under NOA Phase 1 and concluded it successfully. The stage was now set for the NOA array's main construction phase, Phase 2.

Both Phase 1 and Phase 2 were admirably planned and executed. The overall construction effort is documented in great detail in FFI reports:

(1) Final Technical Report, NORSAR Phase 1
(2) Interim Technical Report, NORSAR Phase 2: The 1968 Installation Program
(3) Final Technical Report, NORSAR Phase 2: Installations 1969 and 1970

These documents were approved for public release, sale, and unlimited distribution. The documents have served as important resource material to the operations staff at NORSAR ever since the installation of the array.

As previously noted, the NOA array design, in many ways, used the experience of the Montana LASA array, which was built in 1965. However, many new challenges must be met regarding design, methods, and procedures. For example:

- The planned seismometer location could be difficult to access, especially in mountainous areas
- There might be excessive thickness in the unconsolidated deposits over the bedrock

- The location was too close to a source of seismic noise (e.g., river, timber road)
- The landowner of a proposed site might be reluctant to accept the installation on her/his ground.

After detailed studies, it was concluded that an optimum cost-performance tradeoff would be obtained by constructing 22 subarrays, each consisting of six vertical short-period and one three-component long-period seismometers. The diameter of each subarray would be about eight km, and the array diameter would be 110 km. The geometry of NOA with its original 22 subarrays is shown in Fig. 4.2.1.

Overall, the construction of the NOA field systems and the development of the associated software was a huge undertaking, which encompassed the following:

- Several years of experimental deployments,
- Agreements with 750 landowners, who were affected by cable trenches and seismometer vaults on their ground,
- Fine-tuning of the location of each of 132 short-period seismometer sites and 22 three-component long-period sites,
- Building for each of the 22 subarrays a central terminal vault and a separate vault for long-period seismometers,
- Laying hundreds of kilometers of buried cables connecting each site to the central terminal vault of the associated subarray,
- Arranging for power lines to the subarrays and the seismometers,
- Providing analog to digital conversion of the seismometer data at the central vault of each subarray
- Leasing dedicated telephone lines from each subarray to the NOA data center at Kjeller.

Based on the results of short-period seismic noise studies under Phase 1 and the first stages of Phase 2, it was determined that the increase in the signal-to-noise ratio with seismometer depth was moderate and did not warrant the extra cost involved in drilling deep holes. Thus, a 60 m deep borehole at the center drilled in the A- and B-subarrays was omitted in the C-ring (see Fig. 4.2.1 for the original assignment of subarray denotations).

Project status meetings were usually held every two weeks. The construction of what was going to be the second-largest seismic array in the world was completed on July 1, 1970. See Fig. 2.1.1 for some photos taken in 1969 during the fieldwork. FFI received a total of 41 million NOK from ARPA and the U.S. Air Force for its work associated with the establishment of NOA, which would correspond to approximately 400 million NOK today, adjusting for inflation over the past 50 years. Note that this amount is mostly for the civil works in the field (access roads, trenches, cables, vaults, etc.) and does not include the cost of equipment supplied directly from the United States, such as seismometers, other field electronics, computers and other devices for the NOA data center at Kjeller.

Fig. 2.1.1 *Visitors inspect the field work in 1969 (left). Installation of one of the long-period seismometers (right). Photo credit: Torben Risbo.*

IBM (Federal System Division) had developed the LASA software and obtained the contract to develop the NOA software. About 100 IBM employees worked at the Van Ness Center in Washington, D.C., on the NOA software from 1968 until 1970. At that point, a group of engineers moved temporarily to Kjeller for one year to finalize the system in cooperation with the Norwegian staff.

As described by Njølstad and Wicken (1997), FFI, and in particular its director, Finn Lied, had worked actively since the early 1960s to secure roles for Norway and FFI in a verification regime under discussion at that time of a treaty that would ban underground tests exceeding five kilotons. Finn Lied also took initiatives at the national level to have Norway join the international research efforts on detecting and locating underground nuclear explosions by seismic means. Later, during the negotiations with the United States on the large array cooperation, he tried to convince Norwegian authorities that FFI should be responsible for the development work associated with the processing of the array data. As mentioned, this did not come to fruition. Nevertheless, Finn Lied's contributions to the successful negotiation and implementation of the agreement with the United States can not be overestimated.

2.2 The NOA array data center is established, and the initial NORSAR staff is hired

The NOA array data center was established in 1968. It was built as an extension to the Kjeller Computer Installation, a joint computer facility for the University of Oslo, FFI, and some other institutions at Kjeller. The data center was located outside the fenced FFI premises in order to emphasize the openness of the NORSAR project. This openness was, in fact, stated as a requirement in the Government-to-Government agreement.

The data center facilities were designed to accommodate the full eventual NOA computer installations, which meant that there was sufficient space for two IBM 360-40 mainframes, 15 magnetic tape drives, and large (at that time) disk systems (see Fig. 2.2.1). In addition, there was a storage room large enough to store 30,000 magnetic tapes.

Fig. 2.2.1 *The NORSAR computer facility circa 1970.*

It is interesting to compare the original configuration to today's installation. More than 50 years later, the huge original mainframe computer system has been replaced by microprocessors and the main floor has been converted into a meeting area.

FFI initially employed the NORSAR scientific staff at the data center, which comprised a small group within the Kjeller Computer Installation led by Svein A. Øvergaard. A number of computer operators were hired, initially as FFI employees, to enable 24/7 availability at the data center. Scientists and operators became employees of NORSAR when this new institution was established under NTNF on 1 July 1970.

Field maintenance was the responsibility of FFI until 1 July 1970 and was carried out by the contractor Noratom-Norcontrol A/S. This contractor retained its assignment until 1 October 1971, when NORSAR took over the responsibility for field maintenance using its own employees. Eight of the field technicians employed by this contractor took up employment with NORSAR from this date. A repair and maintenance workshop was set up at Brumunddal, close to the center of the NOA array. A few years later, this workshop moved to Stange and, in the 1980s, to Hamar.

The initial scientific staff at NORSAR comprised Eystein Husebye, Ole Steinert, Frode Ringdal, and Hilmar Bungum, supported by the secretary Linda Tronrud (subsequently Loughran). In particular, Eystein Husebye's contributions as the chief seismologist were invaluable (see Fig. 2.2.2), as he organized research projects and invited experts in the field to come to NORSAR and work with the staff for extended periods of time. The NTNF scholarship program provided essential support in these efforts. Among the invitees were scientists from the United States, the Soviet Union, the United Kingdom, Germany, Sweden, Denmark, Finland, and many other countries.

In 1973, Eystein Husebye initiated a series of half-yearly NORSAR Semiannual Technical reports (see Fig 2.2.3), that were regularly published for nearly 50 years. These reports covered seismic stations operations and ongoing scientific work at NORSAR, were widely distributed, and became well known in the scientific community. They provided an opportunity to quickly disseminate the most recent research results.

Fig. 2.2.2 Eystein Husebye giving a lecture to an audience visiting NORSAR in 1969. Photo credit: Torben Risbo.

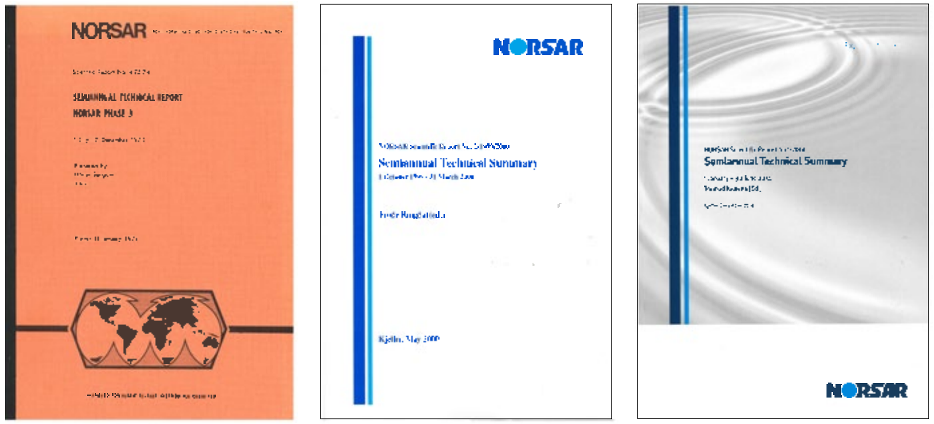


Fig. 2.2.3 Examples of front pages of NORSAR Semiannual Technical Summaries as of 1973 (left), 2000 (middle), and 2014 (right).

2.3 Nordic cooperation in detection seismology

As mentioned in Chapter 1, an agreement was reached in a meeting of the Nordic (Denmark, Finland, Iceland, Norway, Sweden) foreign ministers in Oslo in August

1965 to pursue a co-operative project in detection seismology. The ministers agreed to investigate whether the Nordic countries could contribute to detecting and identifying underground nuclear tests by establishing seismic stations on Nordic territory. In this section, we will review what came out of this initiative, which was one of the earliest international multilateral collaborations on CTBT-related verification.

On 11 January 1966, Alva Myrdal chaired a meeting in Stockholm. She was a well-known Swedish diplomat, politician, author, and advocate for nuclear disarmament and the recipient of the Nobel Peace Prize in 1982, together with Alfonso García Robles of Mexico. It was decided at this meeting to appoint a committee for Nordic cooperation in detection seismology composed of technical and scientific experts. The foreign ministries elaborated and approved a mandate for this committee. This mandate is contained in Box 2.3.1, in which the committee members are also listed.

The committee delivered its report in March 1967. Taking into account that detection seismology was a young science in the Nordic countries at the time, the report is an impressive work. It outlines key issues and open questions related to seismological verification, several of which are still pursued in research today. In line with its mandate, the committee concentrated on assessing the feasibility of various types of seismic stations and arrays for detecting underground nuclear explosions for installation somewhere in the Nordic countries. In particular, the committee considered a large LASA-type array, arrays of the UK type, and the type installed at Ringsaker near Lillehammer in Norway in 1963. In addition, plans by Sweden to install an array station in Värmland, developed at that time, were also taken into account. For possible station locations in the Nordic countries, the committee considered factors such as geological conditions, topography, natural and man-made background noise, seismic signal strength, and existing infrastructure (road access, telecommunications, sources of power).

The committee concluded that a large LASA-type array with a capability of lowering the detection level by as much as 1.5 magnitude units compared to single seismometers for seismic events at distances up to 10,000 km would best be placed in southern Finland, southern Norway, or the border area between southern Norway and Sweden. Alternatively, one or several smaller arrays installed in Finland and/or Sweden, Norway, and Greenland, could also increase the detection capability considerably. The committee also estimated costs but considered it to be “outside its competence to propose a definite financing arrangement.”

BOX 2.3.1

The mandate of the Nordic Committee and its initial members

The mandate for the Nordic committee to investigate options for finding solutions to the verification issues related to a comprehensive nuclear test ban treaty, with the use of seismic stations (in the authors' translation from Swedish):

1. *Consider and assess different systems for the detection of underground nuclear explosions. The options to be considered are:*
    a) A station of the LASA type,
    b) A station or stations of the UK type,
    c) The common use of existing stations,
    d) Possibly other alternatives.
2. *Consider in which way those systems that the committee finds to have scientific merit can be implemented in the Nordic countries and provide preliminary estimates of costs.*
3. *Look into options and forms for cooperation on the exchange of seismic data.*
4. *Report results of the committee's work to the Nordic foreign ministries for their common consideration as this work progresses.*

The respective ministries appointed the following members, who attended the first meeting of the Nordic committee on 1 April 1966 in Copenhagen:

- *Ola Dahlman and Ulf Ericsson, Sweden*
- *Jörgen Hjelme and Henry Jensen, Denmark*
- *Anders Kvale and Yngvar Lundh, Norway*
- *Mauno Porkka and Lauri Vuorela, Finland*

The committee held four meetings. Some replacements and additions were made underway: Anders Sørnes replaced Anders Kvale, Eijo Vesanen replaced Lauri Vuorela, and Ragnar Stéfansson, Iceland, joined the committee.

Anders Kvale was the first chair of the committee. When he left, Jörgen Hjelme was elected chair.

Even though the report does not explicitly state that the goal was to install one or more common Nordic stations, its context and focus indicate that this approach was the intent. In fact, Ola Dahlman, who was a member of this committee and later became a leader in multilateral efforts to develop and implement verification measures for the CTBT, recalls that, at least initially, the idea was to cooperate on one common station (Ola Dahlman, personal communication, 2020). However, he noted that the discussion never went as far as to cover ownership, staffing, and mode of operation.

The Nordic foreign ministers discussed and took note of this report in their meeting in Reykjavik in April 1967. They agreed to continue the work on providing a Nordic contribution to solve the remaining verification issues related to a future comprehensive nuclear test ban treaty, particularly by establishing seismic stations on the Nordic territory. The ministers also decided to establish a new Nordic committee, this time to be composed of both government officials and scientific/technical experts, that would report back to the governments on their assessment of the various aspects of such a contribution.

The new committee held its first meeting in Copenhagen in late June 1967. As we saw in Chapter 1, the plans for cooperation between Norway and the United States on a large LASA-type seismic array in Norway became known to the public on 20 June 1967, just a few days before the committee meeting in Copenhagen. This news certainly changed the starting point for the new committee. At about the same time, Sweden put forward its plans for a national array station at Hagfors in Värmland. The report from the new committee refers to the original idea about a common Nordic station. However, it states that in light of the new developments in Norway and Sweden, the committee would concentrate on an assessment of the possibilities of Nordic scientific cooperation in detection seismology. In this work, the committee profited from the first data available from the new arrays in Norway and Sweden. Ola Dahlman, who was also a member of this second Nordic committee, recalls that the news about the independent plans in Norway and Sweden did not create a sentiment of disappointment among committee members from the other Nordic countries; rather, the news inspired the committee to continue work on providing important Nordic contributions.

The report (we have only found what we believe to be a near-final version) from this second Nordic committee was issued in August 1969. It was forwarded to the Nordic foreign ministers for consideration at their meeting in Reykjavik during 1-2 September 1969.

The committee agreed that the Nordic seismological community could contribute valuable solutions to test ban verification problems. Given the nature of these problems and the resources available in the Nordic countries, the committee made seven recommendations:

- The Nordic countries should establish national programs in detection seismology, with sufficient personnel and other resources
- Annual Nordic seminars in detection seismology should be held to exchange research results and inspire new research projects
- Data from the seismic installations in the Nordic countries should be used for joint research projects to develop methods to discriminate between explosions and earthquakes
- Arrangements should be established for research visits to the larger seismological data centers in the Nordic countries. In this context, Norway proposed to form a Nordic research group at NORSAR
- A Nordic exchange of seismological data should be undertaken, and in anticipation of global data exchange, a provisional Nordic data center should be established
- A sensitive station should be established in northern Scandinavia to complement the arrays in the southern part of Scandinavia
- Finally, provisions should be made for a forum to continue the Nordic cooperation already established in detection seismology.

This report shows again the advanced level of understanding of the challenges in detection seismology and the imminent need for a concerted research effort to solve the problems of detecting and identifying underground nuclear explosions. The committee considered it urgent for the Nordic countries to advance to the forefront of seismological research. According to the report, this could best be achieved through a coordinated and well-organized research effort at a common Nordic level. On the margins of the six meetings of the committee, the scientists in the group held separate symposia for in-depth elaboration on technical matters. This experience, and the discussions during the first committee, led to the important recommendation to hold annual Nordic seminars in detection seismology.

We have not found any official record of the reaction of the foreign ministers to the second report, but there is every indication that it was met with approval. A handwritten comment on the draft of this report states, “in reality approved de facto.” We know that NORSAR organized the first Nordic seminar in detection seismology, held in Oslo already on 20 - 21 November 1969, and that special sessions during this seminar addressed most of the recommendations in the report. Initiatives were taken to start implementing some of them.

The next Nordic seminars were held in Hagfors, Sweden (organized by FOA – the National Defence Research Institute) in March 1971 and in Roskilde, Denmark, in May 1972 (organized by Geodetic Institute). Programs providing titles of presentations at these meetings and available correspondence from this period show that efforts had started on activities related to data exchange, research visits, and a compilation of the Nordic scientific publications in the area of detection seismology. However, there were no efforts to create a common data center for the Nordic countries, and the proposal to form a Nordic research group at NORSAR had not been realized. This is all understandable, in light of the rapid development, since the release in 1969 of the second report, on data centers and research groups associated with the new seismic arrays in Norway and Sweden. Also, it took many years until the array network was complemented with a powerful station in northern Scandinavia (in Karasjok, Norway, in 1987, as we shall see later).

In October 1972, officials from the Nordic foreign ministries met in Oslo to discuss disarmament issues. In this meeting, Norway proposed to formalize the Nordic cooperation in detection seismology and consider options for a joint Nordic research program. Following consultations in the ministries, an expert meeting was held at NORSAR on 30 - 31 January 1973 to discuss plans for enhanced Nordic cooperation on relevant research topics. The list of participants at this meeting follows:

Denmark:
Jørgen Hjelme, Geodetic Institute

Finland:
Heikki Korhonen, University of Oulu
Esko Penttilä, University of Helsinki
Two representatives of the Ministry of Foreign Affairs

Norway:
Hilmar Bungum, NORSAR
Eystein Husebye, NORSAR
Nils Marås, NORSAR
Eivind Rygg, University of Bergen

Sweden:
Ola Dahlman, FOA
Ulf Ericsson, FOA
Hans Israelsson, FOA

Again, the basic idea was to contribute to the international efforts to verify a future ban on underground nuclear tests and to recognize that national research programs should be coordinated at the Nordic level to ensure the effective use of national resources. The participants at this meeting agreed on a research program covering three areas:

- Seismic noise and detection capabilities
- Detection, location, and definition of seismic events
- Source identification.

Each research area contained several projects described in some detail for technical content. For each project, the countries indicated their interest in participating and their estimates of necessary resources in terms of man-months per year.

In July 1973, NORSAR reported to the Norwegian Ministry of Foreign Affairs on the status of the Nordic cooperation on detection seismology. At this juncture, another Nordic seminar had just taken place in Helsinki. At this seminar, eight representatives of NORSAR made 12 presentations, all based on data from the NOA array. Four presentations from other delegates also used NOA data. A seminar participant from the MIT Lincoln Laboratory, the United States leading institution in the field at that time, noted that the research reported was at a high professional level. The seminar also discussed the way forward for Nordic cooperation, and participants agreed that the meeting outcome at NORSAR in January was still a good basis for continuing their cooperation. The report to the Foreign Ministry concludes with an assumption that Nordic cooperation would continue at the level established at that time.

The records from the early stages of Nordic cooperation in detection seismology testify to an impressive engagement by the authorities in the Nordic countries. The test ban issue was at the forefront of the international political agendas of all Nordic countries, with Sweden, in particular Alva Myrdal, as the most visible and strongest supporter. Obviously, this political engagement, coupled with the build-up of technical skills and competence, paved the way for strong Nordic participation. This participation would include future leading roles in international fora related to the test ban issue, particularly in the Group of Scientific Experts of the Conference on Disarmament, as we shall see later.

How did the cooperation at the Nordic level evolve in the longer run? Were the high ambitions described in this section fulfilled? We will revert to these questions in Chapter 11, looking back at 50 years of Nordic cooperation in detection seismology.

Chapter 3

1970 - 1975
Rising up to speed

3.1 NORSAR management is transferred from FFI to NTNF

On 1 July 1970, the Royal Norwegian Council for Scientific and Industrial Research (NTNF) assumed the management of NORSAR, in full accordance with the Government-to-Government agreement of 1968 between the United States and Norway because on this date, FFI completed its task of establishing the NOA array.

With this transfer, NORSAR became an administrative unit under NTNF with initial status as a project. NORSAR assumed the responsibility to operate the Large Seismic Array facility NOA, as stipulated in the agreement with the United States, and engaged in activities to promote research relevant to nuclear test detection. As we saw in Chapter 2, many of the employees of the new institution were transferred from FFI and its subcontractor Noratom-Norcontrol A/S.

NORSAR started regular processing of data from NOA in the spring of 1971 and took over the software development task from IBM on 1 July 1971. NORSAR also assumed responsibility for field maintenance on 1 October 1971, at which point NORSAR acquired full control of all operational tasks associated with NOA. In its early days, NOA was assumed to be the largest facility in Norway regarding real-time data handling, with approximately 50,000 information units being received, processed, and recorded per second.

The United States continued to foot the bill for NORSAR. During the first two years, from 1 July 1970, the United States contributed 8.3 million NOK, whereas NTNF contributed 0.22 million NOK. The corresponding amounts for the following two years (until 30 June 1974) were 10.8 and 0.2 million NOK, respectively. For the two-year period starting on 1 July 1974, the United States contributed 12.1 million NOK, whereas NTNF's share increased to 0.71 million NOK.

3.2 NTNF establishes an Advisory Board for NORSAR

Upon taking over the administrative management of NORSAR, NTNF established an Advisory Board for the project. Professor Markvard Sellevoll of the University of Bergen was the first chair of the Advisory Board. He initiated the seismological cooperation between his university and the United States in the early 1960s and later actively supported and promoted the efforts that led to the NOA array and NORSAR. The initial members of the Advisory Board included:

Professor Markvard Sellevoll, University of Bergen
Research Director Henrik Nødtvedt, FFI
Bureau Chief (later Ambassador) Oscar Værnø, Ministry of Foreign Affairs

The mandate of the Advisory Board was to follow the development of the NORSAR project closely, with emphasis on enhancing its potential contributions to monitoring a comprehensive test ban treaty. The NORSAR Project Manager functioned as Secretary for the Advisory Board.

Appendix 2 shows NORSAR's status and parent organizations until the present time. It also lists NORSAR's leaders and chairs of its board over the years.

3.3 An initial setback

In December 1970, NTNF received a memorandum from ARPA via the Norwegian Ministry of Foreign Affairs, indicating that most of ARPA's research goals for NORSAR would have been met by mid-1972 *(Reference NORSAR archive document 176)*.

Recall that clause 9 of the Government-to-Government agreement stated that it would remain in force until terminated by one year's written notice submitted at any time on or after 30 June 1971. If such termination notice were submitted by the United States on 30 June 1971, the array would cease operation on 30 June 1972.

ARPA had examined six possible options for the array operation after 30 June 1972. The most extreme was to dispose of the equipment and close the array permanently!

These prospects for the future indicated that any secret plans that the United States might have to use the array to spy on the Soviet Union (apart from the obvious stated purpose to detect Soviet nuclear explosions) could not be taken seriously.

The six options proposed by ARPA can be summarized as follows: Alternatives 1 and 2 implied full operation of the array facilities. Alternatives 3 and 4 consisted of operating a subset of the facilities. Alternatives 5 and 6 would stop the operation either in a standby mode or close it permanently. Any one of these options would satisfy the formal legal requirements in the Government-to-Government Agreement. The operational costs would need to be negotiated separately and would no longer be fully covered by ARPA.

In a letter to the Norwegian Ministry of Foreign Affairs on 14 February 1972 *(reference NORSAR archive documents 349 and 373)*, Director Robert Major (NTNF) stated that the NORSAR Advisory Board had considered the memorandum carefully and had recommended that Alternative 2 was preferred since it would maintain the operation and support research. The Advisory Board had arrived at an annual cost of 3.4 MNOK, assuming that ARPA would purchase the IBM computers, which had been leased from IBM, as suggested in their memorandum.

Mr. Major stated that NTNF had no mandate to discuss possible cost sharing of the array operation but would be prepared to continue administrative responsibility for NORSAR after 1 July 1972.

Fortunately for NORSAR's future, a new development occurred on 10 April 1972 when the United States informed Ambassador Oscar Værnø in Washington, D.C., that ARPA had reconsidered its position about NORSAR given recent promising signs of a CTBT and was now interested in continuing its involvement in NORSAR for at least some period beyond 1 July 1973 (*reference NORSAR archive document 372*). This agreement allowed the NOA array to remain in full-scale operation until 1976.

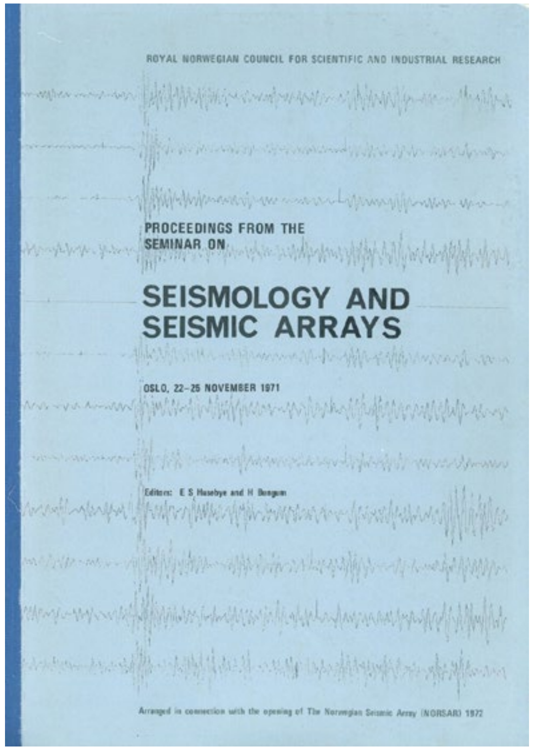
At a meeting on 10 May 1972 (*reference NORSAR archive document 374*), the NORSAR Advisory Board suggested that NORSAR staff should establish a research program for NORSAR and coordinate it with the existing ARPA program and the ongoing Nordic initiatives.

Accordingly, Eystein Husebye and colleagues developed a research program into issues relevant to a CTBT. Some Norwegian funding would be required, and NTNF agreed to allocate the necessary funds for this purpose.

In fact, NTNF consistently provided support for the NORSAR research, thereby contributing to NORSAR's internationally recognized achievements in nuclear monitoring.

3.4 Introducing NOA to the international seismological community

A sustained effort was made from the beginning of NORSAR and the associated array operation to make the facility known to the international seismological community. Eystein Husebye and Hilmar Bungum took the initiative to arrange a seminar on "Seismology and Seismic Arrays," to be held in Oslo on 22-25 November 1971 (Fig. 3.4.1). Many internationally known scientists attended this seminar and presented important research results.



ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

PROCEEDINGS FROM THE
SEMINAR ON

SEISMOLOGY AND
SEISMIC ARRAYS

OSLO, 22-25 NOVEMBER 1971

Editors: E S Husebye and H Bungum

Arranged in connection with the opening of The Norwegian Seismic Array (NORSAR) 1972

Fig. 3.4.1 *The 1971 NORSAR seminar proceedings contained 22 papers comprising 305 pages.*

The seminar was intended to serve three main purposes:

- Mark the successful completion of the NOA array field installation work and software programming efforts which started in 1968
- Perform seismic system evaluation and research on problems related to nuclear monitoring, with special emphasis on the NOA array
- Assess the potential of array data in more general seismological research.

Of particular importance was the participation of Prof. Ivan Passechnik (Fig. 3.4.2), USSR, who made an impressive presentation on the Soviet research program within seismic discrimination. NORSAR scientists were to make a closer acquaintance with Prof. Passechnik when he became the main Soviet spokesman for ten years in the GSE in Geneva (see Section 4.4).

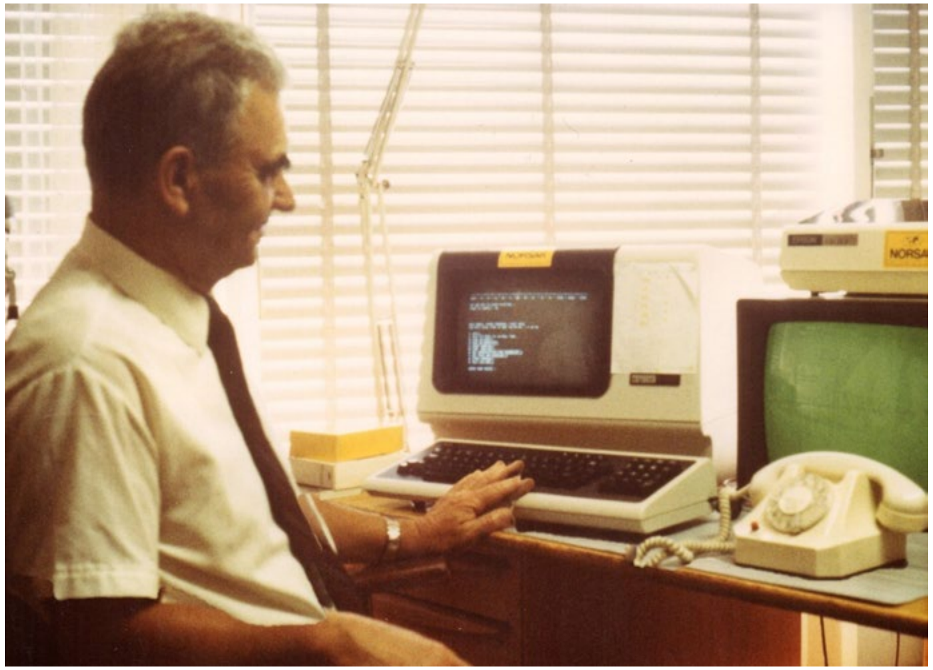


Fig. 3.4.2 *Professor Ivan Passechnik, USSR, photographed at the Norwegian embassy in Geneva, Switzerland, during a GSE session in 1982.*

It is important to emphasize the openness of NORSAR to one of the key Soviet experts in nuclear test monitoring. In the following years, NORSAR hosted numerous prominent visiting scientists from the Moscow Institute of Physics of the Earth.

Later, it also established cooperation with the Kola and Arkhangelsk seismological institutions.

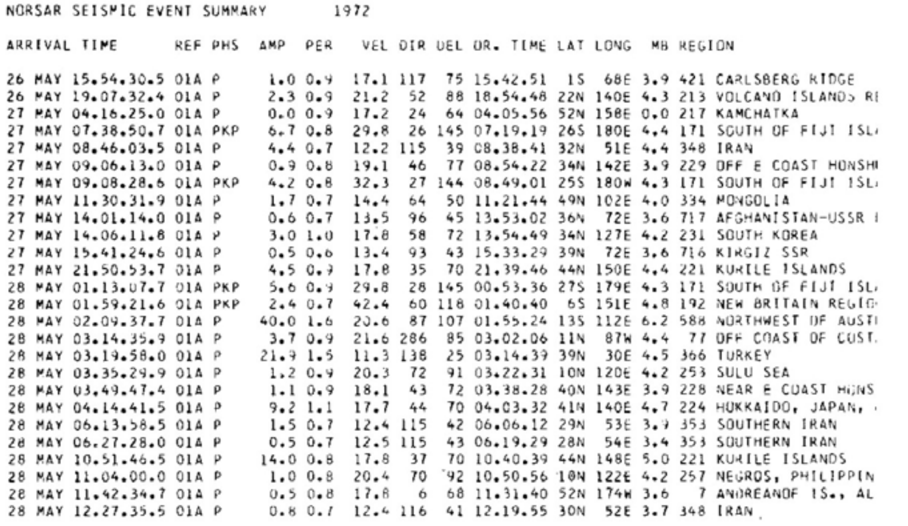
The 1971 seminar was the first opportunity to introduce the NOA array and its potential to an international audience, and it was a definite success. The demonstrations of the array and the data processing particularly impressed the participants. In 1974, a second seminar, entitled "Exploitation of Seismograph Networks," was arranged in Sandefjord, Norway, and was the first one in the NATO advanced study institute series involving NORSAR. It focused on data analysis using the large NOA array, such as wave scattering and its effect on P-wave anomalies at the arrays, multipathing of seismic waves, discrimination between earthquakes and underground nuclear explosions, as well as an initial evaluation of the detection and location capabilities of the NOA array.

The seminars arranged by NORSAR were important in several ways. Primarily, they were designed for scientists to present new ideas and to maintain the international focus on NORSAR as a leader in CTBT verification research. In addition, they served to inform political leaders about the progress in the field and the latest scientific achievements.

3.5 Full operation of the NOA array

Beginning on 1 July 1971, the full NOA array was in continuous operation for five years. Data from the 22 subarrays were transmitted to Kjeller, recorded on magnetic tape, and automatically analyzed for detection of seismic signals. A data retention system was applied to store data from the most significant events while the original tapes were reused.

The analysts at NORSAR began to issue a weekly reviewed seismic bulletin containing all detected seismic events with their approximate location and magnitude (mb). The bulletin was modeled after the weekly LASA bulletin and, since 1976, has continued as a monthly bulletin distributed to all interested institutions (see Fig. 3.5.1). The analyst staff, which has been headed by Per Engebretsen, Bernt Kr. Hokland and Berit O. Paulsen have managed to issue such information for thousands of seismic events each year. In addition, NORSAR has developed various online tools over the years to enable public access to analyzed results of seismic events and other phenomena in Scandinavia and around the world.



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NORSAR SEISMIC EVENT SUMMARY       1972

ARRIVAL TIME       REF PHS  AMP  PER   VEL DIR UEL OR. TIME LAT LONG  MB REGION

26 MAY 15.54.30.5 01A P      1.0 0.9  17.1 117  75 15.42.51  1S  68E 3.9 421 CARLSBERG RIDGE
26 MAY 19.07.32.4 01A P      2.3 0.9  21.2  52  88 18.54.48 22N 140E 4.3 213 VOLCANO ISLANDS R
27 MAY 04.16.25.0 01A P      0.0 0.9  17.2  24  64 04.05.56 52N 158E 0.0 217 KAMCHATKA
27 MAY 07.38.50.7 01A PKP    6.7 0.8  29.8  26 145 07.19.19 26S 180E 4.4 171 SOUTH OF FIJI ISL
27 MAY 08.46.03.5 01A P      4.4 0.7  12.2 115  39 08.38.41 32N  51E 4.4 348 IRAN
27 MAY 09.06.13.0 01A P      0.9 0.8  19.1  46  77 08.54.22 34N 142E 3.9 229 OFF E COAST HONSH
27 MAY 09.08.28.6 01A PKP    4.2 0.8  32.3  27 144 08.49.01 25S 180W 4.3 171 SOUTH OF FIJI ISL
27 MAY 11.30.31.9 01A P      1.7 0.7  14.4  64  50 11.21.44 49N 102E 4.0 334 MONGOLIA
27 MAY 14.01.14.0 01A P      0.6 0.7  13.5  96  45 13.53.02 36N  72E 3.6 717 AFGHANISTAN-USSR
27 MAY 14.06.11.8 01A P      3.0 1.0  17.8  58  72 13.54.49 34N 127E 4.2 231 SOUTH KOREA
27 MAY 15.41.24.6 01A P      0.5 0.6  13.4  93  43 15.33.29 39N  72E 3.6 716 KIRGIZ SSR
27 MAY 21.50.53.7 01A P      4.5 0.9  17.8  35  70 21.39.46 44N 150E 4.4 221 KURILE ISLANDS
28 MAY 01.13.07.7 01A PKP    5.6 0.9  29.8  28 145 00.53.36 27S 179E 4.3 171 SOUTH OF FIJI ISL
28 MAY 01.59.21.6 01A PKP    2.4 0.7  42.4  60 118 01.40.40  6S 151E 4.8 192 NEW BRITAIN REGI
28 MAY 02.09.37.7 01A P     40.0 1.6  20.6  87 107 01.55.24 13S 112E 6.2 588 NORTHWEST OF AUST
28 MAY 03.14.35.9 01A P      3.7 0.9  21.6 286  85 03.02.06 11N  87W 4.4  77 OFF COAST OF COST.
28 MAY 03.19.58.0 01A P     21.9 1.5  11.3 138  25 03.14.39 39N  30E 4.5 366 TURKEY
28 MAY 03.35.29.9 01A P      1.2 0.9  20.3  72  91 03.22.31 10N 120E 4.2 253 SULU SEA
28 MAY 03.49.47.4 01A P      1.1 0.9  18.1  43  72 03.38.28 40N 143E 3.9 228 NEAR E COAST HONS
28 MAY 04.14.41.5 01A P      9.2 1.1  17.7  44  70 04.03.32 41N 140E 4.7 224 HOKKAIDO, JAPAN,
28 MAY 06.13.58.5 01A P      1.5 0.7  12.4 115  42 06.06.12 29N  53E 3.9 353 SOUTHERN IRAN
28 MAY 06.27.28.0 01A P      0.5 0.7  12.5 115  43 06.19.29 28N  54E 3.4 353 SOUTHERN IRAN
28 MAY 10.51.46.5 01A P     14.0 0.8  17.8  37  70 10.40.39 44N 148E 5.0 221 KURILE ISLANDS
28 MAY 11.04.00.0 01A P      1.0 0.8  20.4  70  92 10.50.56 10N 122E 4.2 257 NEGROS, PHILIPPIN
28 MAY 11.42.34.7 01A P      0.5 0.8  17.8   6  68 11.31.40 52N 174W 3.6   7 ANDREANOF IS., AL
28 MAY 12.27.35.5 01A P      0.8 0.7  12.4 116  41 12.19.55 30N  52E 3.7 348 IRAN
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Fig. 3.5.1 *Excerpts from a NOA seismic bulletin in 1972.*

3.6 Developing the maximum-likelihood method for seismic magnitude

In parallel with the NOA operation, NORSAR scientists began assessing the detection capability of the NOA array. As could be expected, the NOA array was found to be far superior to the standard single-station seismographs.

Some scientists noted a discrepancy when comparing the seismic magnitudes published by NORSAR with magnitude estimates calculated by the international seismic network (WWSSN). For low-magnitude seismic events, the network magnitudes tended to be higher than those published by NORSAR.

Most scientists concluded that this discrepancy was likely due to the averaging procedure used by the international network, where only the stations detecting the events were counted, while the non-detecting stations were ignored. However, they found no satisfactory way to address this problem.

Frode Ringdal then developed the maximum-likelihood method for estimating magnitudes of seismic events and published his paper on the subject in the Bulletin of the Seismological Society of America (BSSA) in 1976 (Ringdal, 1976). His method was based on statistical truncated distribution theory. It largely solved the problem of determining an unbiased event magnitude when only a subset of the stations in a network has detected the event (see Figure 3.6.1).

This discovery had several important implications. For example, the number of world-wide seismic events greater than a given threshold turned out to be considerably lower than previously thought (at a level of magnitude 4.0, it was estimated to be a factor of 10 lower), and the discrimination problem (earthquake vs. explosion) would thereby become easier. This is illustrated in Figure 3.6.2, which shows average yearly seismic event statistics for ten years (1971-1980). The maximum-likelihood method was adopted by AFTAC and is now standard at the International Data Center of the Provisional Technical Secretariat of the CTBTO in Vienna.

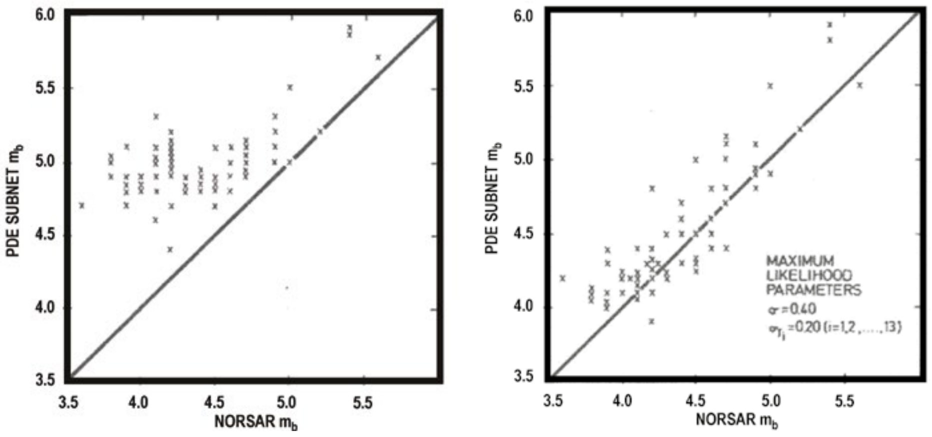


Fig. 3.6.1 *Seismic networks often tend to overestimate the magnitude of seismic events because those stations within the network that do not detect a particular event are ignored in the conventional magnitude-averaging procedure (figure to the left). By applying the statistical technique of maximum likelihood estimation, this problem can be largely corrected (figure to the right).*

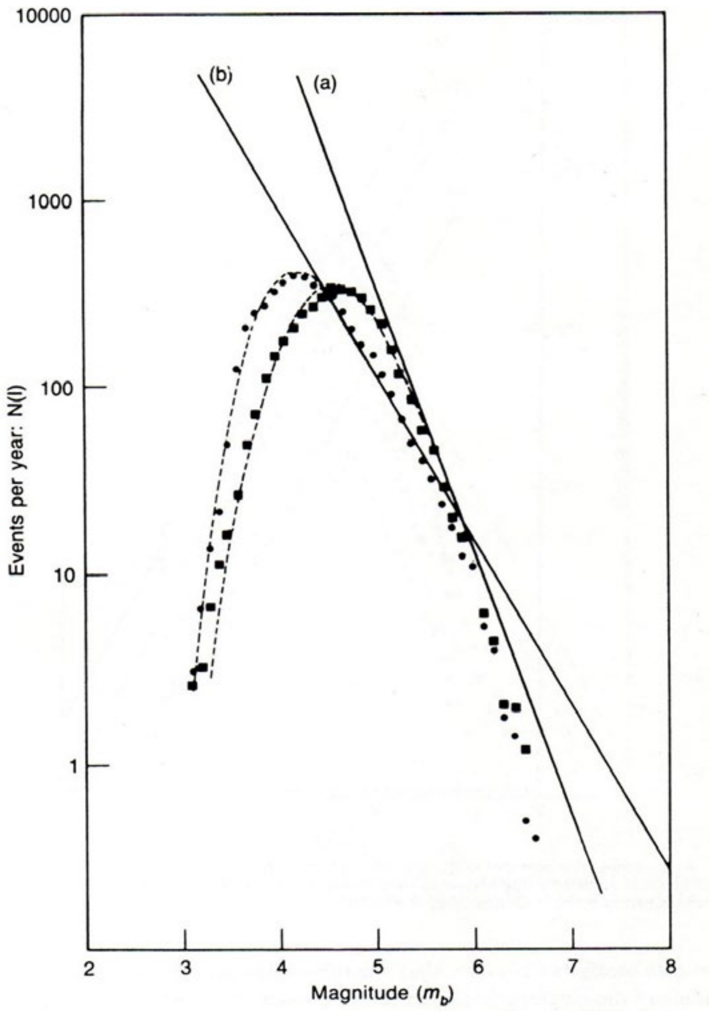


Fig. 3.6.2 *Comparison of (a) conventional mb recurrence statistics and (b) maximum likelihood mb statistics averaged yearly over the period 1971-1980. After Ringdal (1986).*

3.7 ARPANET is established at NORSAR (the first node outside the United States)

In 1970, before its transfer to NTNF, NORSAR used a leased transatlantic telephone connection with Washington, D.C., paid for by ARPA. The link was initially routed via the British satellite station in Goonhilly to the United States. However, it was later rerouted to the Nordic satellite station in Tanum, Sweden, and from Tanum to the USA.

During the initial software development by IBM for the NOA array system, this link was useful for communication between the local IBM staff in Norway and the larger IBM staff at the Van Ness Center in Washington, D.C., as well as for transmitting experimental NOA data. Later, the link, which initially had a capacity of 2400 bps, was upgraded to 9600 bps and was used for a two-way exchange between the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia, USA, and NORSAR. In this two-way exchange, NORSAR received selected LASA data, while SDAC received selected NOA data.

In 1972, NORSAR's Director Nils Marås met with ARPA's Director Lawrence Roberts, who was in charge of ARPANET (see Fig. 3.7.1), in Washington D.C., and was informed that ARPA was considering upgrading the existing link and installing an interface to this link in Norway. Roberts considered that such a setup could be used to establish a link from the USA via NORSAR to the National Physical Laboratory in the United Kingdom, without having to pay for a costly transatlantic link.

Dr. Roberts visited Norway in 1972 and attended a meeting on September 18 at the NORSAR facilities with the participation of NTNF, the Norwegian Telecommunications Authority, and FFI. In a summary letter, Dr. Roberts stated that he intended to install an Interface Message Processor (IMP) at NORSAR and order a line to London, where a larger and much more capable Terminal Interface Processor (TIP) was to be installed.

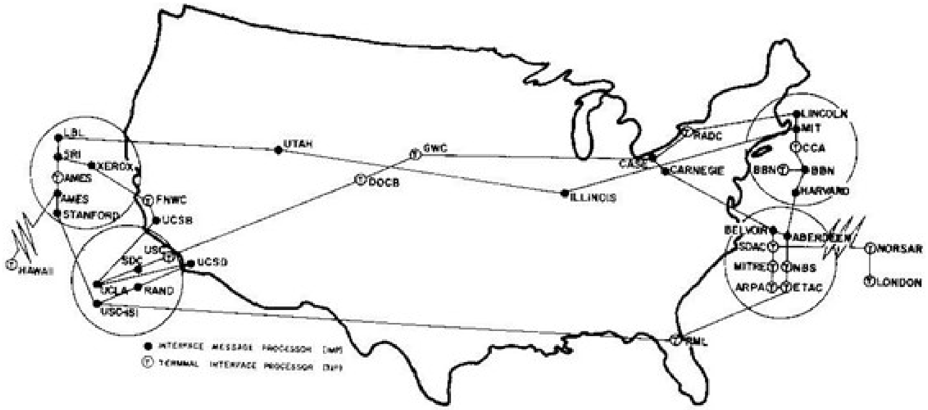


Fig. 3.7.1 *Configuration of the ARPANET as of 1972. The NORSAR TIP is one of the nodes.*

In October 1972, Frode Ringdal went to Washington, D.C., to participate in the International Conference on Computer Communication. This conference represented the breakthrough for the ARPANET concept. There was an impressive demonstration of the packet-switched technology that formed the basis of the ARPANET, with the TIP as an interface to external computers.

Ringdal proceeded to visit the company Bolt Beranek and Newman (BBN) in Boston, where the IMPs (and TIPs) were constructed. After being shown the NORSAR IMP, which was being finalized, he asked how practical it would be to replace the IMP with a TIP and what the cost would be. The answer was that the added features could be easily installed, with an additional cost of approximately USD 20,000.

Upon returning to Norway, Ringdal suggested to NORSAR director Nils Marås that he write a letter to ARPA to request replacing the planned NORSAR IMP with a TIP. The letter would emphasize the much greater flexibility and ease of connecting NORSAR's IBM system to ARPANET if it obtained the same interface that was to be installed at the Seismic Data Analysis Center (SDAC). In addition, such a replacement could promote other use of the ARPANET by additional Norwegian computer facilities.

ARPA approved the suggestion from Director Marås, and in June 1973, a TIP, rather than an IMP, was installed in NORSAR's data center at Kjeller (see Fig. 3.7.2).

Fig. 3.7.2 *The TIP as installed at the NOA computer center in 1973.*

This was undoubtedly a pleasant surprise to the many attendees who remembered the meeting at NORSAR with Lawrence Roberts, where only an IMP had been discussed. NORSAR was now linked to ARPA's net of mutually connected computers via a leased 9.6 Kbps connection to the Tanum, Sweden ground station through INTELSAT IV and a TIP at SDAC in Virginia, USA. Since a TIP was installed at NORSAR, it became simple for other Norwegian institutions to connect to ARPANET through local terminals.

NORSAR became the first node on ARPANET outside the United States! As is well known, the ARPANET later evolved directly into the internet.

Chapter 4

1976 - 1980
A new start

4.1 A United States proposal to reduce the NOA array

On 1 April 1976, Director Carl Romney of ARPA's Nuclear Monitoring Research Office wrote a letter to NTNF Director Major suggesting a substantial reduction in the size of the NOA array and a change to unattended operation during nights and weekends. ARPA explained that it had changed its priorities to focus more on a worldwide network of single-site Seismic Research Observatories rather than on the large arrays NOA, LASA, and the Alaskan long-period array ALPA. ARPA proposed reducing the NOA array from 22 to 3 short-period subarrays and from 22 to 7 long-period 3-component sensors. The United States would continue funding the operations at this reduced level.

4.2 Representatives of NTNF and NORSAR travel to Washington to discuss the NOA array reconfiguration

The NORSAR staff carefully considered the reconfiguration proposed by ARPA and presented its Advisory Board with a detailed report with recommendations. In these recommendations, NORSAR noted that ARPA's change of priorities had made a cutback unavoidable. One important consideration would be to obtain a reasonable transition period for the redundant staff, including analysts, computer operators, and field maintenance technicians.

On the other hand, NORSAR considered that the three subarrays to be retained with short and long-period seismometers could easily be expanded to retain all seven as full subarrays with both short and long-period seismometers, with minimal additional costs and with increased reliability as backup stations.

During the previous five years of the full 22 subarray operation, NORSAR had been obliged to operate the entire original NOA array to the best of its ability and not perform any experiments that might degrade the performance of the full array. This situation had now changed, and the proposed reduction of the NOA array created new opportunities. ARPA had stated that they needed only three subarrays with full short-period instrumentation, which opened the door for using the remaining short-period sensors of the array for experimental purposes.

NORSAR's idea was that the ARPA proposal, if modified to retain all seven subarrays as full subarrays, could provide great possibilities for experimental small array configurations for future research since the short-period data from four subarrays would be available for such experiments.

Director Robert Major informed the Advisory Board that he had called Director Carl Romney and suggested a meeting in Washington, D. C. Director Major would participate with NORSAR Director Nils Marås and Frode Ringdal from the Norwegian side.

The meetings took place on 20 and 21 May 1976 at the Seismic Data Analysis Center (SDAC) in Arlington, Virginia, and were attended by a number of representatives from the United States. Among others, Dr. Carl Romney (ARPA), Dr. Frank Pilotte (AFTAC), Dr. Ralph Alewine (SDAC, later at ARPA), and Dr. John Filson (ARPA, later at USGS) participated. Ambassador Oscar Værnø from the Norwegian Embassy in Washington, D.C., also participated in the meeting on 20 May.

ARPA accepted NORSAR's arguments and, in fact, laid the ground for the immensely successful NORESS experiment that was to be carried out some years later.

The meetings concluded that the United States, through AFTAC, would continue covering the costs of operating the reduced NOA array, including the seven full subarrays (see Fig. 4.2.1), while ARPA would fund a joint research program. It was understood that NTNF would continue its research funding under NORSAR's research plan.

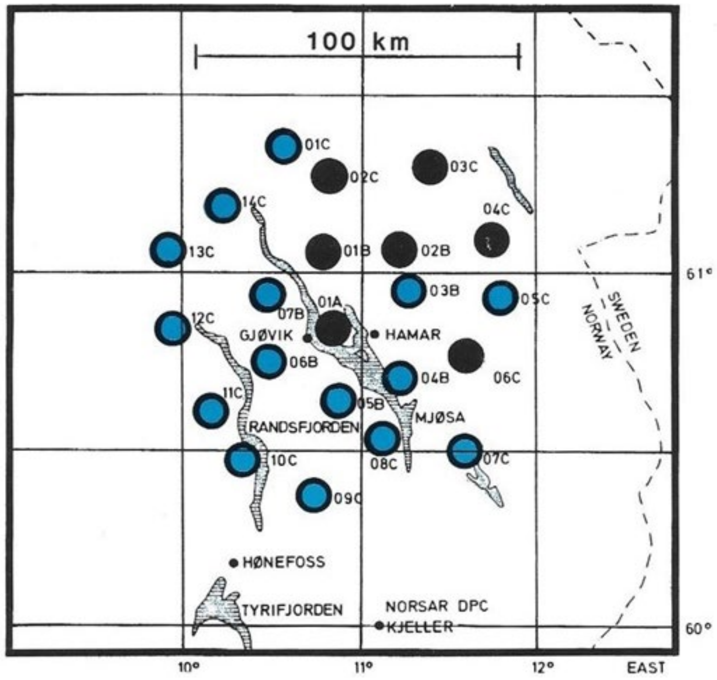


Fig. 4.2.1 *The NOA array was reduced from 22 to 7 subarrays in 1976 (black dots).*

4.3 A game changer – the NORESS array

In 1977, two significant developments took place. First, Frode Ringdal became NORSAR Director after Nils Marås, who assumed a new position at NTNF Headquarters in Oslo. Secondly, Dr. Ralph W. Alewine III became ARPA's main contact person dealing with NORSAR matters. Supported by Dr. Alewine, the NORSAR staff undertook an ambitious project to study the performance of a small-aperture seismic array within the large NOA array.

This area became a major field of development for the NORSAR research group for many years. Beginning with the NORESS project, NORSAR set a standard for the small seismic arrays that would later be established for the CTBTO International Monitoring System. Svein Mykkeltveit, who had joined the NORSAR staff in 1979 as a senior scientist, became the project leader for the design and development of the regional seismic arrays in Norway in the 1980s and 1990s. He also assumed, over the years, an increasing role in advising the Norwegian Ministry of Foreign Affairs on CTBT matters.

The so-called Trilateral negotiations on a CTBT among the U.S., U.K., and USSR during 1976-1979 provided the political context for the research needs regarding the concept of “internal seismic stations” in each country. Such stations would record the higher frequency signals from clandestine explosions that might not be detected by stations at teleseismic distances (more than 3,000 km). NORSAR responded to these research needs by investigating the potential use of small-aperture arrays as “internal seismic stations”.

It should be noted that even after the reduction to seven subarrays, the NOA array was still much larger than any other operational array. Moreover, since AFTAC had stated that the three-subarray configuration originally proposed for the reduced short-period NOA array was sufficient for their monitoring needs, the seismometers in the four remaining short-period subarrays were available for experimental purposes.

Several considerations were involved in selecting the first sites for the small-aperture experiment. NORSAR’s field systems manager, Paul W. Larsen, was the key person in this process. Subarray 06C of NOA was one of the candidates since it was situated in an area with hard surface rocks and therefore did not require deep drilling to place the seismometers. Additionally, the site was easily accessible, which was an important consideration. Furthermore, and most important for the seismologists, subarray 06C had favorable focusing effects for seismic signals from the main USSR nuclear test site in Kazakhstan (see Fig. 4.3.1).

After selecting the area within subarray 06C, an initial six-element mini-array was deployed in October 1979, and it was expanded to 12 elements a year later. NORSAR initially “borrowed” hardware and phone lines from NOA subarrays as needed. However, after a few years, separate communication was established to transmit data from NORESS to Kjeller, and NOA could restore the full operation of the seven subarrays. NOA and NORESS were always two separate stations with independent data processing systems. Further changes to the geometry of NORESS took place in 1983 in preparation for the installation in 1984 of the final version of the NORESS array, as we shall see in Chapter 5.

The initial configuration of the six-element NORESS array is shown in Fig. 4.3.2. The seismometers were intentionally placed such that the signal and noise correlation for various sensor separations could be evaluated. Therefore, the placement of the sensors was not symmetrical.

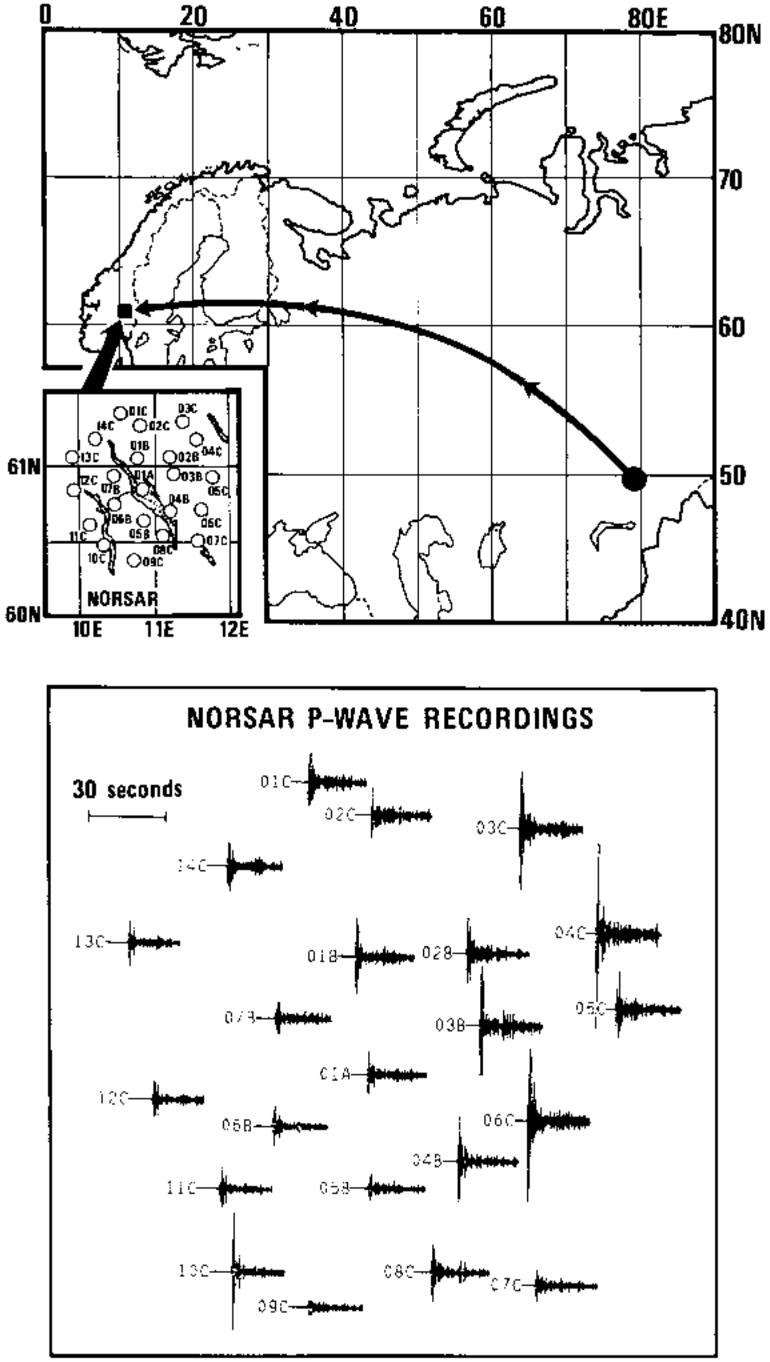


Fig. 4.3.1 Illustration of NOA recordings of a Semipalatinsk nuclear explosion (center sensor only for each subarray). The strongest signal Is seen at the subarray 06C.

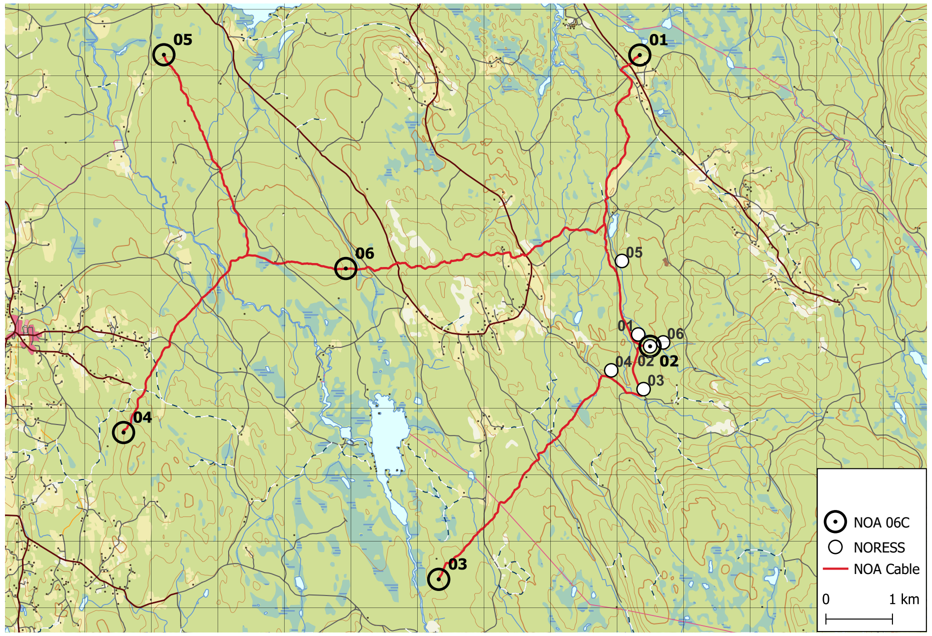


Fig. 4.3.2 Subarray 06C of NOA as originally deployed and the first NORESS deployment. The six bold circles show the seismometer positions, and the corresponding cabling to the central terminal vault 06C02 is shown in red. The area shown on the map covers approximately 13x9 km. The six seismometers in the first NORESS experiment are marked with white-filled circles. Note that one NORESS seismometer is co-located with a NOA seismometer.

NORESS became a game-changer in nuclear monitoring due to the realization that the detection and location procedure for seismic events at local or regional distances could now be completely automated by array processing using an array of a few km in diameter.

Previously, locating such seismic events required a network of seismic stations surrounding the event and combining the times of detection (P phase and S or Lg phase) at each station. The new procedure was introduced by Mykkeltveit and Ringdal (1981) in a seminal paper first presented at the Voksenåsen seminar in 1980 (see Section 4.5).

Their procedure was, in principle, very simple and consisted of the steps shown in Box 4.3.1, which could easily be automated.

BOX 4.3.1

Procedure for regional seismic array location

1. *For each detected seismic phase, apply the so-called frequency-wavenumber analysis (Capon, 1969) to identify the phase as P-phase or Lg-phase.*
2. *Read the onset time of each phase.*
3. *Determine the direction of the phase from the frequency-wave-number analysis.*
4. *Determine the distance to the event using the travel time difference between the P-phase and the Lg phase in combination with a simple crust/upper mantle model.*

The application of the algorithm initially required considerable computer power. However, when the method was implemented in an automated setting some five years later for a full 25-element NORESS array, the computer technology had advanced so much that it was possible to run the system in real-time on a mini-computer!

Fig. 4.3.3 shows that the majority of the processed events using the small array (only six sensors within an area two km across) could be located with an accuracy similar to the location accuracy that would be found using the entire seismic network in the Nordic countries, taking into account the uncertainty of that network!

The main results from the location experiment carried out using the small array compared to the Nordic network can be summarized as follows:

- The median difference of the distance estimate was 11 km
- The median difference in the estimate of direction was 3 degrees
- The median difference in location of the source was 30 km.

It should be noted that the location results of the Nordic network typically had an uncertainty of 10-30 km or more.

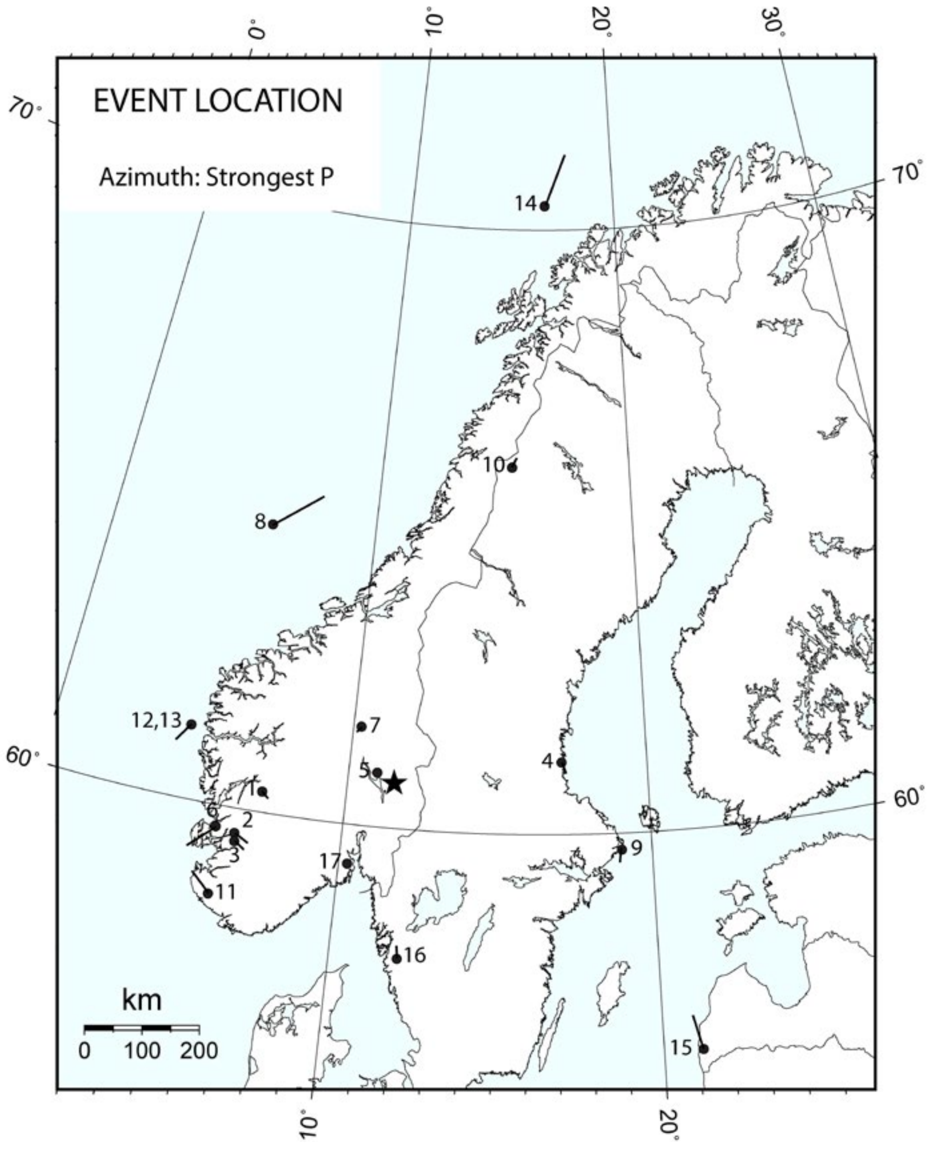


Fig. 4.3.3 *Location "errors" using NORESS (with direction estimated from the strongest P-phase for each event) for regional event location. The dots indicate epicenters determined by the station network of the Nordic countries, while the ends of the arrows show locations from NORESS processing. Notice that the length of the arrows is, in several cases, smaller than the size of the dots. An asterisk indicates the location of NORESS.*

After the NORESS array was completed some years later, this method was successfully implemented in the NORESS online processing system (Mykkeltveit and Bungum, 1984) and named Regional ONline Array Processing Package (RONAPP).

4.4 The Conference on Disarmament (CD) establishes a Group of Scientific Experts (GSE) in Geneva

A groundbreaking event, which was to have important implications for the next 20 years of nuclear test ban negotiations, took place on 22 July 1976 in Geneva, Switzerland.

On that date, the United Nations Conference of the Committee on Disarmament (see Box 4.4.1) decided to establish under its auspices an Ad Hoc Group of Scientific Experts (the GSE) to consider international co-operative measures to detect and identify seismic events (for details, see Dahlman et al., 2020).

While many previous seismology conferences had included experts and politicians, the establishment of the GSE, originally proposed by Sweden, allowed a group of experts to work together independently, yet under the umbrella of the CCD, with a clear mandate from the political body.

The Norwegian Ministry of Foreign Affairs asked NORSAR to name experts to participate in the GSE. Accordingly, Eystein Husebye and Frode Ringdal were nominated as initial GSE participants.

Throughout the 20 years of the GSE's lifetime, NORSAR became a central organization supporting the work of the GSE. Although it was an Observer rather than a Member State of the CD, Norway regularly contributed important Working Papers to the Conference (see Box 4.4.2) based on technical papers relating to the verification of a Comprehensive Nuclear-Test-Ban Treaty primarily elaborated by the NORSAR organization.

At its first Session during 2-6 August 1976 in Geneva, the GSE elected its Chairman (Dr. Ulf Ericsson of Sweden, who was succeeded by Dr. Ola Dahlman in 1983) and its Scientific Secretary (Dr. Frode Ringdal of Norway). It also established a method of work, which was to be based on conference room papers prepared by individual experts or jointly by several experts through informal cooperation.

BOX 4.4.1

Conference on Disarmament

The Conference on Disarmament (CD) is a multilateral disarmament forum based in Geneva. It was established by the international community to negotiate arms control and disarmament agreements.

It succeeded other Geneva-based negotiating fora, which include the Ten-Nation Committee on Disarmament (1960), the Eighteen-Nation Committee on Disarmament (1962-68), and the Conference of the Committee on Disarmament (CCD, 1969-78).

In 1976 the Conference established the Ad Hoc Group of Scientific Experts to Consider International Co-operative Measures to Detect and Identify Seismic Events (the GSE). The GSE was active for 20 years (1976-1996).

During 1994-1996, the Conference negotiated the text of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which was then adopted by the United Nations.

The Scientific Secretary then compiled and coordinated this material in a coherent report.

Dr. Ericsson presented the GSE's first report to the CCD on 9 March 1978. The report described how seismological science could be used in a co-operative international effort to facilitate the verification of a comprehensive nuclear test ban. This international effort would have three main elements:

- A systematic improvement of the observations reported from a network of more than fifty seismological observatories around the globe
- International exchange of these data over the Global Telecommunication System of the World Meteorological Organization (WMO/GTS)
- Processing of the data at special international data centers (IDCs) for the use of participant States.

The data from each individual observatory should be provided at two levels:

- Level I: Routine reporting, with minimum delay, of parameters of detected seismic signals
- Level II: Data transmitted as a response to requests for additional information, mainly waveforms for seismic events of particular interest.

It should be noted that Level I and Level II data are fundamentally different, both in number and volume. Level I data would comprise condensed information of each detected seismic event (typically ten or more per day for each seismological observatory) and include, inter alia, the onset time of energy, the dominant signal frequency, and the signal amplitude. These measurements would then be transmitted to the IDCs for rapid processing using the WMO/GTS links. In contrast, Level II data for each requested event would be many orders of magnitudes more voluminous than the Level I data. However, they would be requested only for seismic events of particular interest in a CTBT monitoring context.

The GSE was planning for a system that could be established at that time and on short notice and naturally did not foresee the rapid development in computing power, data communications, and storage media that has taken place since then. Nevertheless, it is interesting to note that the principal design presented by the GSE as early as 1978 became the basis for the now-implemented International Monitoring System (IMS) of the CTBT.

The GSE report was prepared in time to be available for the United Nations First Special Session on Disarmament in May 1978. In a statement during the Special Session, the Norwegian Minister of Foreign Affairs, Knut Frydenlund, expressed Norway's continued support of a comprehensive test ban treaty and stated that Norway would make the NOA array available as a monitoring station if such a treaty were agreed upon.

BOX 4.4.2

Norway's official contributions during 20 years to the CCD and CD

Norway CCD/411	*Letter dated 16 July 1973 from the Government of Norway: Working Paper on seismic research at the Norwegian Seismic Array.*
Norway CCD/484	*Letter dated 8 April 1976 from the Charge d'Affaires of Norway: Working Paper on some new results in seismic discrimination.*
Norway CD/310	*1 August 1982: Working Paper on a Prototype System for International Exchange of Seismological Data under a Comprehensive Test Ban Treaty.*
Norway CD/395	*19 July 1983: Working Paper: The role of International Seismic Data Exchange under a Comprehensive Test Ban.*
Norway CD/507	*15 July 1984: Seismic Verification of a Comprehensive Nuclear Test Ban: Future Directions.*
Norway CD/599	*20 June 1985: Working Paper: Seismological Verification of a Comprehensive Nuclear Test Ban – Report on the Workshop in Oslo, Norway 4-7 June 1985.*
Norway CD/714	*14 July 1986: Seismological Verification of a Comprehensive Nuclear Test Ban: Utilization of Small-aperture Seismic Arrays in a Global Seismological Network.*
Norway CD/763	*24 June 1987: Verification of a Comprehensive Nuclear Test Ban: Principles for a Modern Seismic Data Exchange System.*
Norway CD/862	*23 August 1988: Verification of a Comprehensive Nuclear Test Ban: Establishing a Global Seismological Network Incorporating Small-aperture Seismic Arrays.*
Norway CD/935	*21 July 1989: Verification of a Comprehensive Nuclear Test Ban: The Norwegian Seismic Verification Programme – Summary of Research Results 1988/89.*
Norway CD/1010	*26 June 1990: Verification of a Comprehensive Nuclear Test Ban: Report on the Workshop on Seismological Aspects of Nuclear Test Ban Verification in Oslo, Norway, 14-17 February 1990.*
Norway CD/1151	*1 June 1992: Summary of a Study on a Comprehensive Test Ban Treaty held in Oslo, Norway 30-31 March 1992.*

These official documents were supplemented by more than 100 scientific and technical GSE papers addressing various aspects of CTBT-related research carried out at NORSAR. These papers were extensively discussed in the GSE and reflected in the Group's reports to the CD.

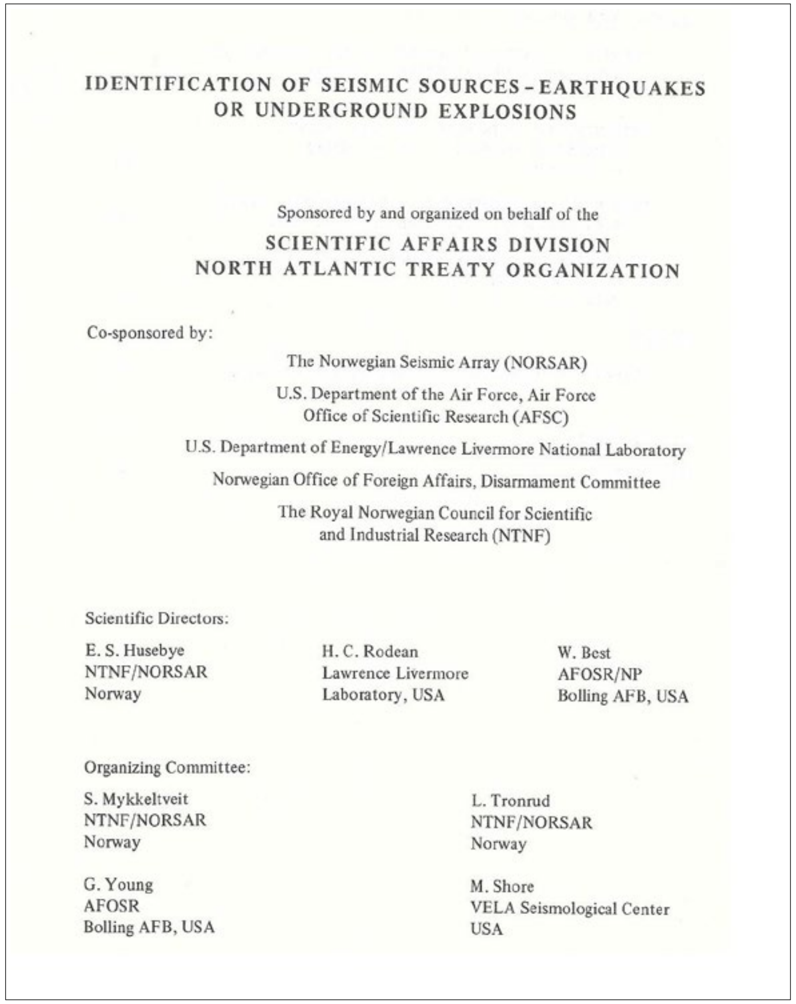
4.5 NATO seminar at Voksenåsen in 1980: Identification of Seismic Sources - Earthquake or Underground Explosion

During the 1970s, NORSAR arranged two successful symposia with broad worldwide participation: "Seismology and Seismic Arrays" in 1971 and "Exploitation of Seismograph Networks" in 1974. NORSAR held another international symposium in 1980 in the NATO Advanced Study Institutes series. The title of the symposium was "Identification of Seismic Sources – Earthquake or Underground Explosion" (see Fig. 4.5.1).

Norwegian Minister of Foreign Affairs, Knut Frydenlund, opened the symposium. He emphasized Norway's commitment to a nuclear test ban and noted, in particular, the important work taking place in the GSE in Geneva.

A total of 45 scientific papers were presented, covering aspects of seismic wave generation and propagation, recording systems, data analysis, and discrimination among different types of seismic sources. The previously mentioned paper by Mykkeltveit and Ringdal (1981) introducing the processing algorithm of the NORESS array undoubtedly held the most significant influence on the future developments of the monitoring of seismic sources.

The proceedings, edited by Eystein Husebye and Svein Mykkeltveit, comprised a comprehensive summary of the state of the art, covering a total of 876 pages.



IDENTIFICATION OF SEISMIC SOURCES – EARTHQUAKES
OR UNDERGROUND EXPLOSIONS

Sponsored by and organized on behalf of the
SCIENTIFIC AFFAIRS DIVISION
NORTH ATLANTIC TREATY ORGANIZATION

Co-sponsored by:

The Norwegian Seismic Array (NORSAR)
U.S. Department of the Air Force, Air Force
Office of Scientific Research (AFSC)
U.S. Department of Energy/Lawrence Livermore National Laboratory
Norwegian Office of Foreign Affairs, Disarmament Committee
The Royal Norwegian Council for Scientific
and Industrial Research (NTNF)

Scientific Directors:

E. S. Husebye NTNF/NORSAR Norway	H. C. Rodean Lawrence Livermore Laboratory, USA	W. Best AFOSR/NP Bolling AFB, USA

Organizing Committee:

S. Mykkeltveit NTNF/NORSAR Norway	L. Tronrud NTNF/NORSAR Norway
G. Young AFOSR Bolling AFB, USA	M. Shore VELA Seismological Center USA

Fig. 4.5.1 Sponsors and organizers of the 1980 seminar.

4.6 NORSAR begins new activities (seismic hazard, modeling)

The intention of establishing a scientific group at NORSAR was to use the facilities in research related to nuclear monitoring and, in general, studies in applied seismology. In the mid-1970s, the NORSAR scientists began to consider applied seismological problems, in particular, earthquake hazard and seismic modeling. The leader of the seismic hazard work was Hilmar Bungum, later supported by Anders Dahle and Conrad Lindholm.

One of the first topics in seismic hazard was a study of the seismicity of Norway. This was followed by a seismic hazard analysis for the Forsmark nuclear power plant in Sweden. Together with the Norwegian Polar Institute, NORSAR was also engaged in a research project to describe the seismicity of Svalbard. In cooperation with Brian Mitchell from St. Louis University, USA, a temporary network of seismometers was deployed in Svalbard, which gave important information on its seismic structure. NORSAR's cooperation with the Norwegian Polar Institute also resulted in the first seismic registrations in 1979-1980 on the uninhabited volcanic Bouvet Island, a Norwegian dependency in the southern Atlantic.

During the 1970s, NORSAR commenced a major seismic hazard analysis of the large dam project in Stiegler's Gorge, Tanzania. When Norway began offshore oil and gas exploration, NTNF supported a project at NORSAR, which was associated with NTNF's program Safety on the Continental Shelf. The seismic hazard group recently produced for Norway and Svalbard a significantly revised seismic zonation (a process of subdividing a territory into regions based on levels of ground motion or seismic hazard).

The seismic modeling activities were led by Håvar Gjøystdal, supported by Ketil Åstebøl. Both started as graduate students at NORSAR.

The seismic modeling activities have developed significantly and are centered around selling software packages and services through NORSAR Innovation AS. NORSAR Innovation AS is a wholly owned subsidiary of NORSAR. NORSAR Innovation AS conducts marketing, sales, and worldwide support of NORSAR's cutting-edge software solutions. The core applications of the NORSAR Software Suite include illumination analysis, survey planning, Kirchhoff modeling, 4D time-lapse studies, reservoir analysis, and microseismic network design and evaluation.

Chapter 5

1981 - 1985
NORESS and diplomacy

5.1 Further development and completion of NORESS

NORSAR continued operating the experimental, preliminary small array within NORSAR subarray 06C, with an interim 12-element array configuration installed in October 1980. The remarkable success of these experiments, which included the development of data processing algorithms and associated software as described in Chapter 4, led to the decision in 1983 to establish a complete, operational NORESS array according to the principles proved in the experiments. NORSAR, ARPA, and the U.S. Department of Energy (Sandia National Laboratories and Lawrence Livermore National Laboratories) joined forces in these developments. These enthusiastic stakeholders agreed to apply the most advanced seismic instrumentation and data communication technology. ARPA covered all of NORSAR's expenditures, whereas the U.S. Department of Energy funded their own efforts, which for Sandia included seismometers, digitizing units, and the data acquisition system installed at the NORESS center point. It is obvious that U.S. authorities prioritized supporting research and development in nuclear explosion monitoring and regarded Norway and NORSAR as exceptional and credible partners in these efforts.

The first basic decision that was required was the array geometry. It was decided to deploy 25 seismometers to detect vertical ground movements in a configuration containing a center seismometer, supplemented by four concentric rings of three, five, seven, and nine sensors (see Fig. 5.1.1). Four of the sites were equipped with a three-component seismometer, which also detects north-south and east-west ground movements. The array design was achieved with important contributions from Fred Followill and David Harris from Lawrence Livermore. A key feature of the design specified certain spacing of the sensors in order to enhance the signal-to-noise ratio at certain frequency bands through special processing (Mykkeltveit et al., 1983), thereby providing optimized detection of seismic signals of specific interest.

Before installing the final version of NORESS, additional experiments were conducted, beginning in the summer of 1983, to ensure that this geometry was appropriate. Five three-component seismometers were installed in an experiment in June, followed in July by a layout of 21 vertical seismometers that remained operational into the spring of 1984. The geometric configuration of sensors in this last experiment was identical to that of the planned final version of the NORESS array, except for four elements that were not installed in the outermost ring. The evaluation of these experiments confirmed the expectations for the design chosen for NORESS. This careful approach was made possible by ARPA's dedication, patience, and generous financial support. So it was with great confidence that NORSAR embarked on establishing the permanent version of the NORESS array in the summer of 1984, in cooperation with Sandia to install the field electronics.

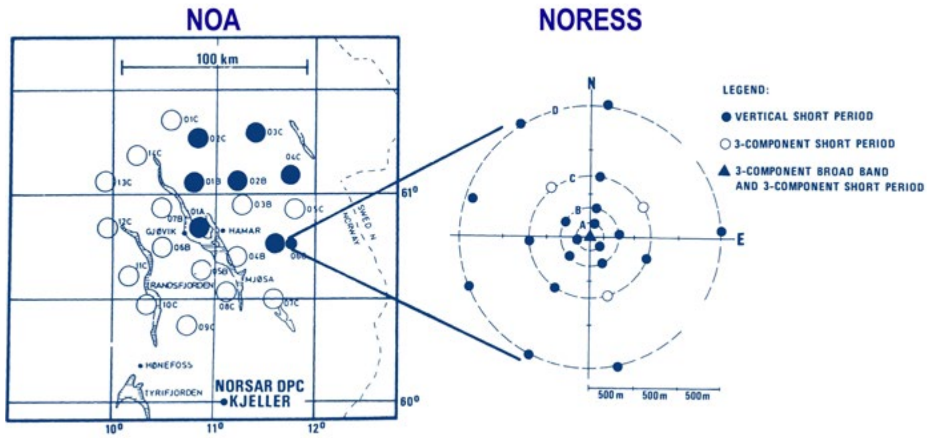


Fig 5.1.1 *The illustration shows the geometry of the NORESS array and its location within subarray 06C of the NOA array (and not next to 06C, as drawn here for clarity). Note the difference in the size of NOA and NORESS.*

Establishing the field infrastructure for NORESS was a major undertaking (see Figs. 5.1.2-5.1.6). NORSAR hired contractors to prepare the seismometer vaults, drill a 60-meter deep borehole, dig cable trenches, lay power, and fiber optic cables for the seismic signals, and construct a building at the center of the array for data collection and transmission functions. The funding for this infrastructure from ARPA amounted to six million NOK in 1984. Approximately six million NOK were also received from ARPA for each of the following three years to complete the field installation and operate the array, furnish the maintenance center with state-of-the-art electronic laboratory equipment, develop the data processing functions at Kjeller, including new algorithms, and evaluate the results. In addition, the U.S. Department of Energy incurred considerable costs in terms of manpower and equipment for their part of the NORESS project.

The raw data from the sensors were digitized in the seismometer vaults and transmitted via fiber optical cables to the central building of the array. The full data stream, including status information about the instrumentation, was then transmitted automatically and without delay to the NORSAR data analysis center via a high-speed (at that time) landline, as well as to three recipients in the United States (Sandia, Lawrence Livermore and an ARPA center in Arlington, Virginia) by satellite. Given the novelty of the technologies applied in the project, some start-up problems could be expected. However, these turned out to be rather few, and after a short while, data flowed reliably to all four data centers.

Fig 5.1.2 *Aerial photo of NORESS, with the A-, B-, C- and some of the D-ring indicated (see Fig. 5.1.1). NORESS is located in a quiet forest area, at some distance from sources of background seismic noise.*

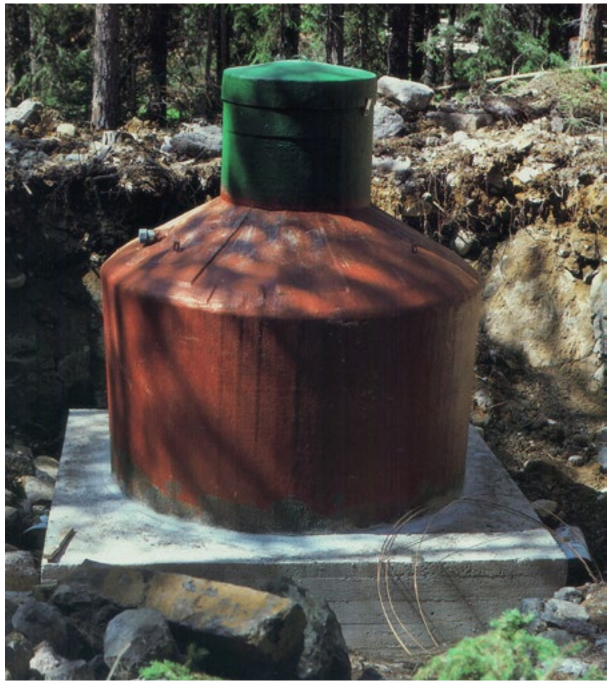


Fig 5.1.3 *The seismometers and associated electronics of NORESS were placed on concrete pads and housed inside fiberglass tanks.*

Fig 5.1.4 *The photo shows the short-period seismometer used in NORESS (38 cm long).*

Fig 5.1.5 *The three-component broadband center seismometer of the NORESS array was originally placed in a 50-meter-deep borehole.*

Fig 5.1.6 *NORESS data were initially transmitted to the United States by satellite. A clearing had to be made in the forest to make the antenna visible to the low-elevation geostationary satellite. The original building was later rebuilt to house the Stendammen facility for equipment testing and experiments.*

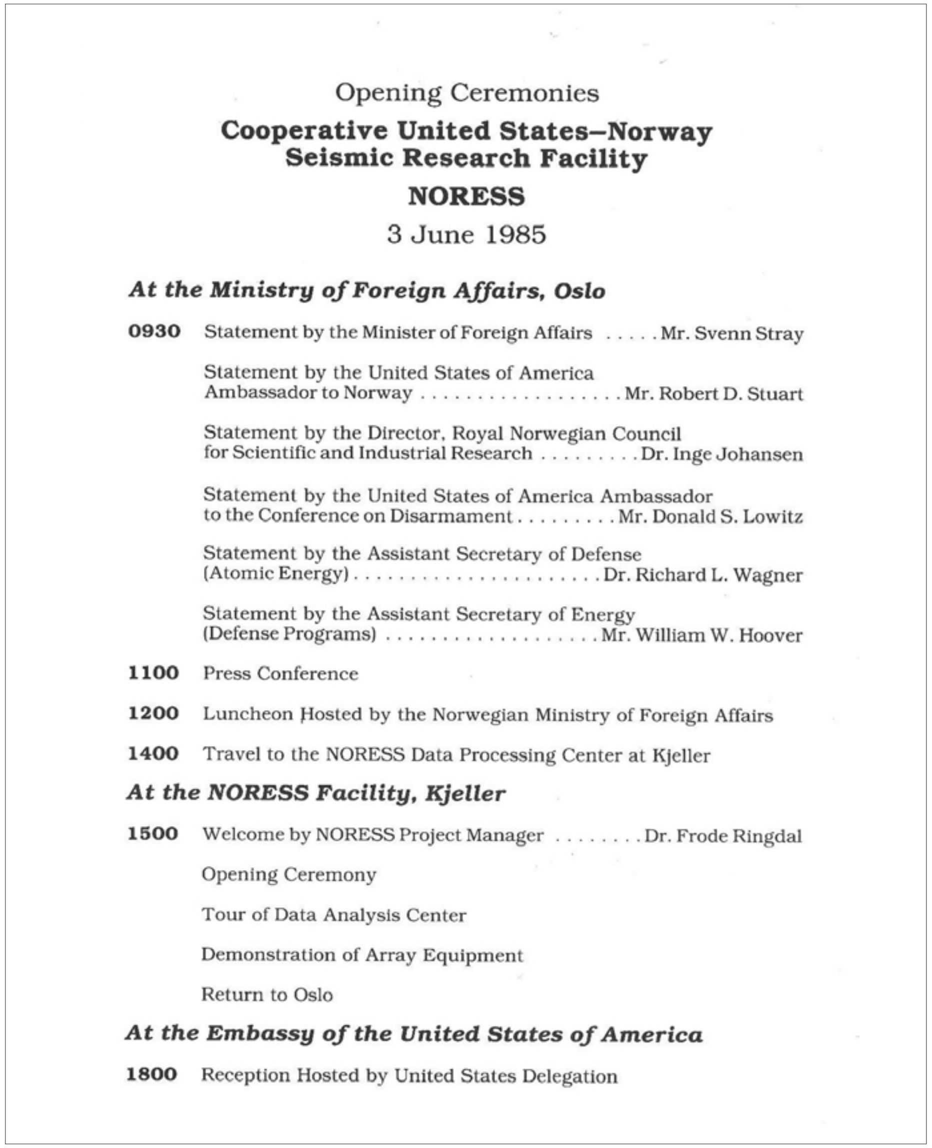
In parallel with these developments, the NORSAR experts regularly informed the GSE and the Conference on Disarmament in Geneva about the progress in the NORESS work in the form of CD working papers. These papers created great interest among CD delegations. Accordingly, Mr. Sten Lundbo, Minister Counsellor at the Norwegian Embassy in Geneva, suggested that NORSAR arrange a workshop in Norway in June 1985 for the delegations in the Conference on Disarmament. The Norwegian Ministry of Foreign Affairs approved these plans.

NORSAR pointed out that the budgetary implications of the workshop would necessitate additional funding from the Ministry of Foreign Affairs, especially travel grants for participants from developing countries, and such funding was granted. The NORSAR director sent invitations to all CD participants and received overwhelmingly positive responses.

At the same time, the United States suggested to the Norwegian Ministry of Foreign Affairs that a formal opening of the NORESS facilities should be arranged in connection with the CD workshop. It was decided to arrange a bilateral opening on the day preceding the workshop. There were thus two separate events, described in the following sections.

5.2 The opening of NORESS in Oslo 3 June 1985

The formal bilateral dedication of the NORESS research facility was held on 3 June 1985 at the Ministry of Foreign Affairs in Oslo (see Fig. 5.2.1 for the program and Fig. 5.2.2 for a photo of the U.S. participants).



Opening Ceremonies

Cooperative United States–Norway
Seismic Research Facility
NORESS

3 June 1985

At the Ministry of Foreign Affairs, Oslo

0930 Statement by the Minister of Foreign Affairs . . . . . Mr. Svenn Stray

Statement by the United States of America Ambassador to Norway . . . . Mr. Robert D. Stuart

Statement by the Director, Royal Norwegian Council for Scientific and Industrial Research . . . . Dr. Inge Johansen

Statement by the United States of America Ambassador to the Conference on Disarmament . . . . Mr. Donald S. Lowitz

Statement by the Assistant Secretary of Defense (Atomic Energy) . . . . Dr. Richard L. Wagner

Statement by the Assistant Secretary of Energy (Defense Programs) . . . . Mr. William W. Hoover

1100 Press Conference

1200 Luncheon Hosted by the Norwegian Ministry of Foreign Affairs

1400 Travel to the NORESS Data Processing Center at Kjeller

At the NORESS Facility, Kjeller

1500 Welcome by NORESS Project Manager . . . . Dr. Frode Ringdal

Opening Ceremony

Tour of Data Analysis Center

Demonstration of Array Equipment

Return to Oslo

At the Embassy of the United States of America

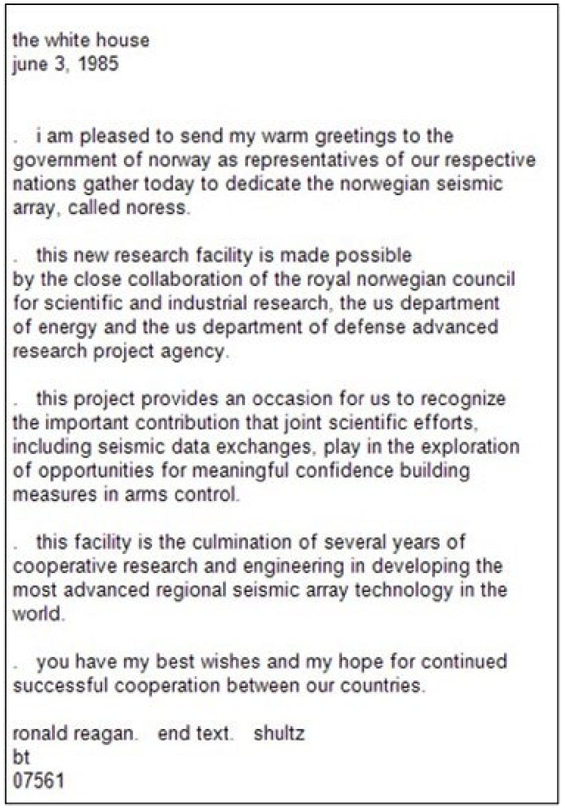
1800 Reception Hosted by United States Delegation

Fig. 5.2.1 *The agenda for the NORESS opening ceremonies.*

Fig. 5.2.2 *The United States delegation in front of the Foreign Ministry building in Oslo on 3 June 1985.*

The Norwegian Minister of Foreign Affairs, Mr. Svenn Stray, presented a welcome address, stating that the opening of the new seismic research facility - NORESS - was yet another sign of the very close cooperation between Norway and the United States in a large number of areas: political, economic, cultural, and scientific. He stressed the great importance that the Norwegian Government attached to the bilateral cooperation between the two countries in the field of seismology, dating back to the cooperative agreement of 15 June 1968.

He noted that the events in Oslo and at Kjeller this day marked the culmination of several years of cooperative research and engineering in developing one of the world's most advanced seismic array facilities. He stressed Norway's gratitude to the United States Government for its generous financial and other support over the years. He confirmed the interest in continuing and further developing this bilateral cooperation. He was also pleased to note that several American guests would prolong their stay in Norway and participate in the workshop for the



the white house
june 3, 1985

. i am pleased to send my warm greetings to the government of norway as representatives of our respective nations gather today to dedicate the norwegian seismic array, called noress.

. this new research facility is made possible by the close collaboration of the royal norwegian council for scientific and industrial research, the us department of energy and the us department of defense advanced research project agency.

. this project provides an occasion for us to recognize the important contribution that joint scientific efforts, including seismic data exchanges, play in the exploration of opportunities for meaningful confidence building measures in arms control.

. this facility is the culmination of several years of cooperative research and engineering in developing the most advanced regional seismic array technology in the world.

. you have my best wishes and my hope for continued successful cooperation between our countries.

ronald reagan. end text. shultz
bt
07561

Fig. 5.2.3 *A greeting to Norway from the United States White House signed by President Ronald Reagan on the occasion of the NORESS dedication. Photo credit: Matt H. Wade at Wikipedia, http://en.wikipedia.org/wiki/User:UpstateNYer*

Conference on Disarmament over the next days on seismological verification of a Comprehensive Nuclear-Test-Ban.

Mr. Stray's address was followed by a statement from the United States Ambassador to Norway, Mr. Robert D. Stuart. Statements were also made by the Director of NTNF, Dr. Inge Johansen, the United States Ambassador to the Conference on Disarmament, Mr. Donald S. Lowitz, the American Assistant Secretary of Defense (Atomic Energy), Richard L. Wagner and the American Assistant Secretary of Energy (Defense Programs), William W. Hoover.

The statements were followed by a press conference attended by a number of Norwegian and international news agencies.

In the afternoon, an opening ceremony was held at the NORSAR facilities at Kjeller, where the data processing center for the NORESS installation is located.

The NORSAR Director, Frode Ringdal, welcomed the distinguished guests. The United States Ambassador to Norway, Robert D. Stuart, then presented to Director Frode Ringdal a congratulatory letter from the President of the United States of America, Mr. Ronald Reagan. The letter is displayed in Fig. 5.2.3.

A tour of the data analysis center and a demonstration of the NORESS array equipment was conducted by Norwegian and United States experts, who had jointly participated in the development of the NORESS array over several years.

The day ended with a reception hosted by the United States Delegation at the Embassy of the United States.

5.3 The Conference on Disarmament Workshop 4-7 June 1985

Immediately following the NORESS opening ceremony, NORSAR arranged a workshop for the Geneva Conference on Disarmament. This workshop was intended for representatives of member delegations to the Conference on Disarmament, representatives of the Secretariat of the Conference, and seismologists participating in the GSE.

The workshop intended to shed further light on the seismological verification aspects of a comprehensive test ban through briefings and demonstrations of the seismological facilities in Norway. The workshop was attended by 84 participants from 41 countries and the Secretariat of the Conference on Disarmament. NORSAR arranged for a chartered airplane from Geneva to Oslo and return, as well as hotel accommodations and meals for all participants, using the Ministry of Foreign Affairs funds.

In his welcoming address at the opening of this workshop, the Norwegian Minister of Foreign Affairs, Mr. Svenn Stray, stated that the holding of this workshop in Oslo demonstrated the great importance that the Government of Norway attached to the Conference on Disarmament and Norway's participation in the Conference. He stressed that effective verification was vital to a test ban, ensuring compliance and building confidence.

Regarding the work of the GSE, Mr. Stray said that a global seismological network would constitute an essential element of a verification system for a nuclear test ban. In the opinion of the Norwegian Government, such a network should be equipped with instrumentation of high standards. It should incorporate recent technological advances with respect to computer and data communication technology.

The minister of foreign affairs stressed that the research at NORSAR was an effort by Norway to find solutions to outstanding verification issues relevant to a nuclear test ban. He attached considerable importance to maintaining NORSAR as a research facility open to scientists from all countries. Some of them had conducted research at NORSAR for up to two years. Mr. Stray also confirmed that the Norwegian government would make NOA available within a global network. This was a reconfirmation of Norway's previously expressed commitment to contribute to a future monitoring system for a nuclear test ban. As we shall see, this promise was fulfilled years later when Norway ratified the CTBT, and the Treaty's verification arrangements were implemented.

The program for the workshop included a demonstration of the processing of NOA and NORESS data at NORSAR's headquarters at Kjeller, which emphasized the differences between the two types of arrays: NOA is the world's largest seismological array, designed to detect seismic events occurring at teleseismic distances (3,000-10,000 km away), whereas NORESS is designed to detect seismic events occurring at close distances (less than 3,000 km). The demonstration included the following:

- Detection of seismic signals from earthquakes and nuclear explosions
- Seismic signal analysis, interactive graphic displays
- Seismic instrumentation, station calibration, and monitoring
- International exchange of seismic data.

The participants also inspected the field installations of NORESS (see Fig. 5.3.1) and were given briefings about:

- NORESS broadband and short-period seismometer installations
- NORESS central terminal
- Satellite transmission facilities
- NOA subarray 06C central site, located at the NORESS central point.

As a background to these demonstrations, lectures were presented by Frode Ringdal on "Seismological Verification of a Comprehensive Test Ban Treaty" and by Svein Mykkeltveit on "Seismological Facilities in Norway."

Fig. 5.3.1 *Frode Ringdal addresses CD delegations visiting the NORESS site in 1985.*

The conclusions drawn by Norwegian authorities based on the demonstrations and briefings were summarized as follows (CD/599):

- Substantial technical progress has been achieved during the last few years as regards seismological verification of a comprehensive nuclear test ban
- Establishing a global seismological network, as proposed by the GSE, is essential. Such a network should ensure international data exchange based on the most modern technology available at the time of its establishment
- Some technical problems remain to be solved. These problems concern detecting and identifying very low-yield explosions, and explosions conducted in an environment that produces very weak seismic signals (e.g., underground cavities). The reduced seismic detection possibilities immediately after the occurrence of large earthquakes is also a problem that needs further study.

Chapter 6

1986 - 1990 Network of small arrays

6.1 Beginning of a network of small seismic arrays

The opening of NORESS and the successful CD Workshop led to a sustained effort to develop a network of regional arrays. The design of NORESS gave rise to a prototype that was copied in many countries, and NORSAR experts were consulted in these efforts.

At this time, Jan Fyen rejoined the NORSAR staff. He originally started working at NORSAR as a computer operator before he obtained a degree at the University of Oslo and continued working as a seismologist at NORSAR. He also worked at IBM for some years. After that, he rejoined NORSAR as manager of computer operations.

Jan Fyen acquired many international contacts and had a significant role in the establishment and technical operation of many of NORSAR's partner systems, as well as having a key role in the organization of CTBT workshops of various kinds in several countries.

6.2 FINESS is established in southern Finland

In cooperation with NORSAR, the Institute of Seismology, University of Helsinki, built a seismic array in the southern part of Finland. The FINESA array (later expanded and named FINESS, see Fig. 6.2.1) became an excellent supplement to the NORESS array. ARPA later supported NORSAR's processing of data from the FINESA array, including financing a data transmission link to NORSAR.

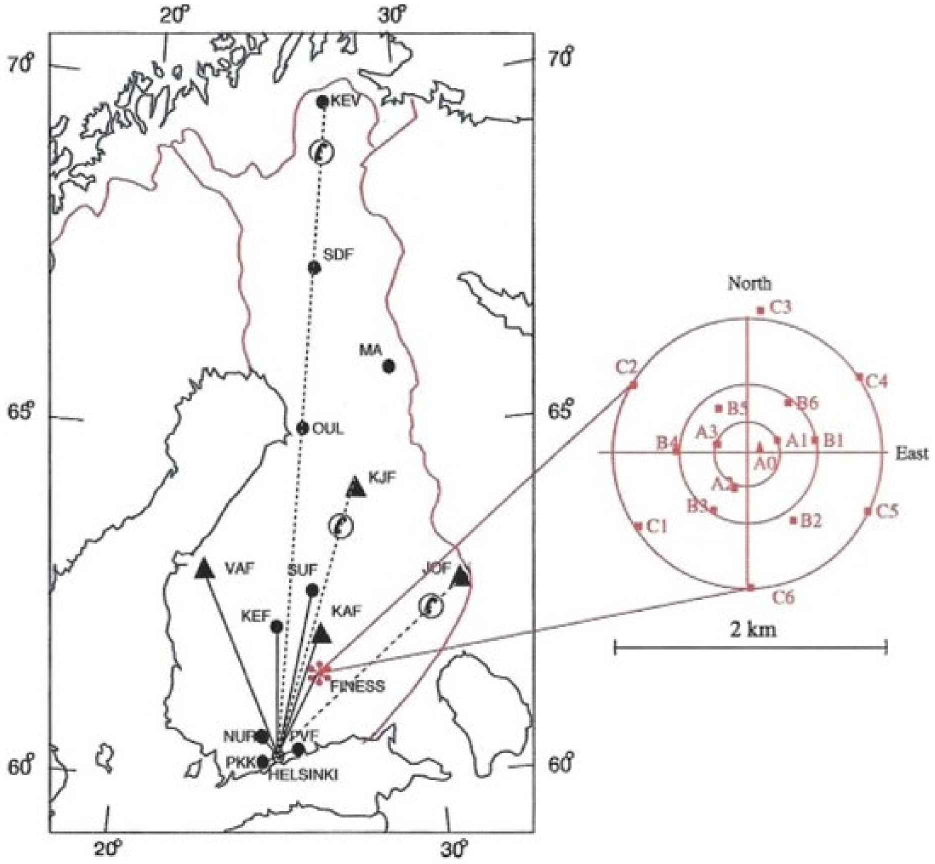


Fig. 6.2.1 *The FINESS array and the network of conventional seismographic stations in Finland.*

6.3 ARCESS is built in northern Norway

The United States initially considered establishing NORESS-type arrays in northern Finland and Germany. While the array in Germany was built as planned, ARPA's plans for a NORESS-type array in northern Finland encountered some resistance (of a political nature). Instead, NORSAR built the ARCESS array with ARPA funding in northern Norway. Svein Mykkeltveit and Anders Dahle carried out a site survey in 1986 in eastern Finnmark, and found an ideal location for a small NORESS-type array close to the town of Karasjok. Since the location chosen for the array was in the trekking area of reindeer herds, it was necessary to obtain the consent of the Sami population, and this was achieved by making the seismometer vaults as inconspicuous as possible. Frode Ringdal and Anders Dahle met with Sami representatives and obtained the required consents, and the array was constructed in 1987. The geometry of the array is shown in Fig. 6.3.7. Figs 6.3.1-6.3.3 show photos from the ARCESS site.

Fig. 6.3.1 *Scene from Karasjok, Norway, at the location of ARCESS.*

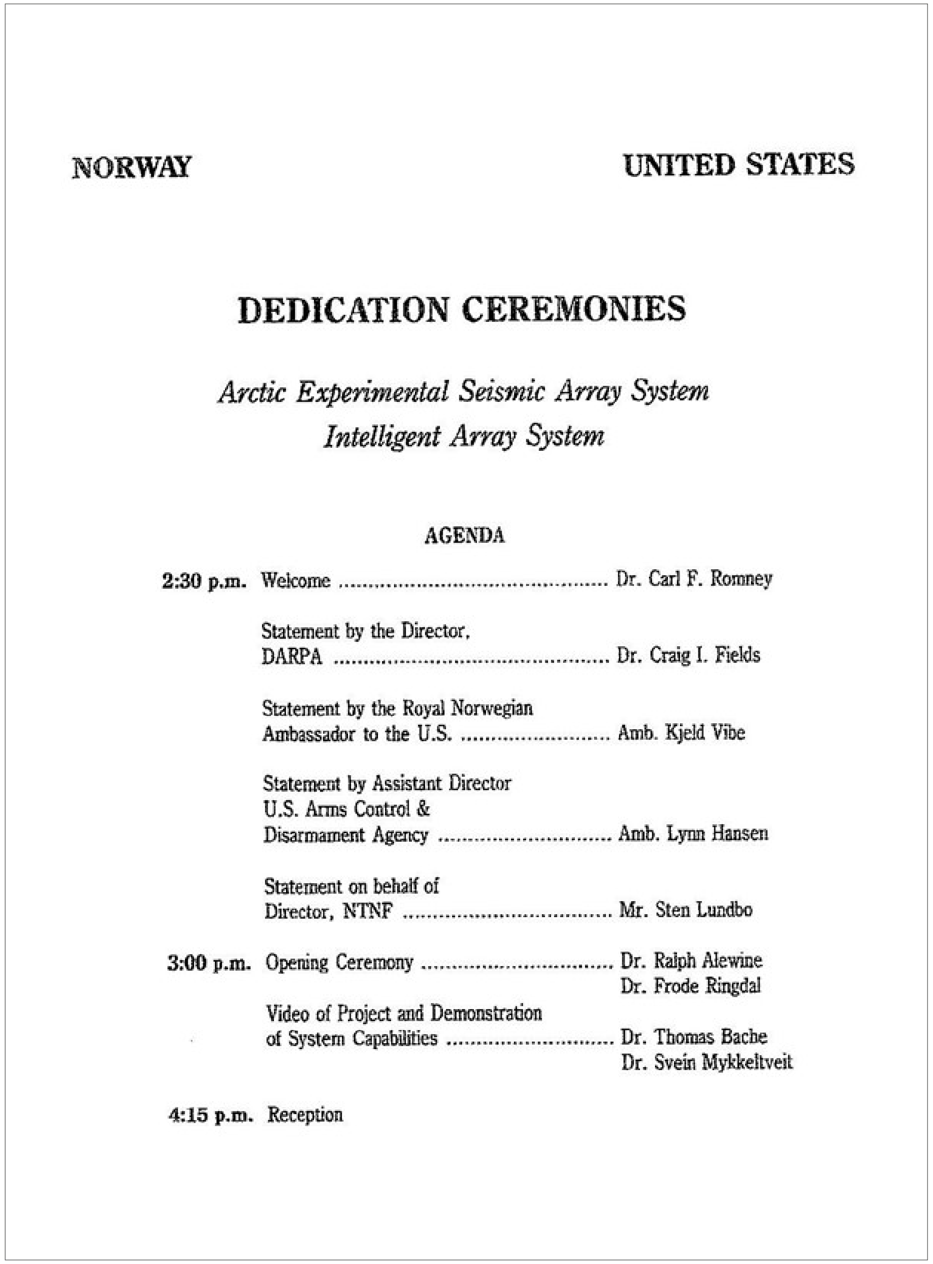
Fig. 6.3.2 *This photo from the installation phase in 1987 shows one of the ARCESS three-component sites, with electronics and seismometers that record the ground motion in the vertical, north-south, and east-west directions. The picture is taken before these units are carefully covered with turf and peat moss to make the site as inconspicuous as possible.*

Fig. 6.3.3 ARCESS data were transmitted to the NORSAR data center by satellite.

As a curiosity, we might note that NORSAR's plans to place an infrasound array in the Karasjok area many years later were not approved, even after negotiations that lasted about a decade. The sticking point was the need to place a fence around the infrasound detectors. The infrasound array, part of the International Monitoring System (IMS), was eventually constructed in Bardufoss, northern Norway (see Section 11.2).

The ARCESS seismic array became an excellent supplement to the two regional seismic arrays NORESS and FINESA. The combination of NORESS, ARCESS, and FINESA became the cornerstone of the Intelligent Monitoring System that was, at the time, the centerpiece of the ARPA research program.

On 20 June 1989, the Norwegian ambassador and U.S. dignitaries dedicated ARCESS at a ceremony in Washington, D.C. Frode Ringdal and Svein Mykkeltveit participated from NORSAR (see Figs. 6.3.4-6.3.6). Minister Counselor Sten Lundbo from the Norwegian Embassy in Geneva made a statement on behalf of the Director of NTNF. This statement demonstrated the continued interest of NTNF, as the Norwegian partner in the government-to-government agreement, in supporting NORSAR's activities.



NORWAY **UNITED STATES**

DEDICATION CEREMONIES

Arctic Experimental Seismic Array System
Intelligent Array System

AGENDA

2:30 p.m.	Welcome	Dr. Carl F. Romney
	Statement by the Director, DARPA	Dr. Craig I. Fields
	Statement by the Royal Norwegian Ambassador to the U.S.	Amb. Kjeld Vibe
	Statement by Assistant Director U.S. Arms Control & Disarmament Agency	Amb. Lynn Hansen
	Statement on behalf of Director, NTNF	Mr. Sten Lundbo
3:00 p.m.	Opening Ceremony	Dr. Ralph Alewine Dr. Frode Ringdal
	Video of Project and Demonstration of System Capabilities	Dr. Thomas Bache Dr. Svein Mykkeltveit
4:15 p.m.	Reception	

Fig. 6.3.4 Program for the official dedication of ARCESS in Washington, D.C. on 20 June 1989.

Fig. 6.3.5 Frode Ringdal in Washington, D.C. during the dedication of the ARCESS array.

Fig. 6.3.6 Ralph Alewine and Frode Ringdal during the dedication ceremony.

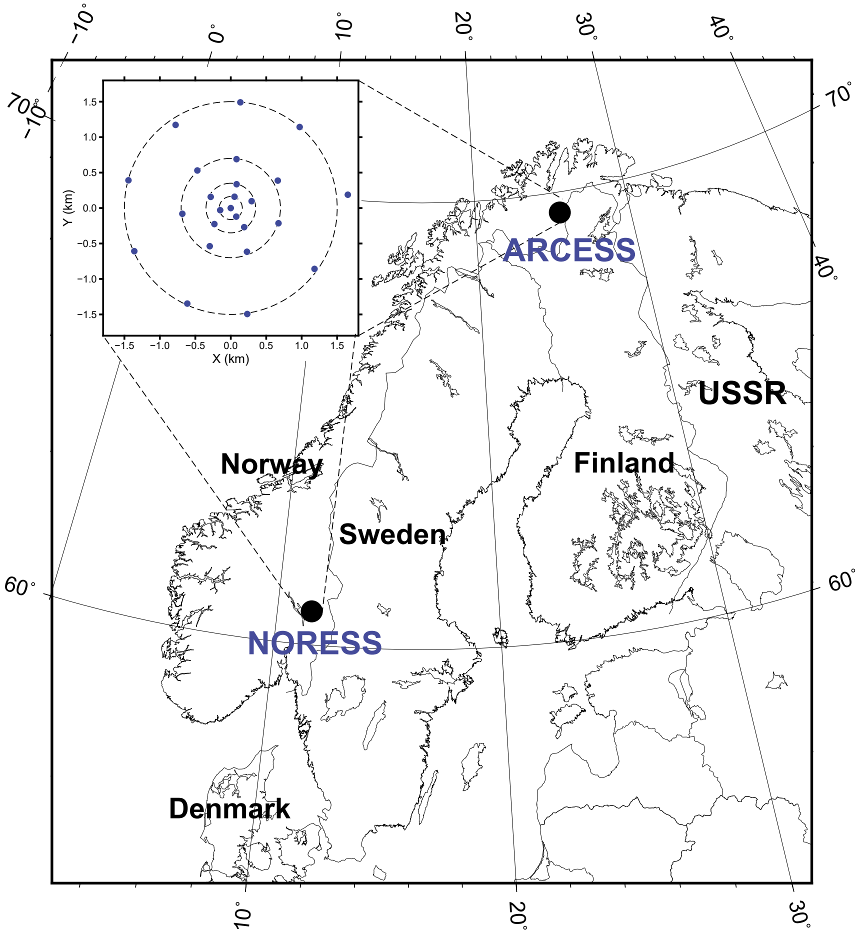


Fig. 6.3.7 Illustration of the NORESS/ARCESS combination. The two arrays have identical layouts and dimensions.

6.4 GERESS is built in Germany

ARPA also financed a NORESS-type array in Germany. The GERESS array (see Fig. 6.4.1) was built as a slightly larger array than NORESS but with the same number of sensors and a similar layout.

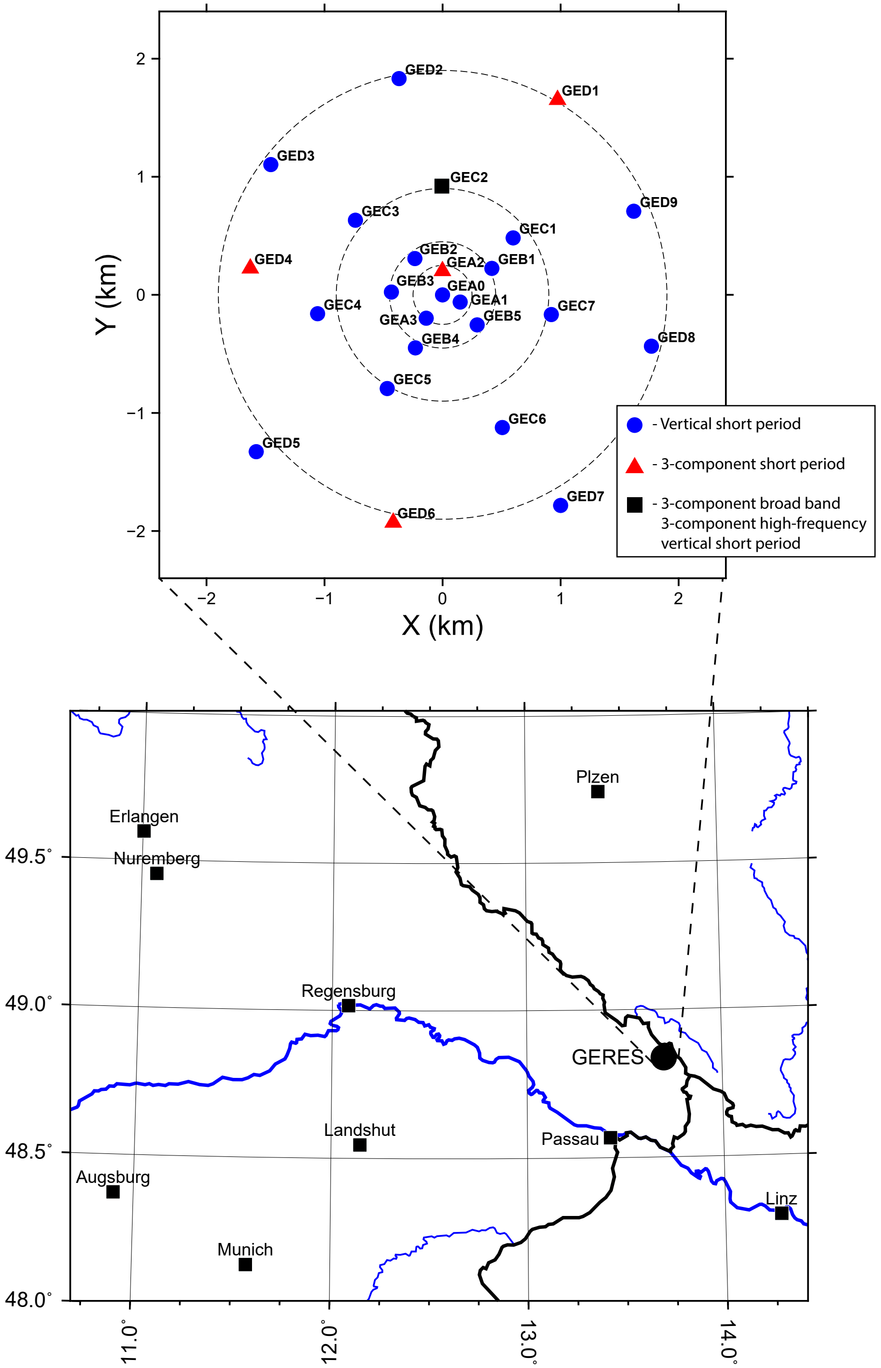


Fig. 6.4.1 *Geometry and location of the GERESS array.*

Fig. 6.4.2 shows a variety of seismic arrays around the world, established for test ban monitoring purposes. Note that many of them are similar to NORESS and ARCESS in their geometrical shape and size but that there are also a number of larger, differently shaped arrays, most of which were established before the 1980s.

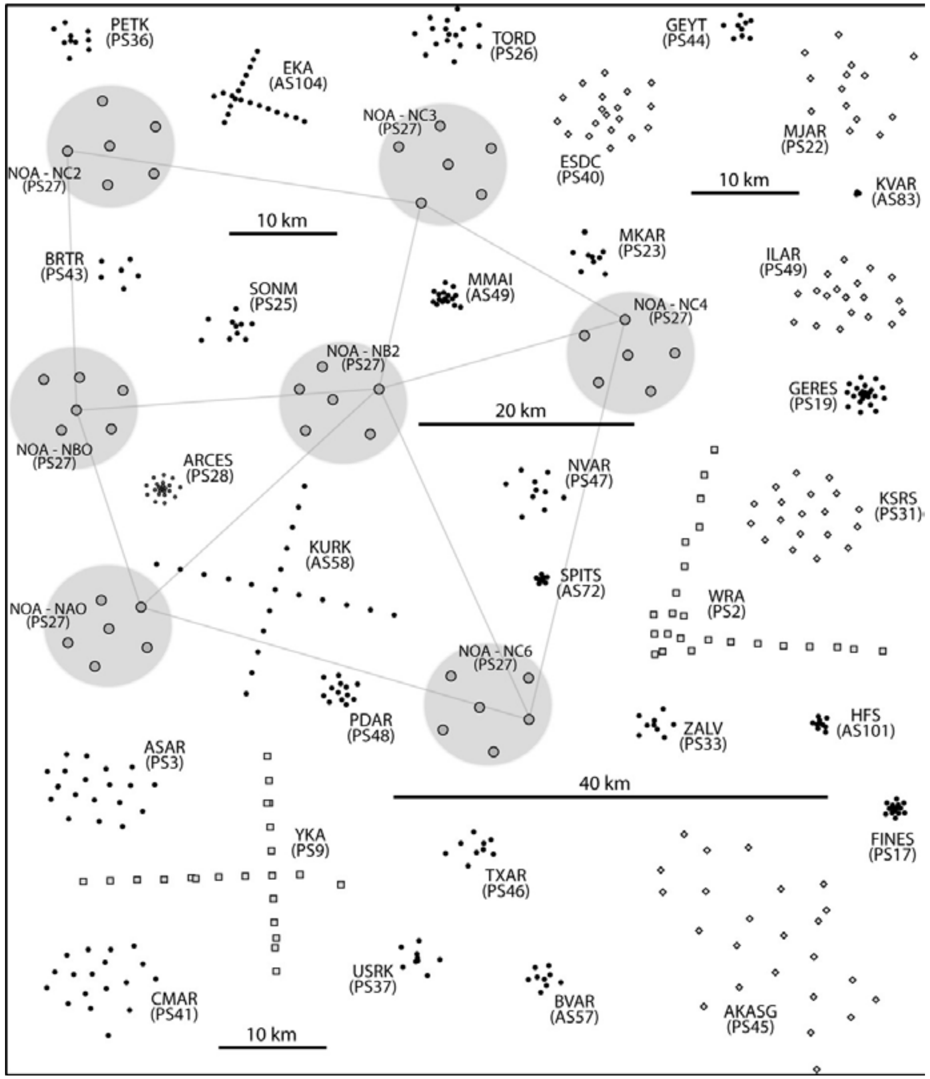


Fig. 6.4.2 *Seismic arrays come in various sizes and shapes. Here are some samples of those used in the CTBT International Monitoring System (IMS). Note that PS27 (NOA) is far larger than any other IMS array.*

6.5 High-frequency seismic recordings

The characteristics of seismic noise and signals at high frequencies (5 Hz and above) have been a topic of attention in the test ban community for many years. This interest is largely driven by the importance of the high-frequency band in the detection and identification of underground nuclear explosions recorded at local and regional distances.

Two types of possible evasion during a test ban will be discussed here:

- The hide-in-earthquake scenario
- Cavity decoupling (i.e., detonating a nuclear explosion in a large underground cavern).

Hide-in-earthquake

When the NOA array was first established, the system was set such that the highest usable frequency was 4.5 Hz, and the analysis was mainly conducted in the frequency band 1.2-3.2 Hz. Only when the array was reduced in 1976 did NORSAR obtain agreement with ARPA and AFTAC to begin experiments with NOA. One of NORSAR's first actions was the update of the system such that frequencies up to 8 Hz could be considered at some short-period sensors.

The hide-in-earthquake scenario is to conceal a nuclear test by detonating the nuclear device immediately following a large earthquake. As explained below, this possibility was effectively eliminated when a NOA recording from 1979 was published in a NORSAR Semiannual Report (Scientific Rept. 1/84-85, Nov. 1984, pp. 54-62) and later in Sykes (1998) and Hannon (1998). The data start time was 14 September 1979 at 07.39.00, and the record is shown, in two different filter bands, in Fig. 6.5.1.

The upper trace in Fig. 6.5.1 is filtered with the standard band of frequencies between 1.2 and 3.2 Hz and shows a large earthquake in Kamchatka, USSR. The lower trace, which clearly shows a large, high-frequency signal from the small underground nuclear explosion (less than one kiloton) one minute later, is made with a passband of 3.2-5.2 Hz.

Obviously, any country under a CTBT that tries to hide a nuclear explosion by setting it off immediately following an earthquake in the vicinity runs a significant risk of being caught cheating.

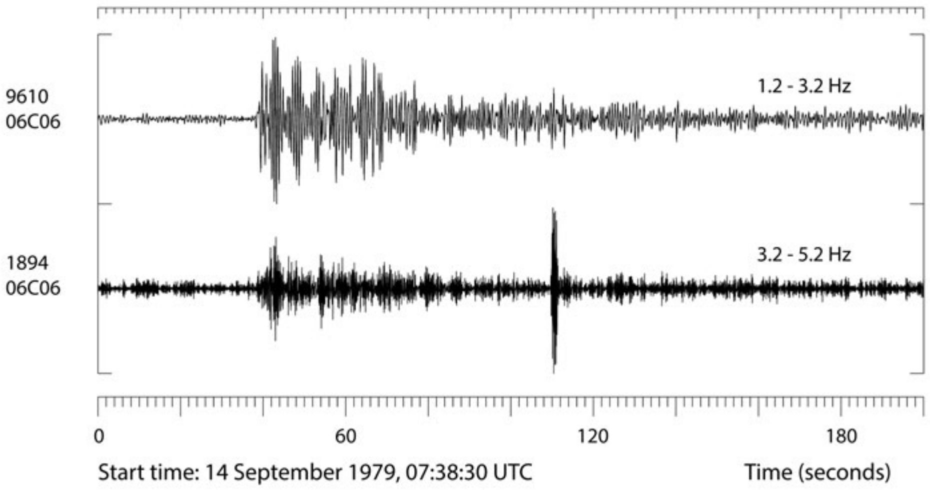


Fig. 6.5.1 *An example of a recording by one seismometer at NOA (channel 06C06) of a large earthquake in Kamchatka (magnitude 5.8) followed by a very small underground explosion (less than one kiloton) at the eastern Kazakhstan test site, USSR.*

Decoupling

After the success of the NORESS development, ARPA expressed interest in studying even higher frequencies. A three-component seismometer recording seismic signals with frequencies of up to 50 Hz was established at the NORESS center site in 1986. This required a digitizer with a large dynamic range, and Sandia Laboratories provided a 24-bit digitizer manufactured by Gould, Inc. To our knowledge, this was one of the first 24-bit digitizers used in the seismic community. Later on, similar instrumentation was established at the ARCESS and SPITS arrays.

It is well known that a decoupled explosion (i.e., an explosion set off in a large cavity) will reduce the seismic signals transmitted into the earth. From theoretical studies, it is predicted that the decoupling factor is less at higher frequencies, indicating that using high-frequency sensors increases the probability of detecting decoupled explosions.

NORSAR's initial studies of data sampled with the 24-bit digitizer confirmed the presence of significant high-frequency energy from events at local and regional distances. NORSAR later teamed with American contractors to investigate some small, decoupled explosions conducted in Sweden in 2000 and 2001 when the

NOA/NORESS high-frequency seismometers stations were operational.

The results from these experiments confirmed the theoretical models, i.e., that the decoupling is less effective at higher frequencies. Reference is made to Stevens et al. (2001) and Gibbons et al. (2002).

6.6 New analysis methods for regional array data are developed

In the meantime, the scientists at NORSAR continued developing processing software. One important achievement was the broadband estimation technique developed by Kværna and Doornbos (1986). This technique provided more stable results than the original single-frequency estimation method, as shown by Kværna and Ringdal (1986). It was implemented in the automatic processing for all the regional arrays.

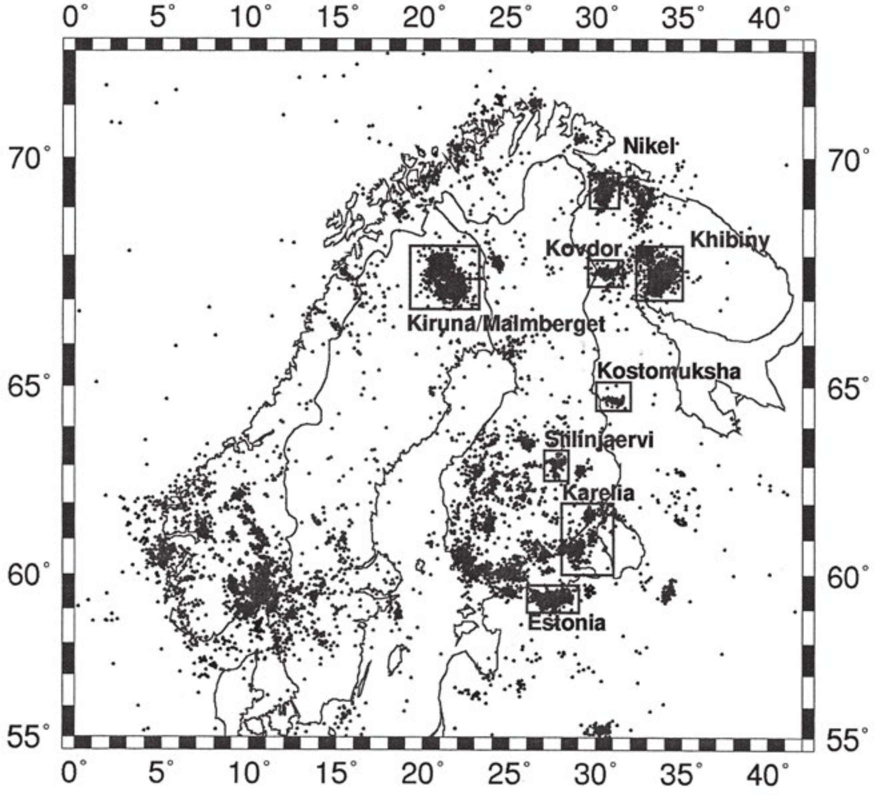


Fig. 6.6.1 Example of events determined by the artificial intelligence system – more than 12000 seismic events in Fennoscandia and NW Russia were detected and located during 18 months in 1991-1993, most of them mining explosions.

Another interesting development was the introduction of artificial intelligence systems, which were pursued at ARPA at the end of the 1980s. American experts pioneered the development of such systems for detection and location purposes (see Fig. 6.6.1). The initial implementation details are extensively covered in the paper by Bache et al. (1990). Note that the solutions by the system would still be subject to review and acceptance by the analyst.

6.7 New atmosphere in GSE, Geneva, as Gorbachev assumes power

A radical change in the atmosphere of the GSE occurred after Mr. Gorbachev assumed power in the Soviet Union in 1985. This change became apparent to GSE participants when the Soviet ambassador to the CD, Victor Israelyan, made a remarkable statement in July 1986 concerning the GSE work. The Soviet Union and allies had until then been cautious and wanted to move slowly in small steps, but the Soviet ambassador's statements changed the situation significantly. He suggested that the extensive development and use of digital registration of seismic signals, in combination with improved means of transmitting and processing of waveform (Level II) data at international data centers, would allow a significant increase in the effectiveness of the international system of exchange of data developed by the GSE. This statement indicated a greatly improved flexibility on issues that had previously been contentious in the GSE. See the picture of the GSE leadership in 1986 in Fig. 6.7.1.

There was also a change regarding the Soviet GSE delegation. Previously, their experts had not attended technical workshops outside Geneva for many years. However, this practice then changed, and as a result, the experts could attend and contribute to such workshops.

This meant that several Soviet experts, among them the future Russian Minister of Atomic Energy, Mr. Viktor Mikhailov, were able to visit NORSAR on 12-15 May 1987. During the demonstrations of NORESS capabilities, he remarked "amazing" in Russian to his colleagues, according to a Norwegian diplomat who was accompanying the Soviet delegation.

With this fundamental change in Soviet attitude, the ground was laid for a new, more ambitious task: to revise the design of the initial GSE system to take advantage of the technological developments that had occurred since the Group's first report in 1978. This was achieved by GSE's Fifth Report (CD/903), issued on 17 March 1989, and provided a revised technical description of the concepts for a global international seismic data exchange system.

Fig. 6.7.1 *GSE Chairman Ola Dahlman (center), GSE Scientific Secretary Frode Ringdal (left), and CD Secretary Michael Cassandra (right) in July 1986.*

The new openness of the Soviet Union was also apparent in many other ways. For example, since 1986, the Soviet Government reported each nuclear test on the next day (although they would soon cease testing). Thus, on 28 December 1988, the USSR reported that they had carried out a nuclear test at their eastern Kazakhstan test site. We are only aware of two seismic stations outside the Soviet Union that automatically detected and reported this test: the NOA and NORESS arrays. The NORESS signal-to-noise ratio on the beam (see Fig. 6.7.2) was remarkably high, demonstrating that even a much smaller test would have been detected.

Experts from China also visited NORSAR and the NORESS facilities for the first time during 12-16 September 1986. They had obviously been impressed by the new technology demonstrated by Norway's presentations and demonstrations of NORESS and NOA at the GSE in Geneva. They were interested in seeing both the facilities at the data center and the state-of-the-art instrumentation in the field and appreciated the advanced processing algorithms.

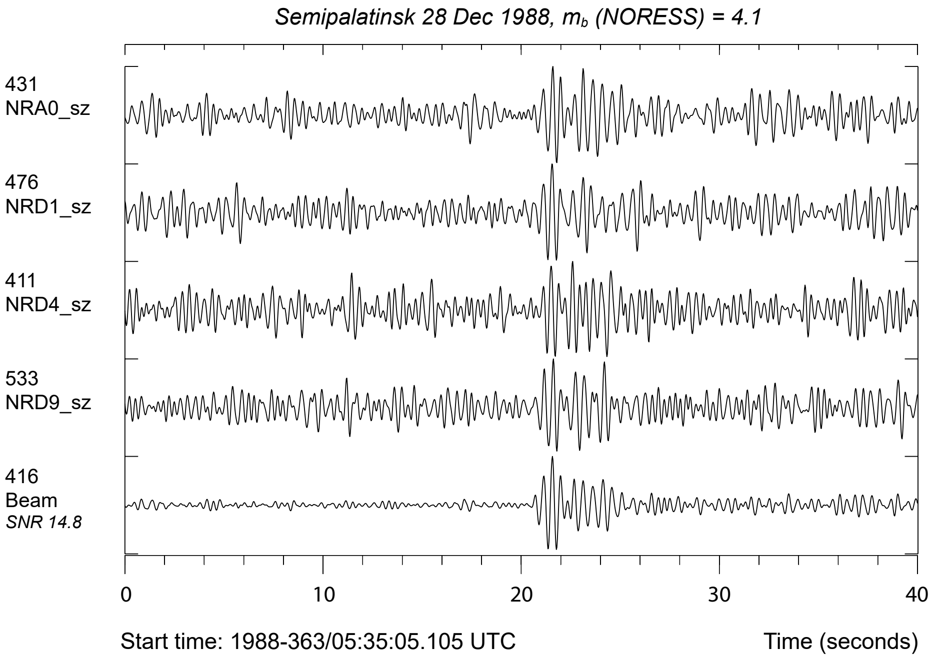


Fig. 6.7.2 *NORESS single sensors and array beam plot of NORESS from the small (0.2 kilotons) nuclear explosion in Kazakhstan on 28 December 1988. Note the high signal-to-noise ratio on the array beam. Note that many more channels are used when forming the beam than shown in the figure.*

6.8 Joint Verification Experiment US-USSR: NORSAR contributes to resolving a disagreement

In 1974, the U.S. and USSR agreed to the Threshold Test Ban Treaty (TTBT), which restricts underground nuclear weapons testing to yields no greater than 150 kilotons (kt). In 1976, the PNET was signed as a complement to the TTBT, and it restricts individual peaceful nuclear explosions (PNEs) to yields no greater than 150 kt. (The term "peaceful" in this connection means that they would be used for non-military purposes).

For many years, there was an ongoing debate in the United States over whether the Soviet Union was violating this agreement. Part of the problem was the lack of calibration data for the two main test sites (in Nevada, U.S., and in Kazakhstan, USSR). The Nevada test site in the western U.S. is a geologically young and active area that is being deformed by the motion between the North American and Pacific tectonic plates. As a result, when an explosion occurs at the Nevada test site, the rock beneath the test site absorbs a large proportion of the seismic energy. The Soviet test site, on the other hand, is situated in a geologically old and stable area, and the seismic energy from an explosion is transmitted more efficiently. Unless this difference is considered, the size of Soviet explosions will be greatly overestimated.

Even with this general understanding, there was suspicion that some explosions at the Soviet test site near Semipalatinsk were well in excess of 150 kt when the yields were estimated by the seismic P-wave. These explosions were detonated in the southern part of the test site.

In a seminal paper in 1986, the American scientist Otto Nuttli was the first to suggest that the Lg wave could be a candidate for a more reliable magnitude of the large explosions than the traditional P-wave (Nuttli, 1986). Although he worked exclusively from analog seismograms, he was able to calculate reliable Lg magnitudes for the largest Soviet explosions using world-wide seismic data.

NORSAR scientists had the advantage of using digitized data from the NOA array. Even though the distance from NOA to eastern Kazakhstan is as large as 4000 km, they could estimate Lg wave magnitudes accurately (RMS or Root Mean Square Lg) for large explosions. They identified a systematic bias between the northern and southern Semipalatinsk test sites. The southern test area showed significantly larger P-waves compared to the Lg waves. This result was documented in a paper in a NORSAR Semiannual report (Ringdal and Hokland, 1987) and is illustrated in Fig. 6.8.1.

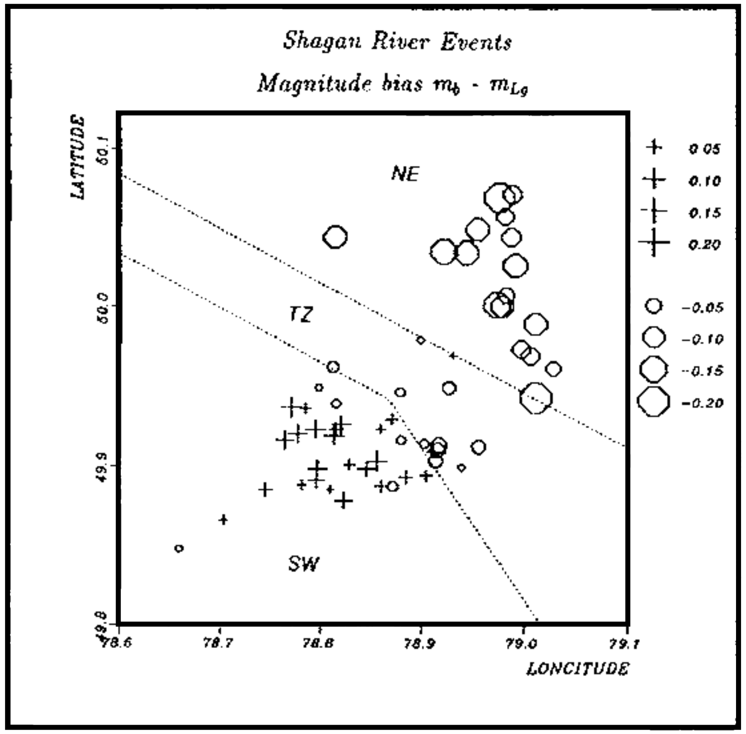


Fig.6.8.1 *Magnitude residuals (NOA P coda magnitude minus NOA RMS Lg magnitude) for large nuclear explosions at Semipalatinsk.*

In the late 1980s, the United States and the Soviet Union agreed to carry out calibration explosions at the other party's test site and compare the results obtained by on-site instrumentation installed temporarily by the counterpart. The United States installed instrumentation named CORRTEX, a direct hydrodynamic yield measurement system.

The Soviet calibration explosion was carried out in 1988 in the southern region of the test site. NORSAR was able to report immediately the estimated yield of the explosion based on the NOA recordings. The yield estimate was based on an RMS Lg magnitude of 5.969, consistent with previous measurements for the southern parts of the Semipalatinsk test site (see Fig. 6.8.2).

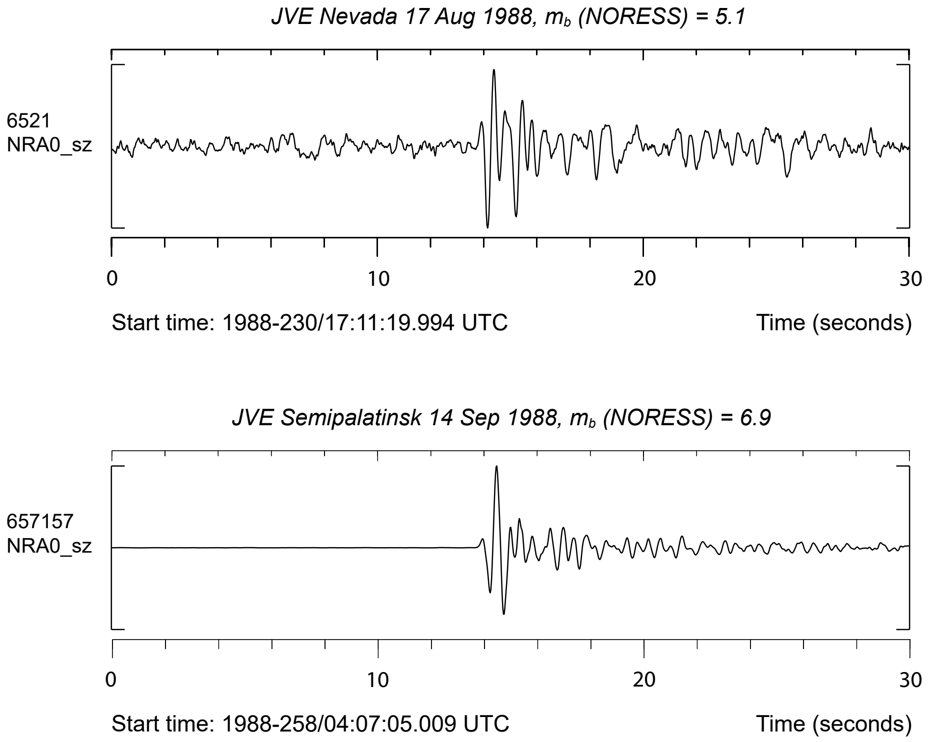


***Figure 6.8.2** This plot illustrates the reasons for concern expressed by the United States regarding the Soviet Union potentially violating the TTBT. In 1988, the two countries carried out a nuclear explosion of similar yields. It turned out that the Soviet explosion with Richter P-wave magnitude 6.9 was almost two orders of Richter magnitude larger than the U.S. explosion. In contrast, the NOA RMS Lg measurement of 5.969 of the Soviet explosion was consistent with the TTBT limit, considering the geological conditions.*

A detailed review of the CORRTEX activities has been published in the paper "Collaborative Verification and the Control of Nuclear Tests" by Nancy W. Gallagher (1995) of the Department of Government Wesleyan University Research. It became well known in the community that the yield result obtained by the NOA RMS Lg method was superior in accuracy compared to the traditional estimates based on P-wave magnitudes.

In any case, there was no longer any sign of controversy between the United States and the USSR about yields. The yield estimates by the RMS Lg method for 100 presumed nuclear tests at the Kazakhstan Test Site were later published in a paper by Ringdal, Marshall, and Alewine (1992).

6.9 Seminar on regional arrays at NORSAR

In 1990, NORSAR organized an international workshop on seismic arrays and the nuclear test ban. The Norwegian Ministry of Foreign Affairs hosted the workshop, which NORSAR organized in cooperation with the Norwegian Advisory Council for Arms Control and Disarmament (Nedrustningsutvalget).

The workshop intended to shed further light on seismological verification aspects of a comprehensive nuclear test ban through briefings and demonstrations on seismological facilities in Norway and through presentations of recent research achievements.

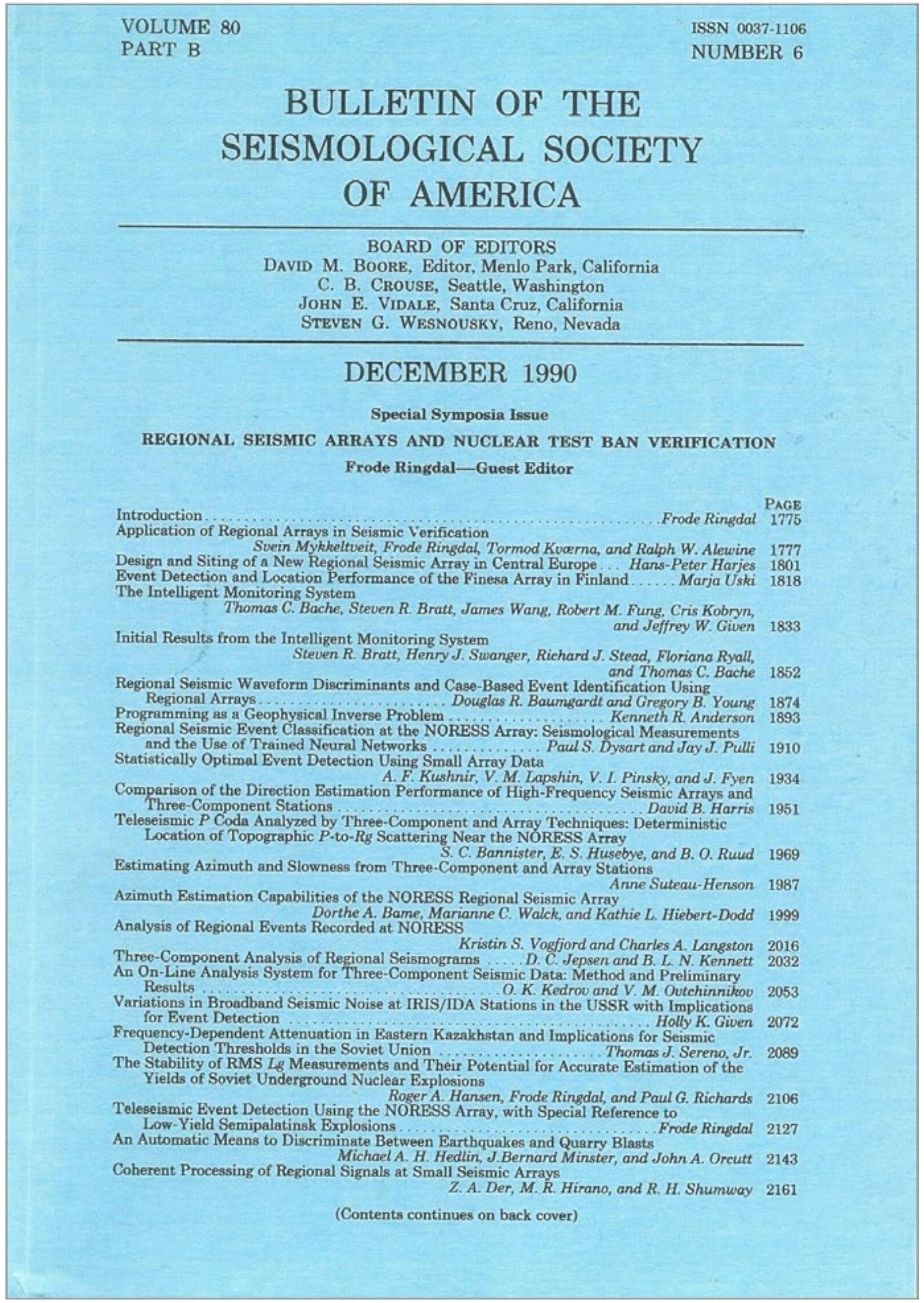
The workshop was attended by 76 representatives from 21 countries, including a number of seismologists participating in the work of the CD's GSE in Geneva. Ambassador Miljan Komatina, Secretary General of the Conference on Disarmament, participated as a special guest by invitation from the Norwegian Government.

In his welcoming address, the Norwegian State Secretary of Foreign Affairs, Mr. Knut Vollebæk, stated that holding this workshop in Oslo demonstrated the great importance the Norwegian Government attached to the Conference on Disarmament and Norway's participation in the Conference.

With reference to the work of the GSE, Mr. Vollebæk said that a global seismological network would constitute an essential element of a verification system for a nuclear test ban. In the opinion of the Norwegian Government, such a network should be equipped with instrumentation of high standards. It should incorporate recent technological advances with respect to computer and data communication technology. Mr. Vollebæk made special reference to the advanced small-aperture arrays NORESS and ARCESS installed in Norway in recent years and said that arrays of this type could form important contributions to a global network as proposed by the GSE. He also stressed that Norway's research at NORSAR aimed to find solutions to outstanding issues relevant to a nuclear test ban.

The NORSAR director, Frode Ringdal, gave an introductory presentation on the Norwegian seismological verification program, including:

- Presentation of the Norwegian arrays
- Detection of earthquakes and underground nuclear explosions



VOLUME 80
PART B

ISSN 0037-1106
NUMBER 6

BULLETIN OF THE
SEISMOLOGICAL SOCIETY
OF AMERICA

DECEMBER 1990

Special Symposia Issue

REGIONAL SEISMIC ARRAYS AND NUCLEAR TEST BAN VERIFICATION

Frode Ringdal—Guest Editor

(Contents continues on back cover)

Fig. 6.9.1 *Cover page of the BSSA December 1990 special issue.*

- Seismic signal analysis using regional array data
- International exchange of seismic data, with emphasis on the GSETT-2 experiment.

The participants also surveyed the field installations of the NORESS array. Norway had proposed to the CD that the NORESS/ARCESS concept should form the basis for seismic stations within the global network envisaged by the GSE.

A three-day scientific symposium followed the briefings and demonstrations to assess the state of the art of regional seismic arrays and associated topics. In particular, the development and application of seismic verification research of the regional arrays in Europe (NORESS, ARCESS, FINESA, GERESS) were presented (Mykkeltveit et al., 1990). The symposium also focused on developing expert systems for processing data from such arrays. Also, the initial results from the emerging prototype International Data Center in Arlington, Virginia, were discussed. A total of 30 scientific papers were presented, and the proceedings were published in a special issue of the Bulletin of the Seismological Society of America (Fig. 6.9.1).

Chapter 7

1991 - 1996
Times of change and CTBT negotiations

7.1 Generalized Beamforming: A game changer in global seismic monitoring

In this section, we will describe the development by NORSAR of Generalized Beamforming for processing seismic network data. To provide context, we describe the three global experiments performed by the Group of Scientific Experts (GSE) as part of this group's effort to develop and test the seismological component of a monitoring system for a future CTBT.

In 1984, GSE had already carried out a global test named GSETT-1 (see Box 7.1.1) of the exchange and analysis of parameter (Level 1) data using the Global Telecommunication System of the World Meteorological Organization (WMO/GTS).

The three data centers were established in countries with the necessary interest, resources, and staff available at the time. NORSAR's national funding was too limited to offer a data center on its premises. Moreover, NORSAR concentrated its research efforts on methods for optimizing the performance of individual seismic arrays and not on processing data from a global network of stations.

The NORSAR staff participated in this test with data contributed from the NOA array but had a limited role in the processing at the data centers. This role changed significantly during the second and third GSE technical tests: GSETT-2 and GSETT-3.

During GSETT-2 (see Box 7.1.2) in 1991, four experimental International Data Centers (IDCs), connected by high-speed computer links, operated in Moscow, Stockholm, Canberra, and Arlington, Virginia. These centers not only used the

Level I data to calculate the location and characteristics of the recorded events but also provided analysis of the seismic waveform (Level II) data to refine and supplement the solutions. Each experimental IDC also assumed, on a cyclical basis, responsibility for issuing an event list merged from all four centers.

BOX 7.1.1

GSETT-1: The GSE First Technical Test

The GSE carried out its first global test of seismic data exchange (GSETT-1) from 15 October through 14 December 1984. It featured:

- *Use of the Global Telecommunication System of the World Meteorological Organization for data transmission*
- *Exchange of only basic seismic readings*
- *Participation of 75 seismic stations in 37 countries*
- *Data analysis at three centers: Moscow, Stockholm, and Arlington*

The test was coordinated by Dr. Peter McGregor (Australia). It provided valuable experience but revealed that further work would be needed, especially on equipment and standardization.

NORSAR staff participated in the daily data analysis at the centers in Arlington, Virginia, and Stockholm, which included processing and analysis of waveform data in addition to the phase detection data that the participating stations generated.

The countries hosting the data centers spent considerable resources on developing and operating their centers, which by then included the handling of waveform data. Again, it was out of reach to offer a data center at NORSAR.

While GSETT-1 and GSETT-2 were carried out to test and evaluate specific components of the envisaged seismic monitoring system, the GSETT-3 (see Box 7.1.3) exercise aimed at testing the overall functioning of such a system.

BOX 7.1.2

GSETT-2: The GSE Second Technical Test

The GSE carried out its second global test of seismic data exchange (GSETT-2) from 22 April through 9 June 1991. It featured:

- *Use of the WMO/GTS and other available links for the exchange of basic seismic readings*
- *Exchange of waveform segments through high-speed transmission channels*
- *Participation of 60 seismic stations in 34 countries*
- *Data analysis at four centers: Moscow, Stockholm, Canberra, and Arlington*

The test was coordinated by Dr. Peter Basham (Canada). It provided experience using waveform data to refine and supplement the solutions and confirmed that the eventual monitoring system should have only one data center.

GSETT-3 was planned and designed while the negotiations in the CD on a CTBT were underway. The objectives for GSETT-3 (see Box 7.1.3) were formulated in anticipation of a positive outcome of these negotiations. The concepts tested during GSETT-3 included:

- A single centralized IDC
- A specifically designed, high-quality seismic network consisting of primary stations (originally called alpha stations), with data transmitted continuously to the IDC
- A network of auxiliary stations (originally called beta stations), which would provide, on request from the IDC, supplementary data so that seismic events could be located with improved accuracy
- National data centers (NDCs) in participating countries and a modern communications system to support data exchange among these elements.

BOX 7.1.3

GSETT-3: The GSE Third Technical Test

The GSE began its third global test of seismic data exchange (GSETT-3) in 1995 and continued the test through 2000. The test was more ambitious than the previous tests and aimed:

- *To develop and test new concepts for an experimental International Seismic Monitoring System, building on previous experience*
- *To provide a practical basis upon which to furnish the Conference on Disarmament with timely technical information*
- *To develop a system that could evolve and adapt to support future requirements that might be specified for an International Seismic Monitoring System*

The test included a single International Data Center (IDC) in Arlington, Virginia. After the GSETT-3 IDC had been in operation for five years, the software and documentation were transferred to Vienna to become the initial seismic data processing system for the CTBT.

It became obvious that the software for network processing applied during GSETT-2 was insufficient for the GSETT-3 experiment. Fortunately, the solution, Generalized Beamforming (GBF), was available. NORSAR developed this method in 1989, see Ringdal and Kværna (1989). We take the liberty of quoting two excerpts from an anonymous reviewer of the draft publication submitted to the Bulletin of the Seismological Society of America (see Box 7.1.4).

In order to briefly describe the GBF methodology, we will contrast it with a description of the traditional method as follows:

In the processing of seismic network data, individual phase detections at different stations corresponding to the same seismic event must be properly associated and grouped together. Traditionally, this has been done by starting with an initial trial epicenter and then applying various search strategies supplemented by combinatorial techniques.

BOX 7.1.4

Reviewer's comments (excerpts)

"A Multichannel Processing Approach to Real Time Network Detection, Phase Association and Threshold Monitoring.

by Frode Ringdal and Tormod Kværna

1. *Overall, this is one of the best papers I have read concerning useful analysis of regional travel-time data and detection threshold monitoring. The concept of the "generalized beamforming" for automatic phase association for location and the continuous monitoring of detection threshold are both very simple concepts, but both offer effective solutions to important problems.*

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4. *The continuous monitoring of detection thresholds is fascinating. The authors suggest the study was done to determine whether interfering events were effecting the monitoring of events within a target region."*

In contrast, generalized beamforming (GBF) starts with a grid covering the area of interest, and assigns a value to each point in the grid by adding together the value of a specified function, for example, a boxcar, and applying this process continuously along the time axis. An event is declared when a threshold of detections is reached at an event source position. The function can be arbitrarily selected. In the seismic case, it could be a simple conventional delay-and-sum beamforming or a more complex capability estimate of a network detection threshold.

The method had been in continuous operation at the NORSAR data center since 1989. In this local NORSAR processing, the GBF method is applied only to regional data from the network of arrays in Norway and neighboring countries (see Fig. 7.1.1) and is published automatically. The method is equally effective for the global processing of teleseismic, local, and regional monitoring, which is required for a global monitoring system (see Fig. 7.1.2).

Another approach to GBF is to obtain an estimate of the network detection capability by combining the amplitude values at each grid point, also called Threshold Monitoring (TM). We can compare this approach with the standard estimation of the detection threshold as follows:

1. The conventional *detection threshold* is an estimate of the *smallest* hypothetical seismic event at a given site or in a given region that could possibly be *detected and located* (e.g., by three stations)
2. *Threshold monitoring* provides an estimate of the *largest* hypothetical seismic event at a given site or in a given region that could possibly have *occurred.*

The two approaches are, therefore, complementary, and each provides useful information in the context of seismic monitoring. The threshold monitoring approach could be especially useful to identify time intervals when the possibility of significant “hidden” seismic events is particularly high, thus enabling the analyst to concentrate on such time intervals for extensive analysis. Furthermore, the method provides an upper limit of the magnitude of non-detected events, which could be useful, e.g., to assess the maximum MS value for events for which no surface waves are detected.

We will revert to the method of threshold monitoring (TM) in Section 8.5, where we discuss the Indian and Pakistani nuclear tests in May 1998, and in Sections 7.2 and 8.6, where we will show that site-specific TM has the potential to improve the monitoring of the Novaya Zemlya nuclear test site by about one whole order of magnitude compared to standard processing.

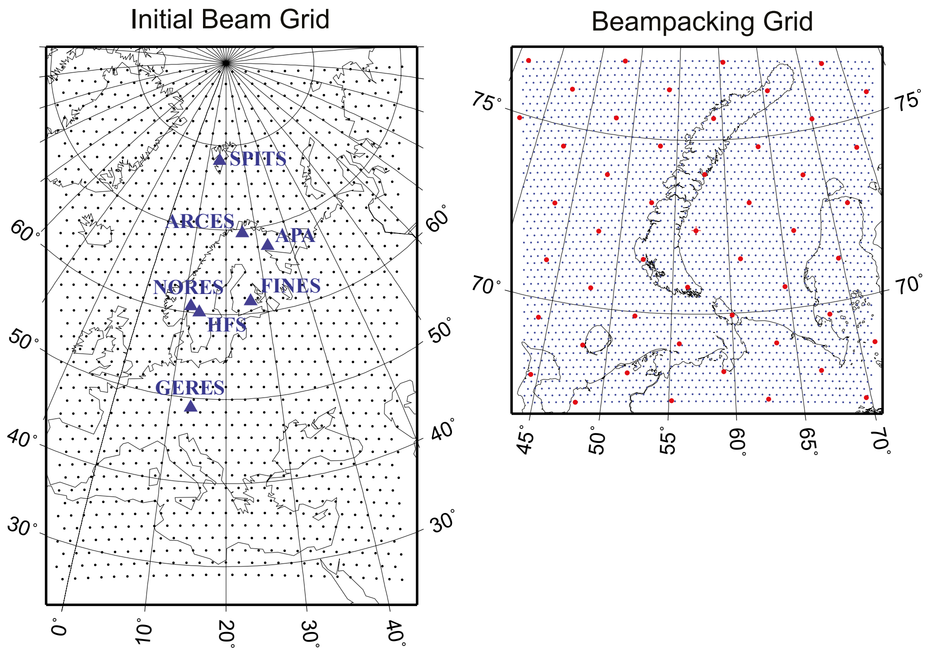


Fig. 7.1.1 *Grid used in Generalized Beamforming – regional case. The figure illustrates the station network and the initial grid system (left) and a denser system for detailed search (right).*

When the development of the GSETT-3 IDC started, the automatic processing used the GBF method on a global scale rather than traditional techniques. The processing method was named Global Association (GA) and was simply an extended version of GBF to cover the entire globe. The United States, through ARPA, funded a contractor (SAIC) to develop the GSETT-3 IDC processing, which was also used by the United States National Data Center at AFTAC for CTBT monitoring.

The GSE accepted with appreciation the offer by the United States to host the experimental international data center in Arlington, Virginia, during GSETT-3. This center would be developed to become a “Prototype International Data Center” (PIDC) if or when a treaty was negotiated. During GSETT-3, the staff at the PIDC included about 50 full-time employees, and the annual cost was estimated at USD 30 million. In particular, the software development was an extremely complex undertaking since no similar processing system was available at the time. During the GSETT-3 experiment, about ten people from different countries worked for periods at the PIDC along with the American staff. Among these were NORSAR's chief seismic analyst Bernt Hokland, who spent eight months at the PIDC in 1995. Bernt Hokland later took up a position as a lead analyst at the IDC in Vienna and served there for seven years. Tormod Kværna also worked at the PIDC, assisting in installing an experimental version of the Threshold Monitoring system and demonstrating its use in seismic monitoring.

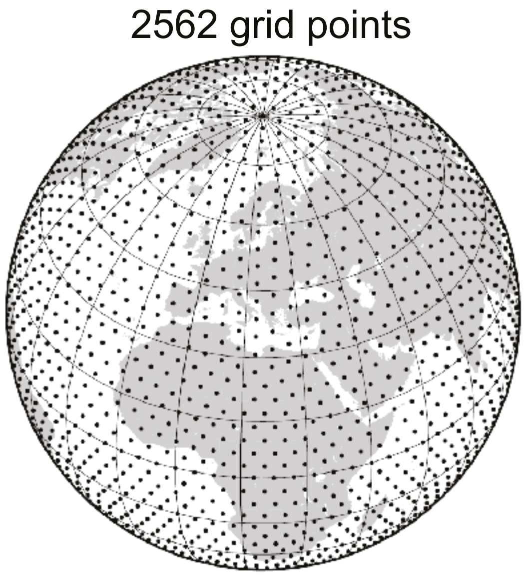


Fig. 7.1.2 The grid used in Generalized Beamforming – global coverage.

The GSE organized its activities during GSETT-3, as shown in Fig. 7.1.3, with the GSE Chairman and the GSE Scientific Secretary as Coordinators and three Working Groups on Planning, Operations, and Evaluation. Each of these fulfilled an important and distinct responsibility for overseeing the work on GSETT-3. Fig. 7.1.4 shows a photo of the Group of Scientific Experts (GSE) in Geneva at its last session in August 1996.

GSETT-3 began regular operation in January 1995 with daily event bulletins and continued beyond the test-ban negotiations and the adoption in 1996 of the CTBT. GSETT-3 even continued during the initial build-up of the actual monitoring system, which commenced in the spring of 1997 at the Provisional Technical Secretariat (PTS) of the CTBTO PrepCom in Vienna. The Prototype IDC in Arlington, Virginia, was not closed until March 2000. After that, the United States donated the software and the associated documentation to the PTS. At that time, 60 countries participated in GSETT-3, contributing data from 43 primary and 90 auxiliary seismological stations. Thus, the GSE succeeded in enabling a smooth and orderly transition from GSETT-3 to the eventual monitoring system for the CTBT.

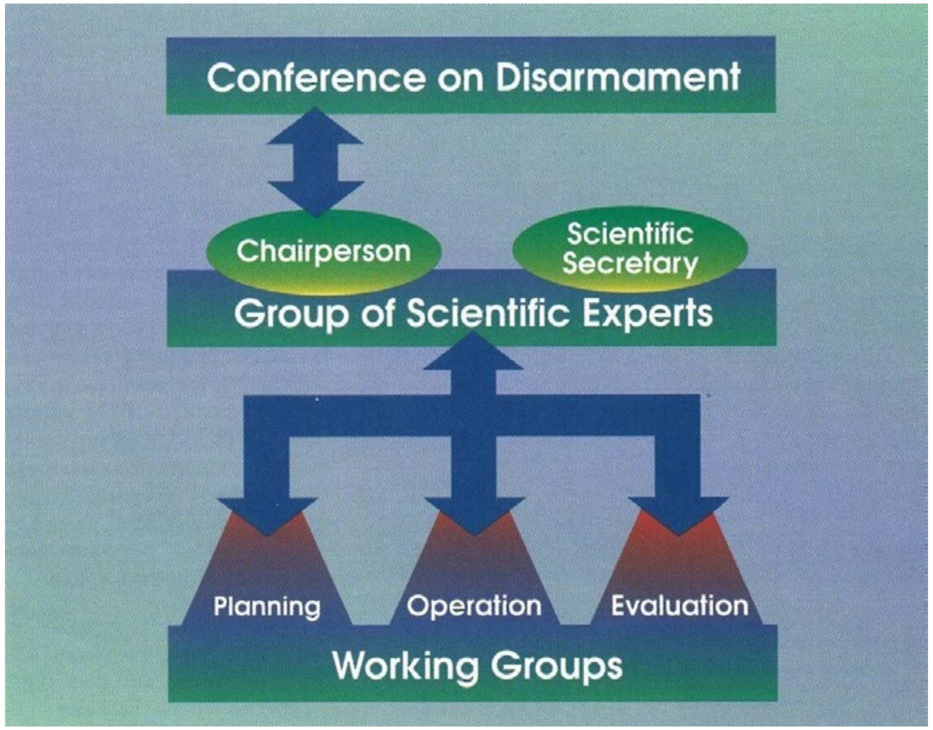


Figure 7.1.3 *Structure of the Group of Scientific Experts (GSE) for GSETT-3*

Participation in GSETT-3 was based solely on voluntary, national funding. The largest amounts were contributed by the United States by footing the bill for the IDC operations, as we have seen, and for many communication links from stations around the world to the IDC. Some countries assisted other countries technically and financially to build competence and expand participation in the test. The political climate of the time enhanced the success of the GSETT-3, with a strong will on the part of many countries around the world to achieve a CTBT with an effective verification regime. The high degree of trust that had developed within the GSE over the years also contributed to this success. Issues related to GSETT-3 were generally uncontroversial and settled easily in discussions in the GSE.

Figure 7.1.4 *The Group of Scientific Experts (GSE) in Geneva; the photo was taken at its last session in August 1996.*

Together with national contributions by other countries, the more than 100 Norwegian working papers were thoroughly discussed in GSE and influenced GSE's design of the seismic component of a future monitoring system. NORSAR's main contributions during the later phases of GSE focused on designing small aperture seismic arrays, Generalized Beamforming, and Threshold Monitoring.

7.2 Towards a comprehensive test ban treaty

On 24 October 1990, the Soviet Union carried out a large nuclear explosion at its Novaya Zemlya test site. This was to be their final nuclear test, and it happened to occur less than a month after the Soviet Premier, Mikhail Gorbachev, had been awarded the Nobel Peace Prize.

Norway has taken a particular interest in monitoring the Novaya Zemlya nuclear test site because of its proximity to the country. As shown in Fig. 7.2.1, the seismic arrays in the Nordic countries cover this site quite well.

We illustrate in Fig. 7.2.2 the seismic monitoring threshold technique by applying it for the day 24 October 1990, see Ringdal and Kværna (1992). For this purpose, we use the three arrays ARCES, NORES, and FINES (until the 1990s, referred to as ARCESS, NORESS, and FINESS). The SPITS array was not yet constructed at the time. The figure displays, for each array, the thresholds of a beam steered toward the test site. Each array has several peaks outside the main peak (1) corresponding to the explosion.

On the network trace, which is a combination of the three individual array traces and is also steered toward the explosion site, the number and the sizes of the peaks are greatly reduced. This reduction occurs because an interfering seismic event, such as a local chemical explosion, will not generally provide matching signals at all three arrays. The two peaks just before midnight, marked (2) in the figure, originate from two earthquakes at teleseismic distances in the northern part of Xinjiang, China, and can easily be identified by the IDC using traditional detection techniques.

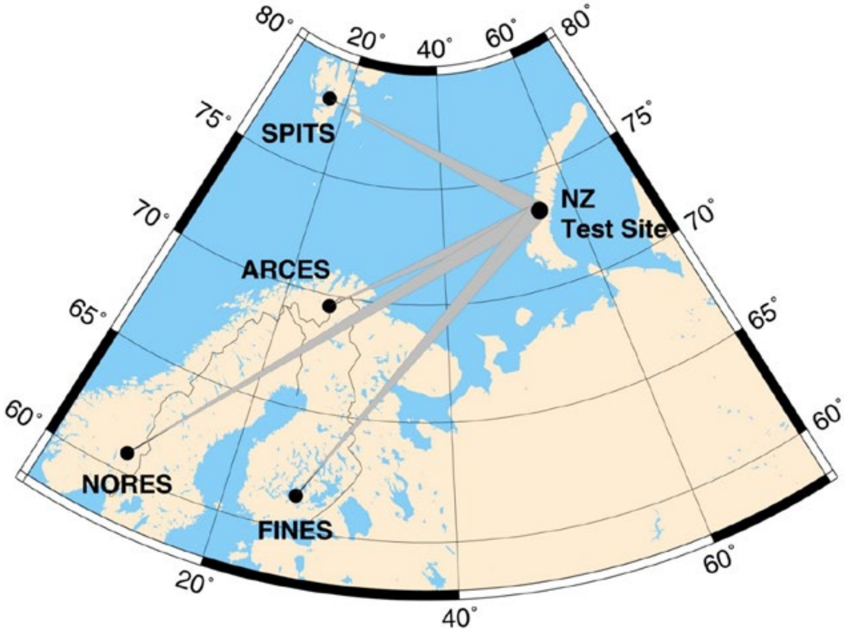


Fig. 7.2.1. *The Novaya Zemlya nuclear test site is well covered by the Nordic seismic arrays.*

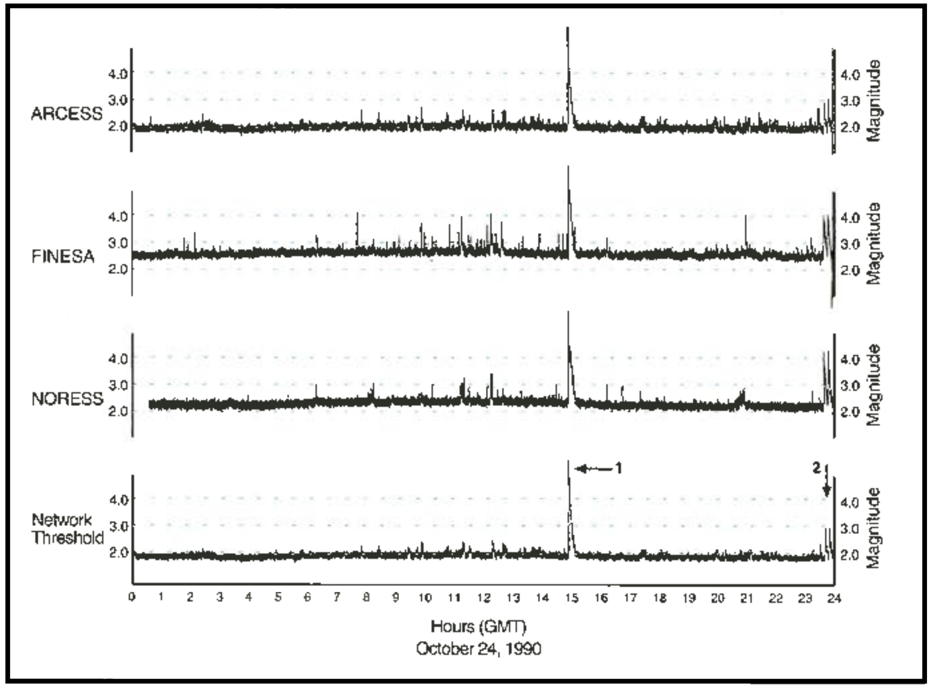
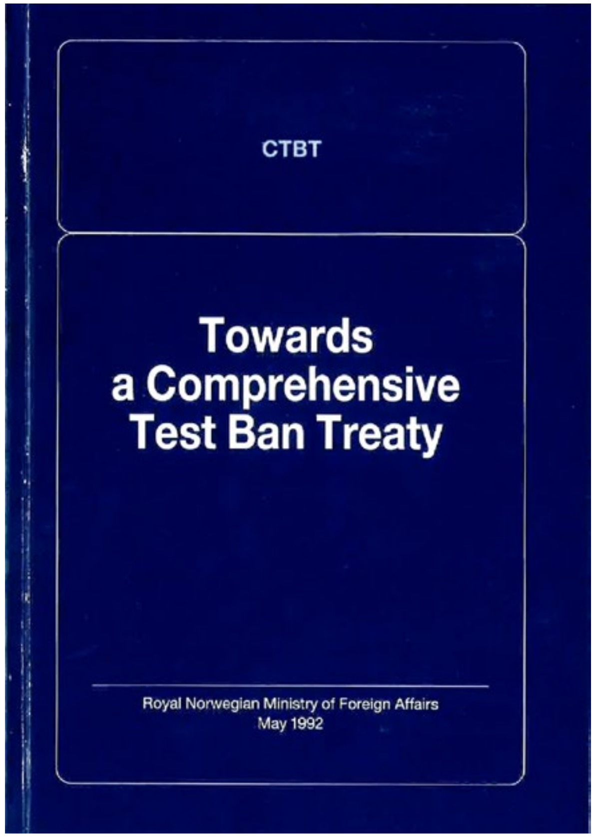


Fig. 7.2.2 Site-specific threshold monitoring of Novaya Zemlya for one day, October 24, 1990, covers the last Soviet nuclear explosion (1). An earthquake occurred later in Xinjiang, China (2).

Needless to say, the nuclear explosion on Novaya Zemlya was uniformly condemned by the world and by the Scandinavian countries in particular. In reaction to a question in the Norwegian Parliament, Norwegian Foreign Minister Thorvald Stoltenberg announced the initiative to carry out an expert study on technical questions related to a comprehensive test ban treaty.

The ministry contacted two institutions in Norway with experience in the subject of nuclear test ban, through Director Sverre Lodgaard of the Peace Research Institute Oslo (PRIO) and Director Frode Ringdal of NORSAR. Acknowledged experts from abroad were also invited to contribute to a report finalized at a workshop in Oslo on 30-31 March 1992. Among the authors was the future Nobel Peace Prize laureate, Dr. Joseph Rotblat. NORSAR's participants included Frode Ringdal and Svein Mykkeltveit. Sverre Lodgaard chaired the workshop.


CTBT

Towards
a Comprehensive
Test Ban Treaty

Royal Norwegian Ministry of Foreign Affairs
May 1992

Fig. 7.2.3 Expert study initiated by the Norwegian Ministry of Foreign Affairs.

A final summary chapter: "Perspectives for a future CTBT," based on the contributions from the experts, was edited by Frode Ringdal. The summary addressed:

I. Purpose and Objectives of a CTBT
  - Environmental Aspects
  - Non-Proliferation Aspects
  - Military and Political Implications

II. Arguments for Further Testing – an Assessment
  - Safety considerations
  - Development of New Warheads
  - Stockpile Confidence
  - Maintaining Expertise

III. Verification of Compliance with a CTBT
IV. Possible Approaches to a CTBT

The report concluded with a recommendation for the early signing and ratification by the nuclear weapon states of a CTBT estimated to take effect in 1995.

The Norwegian Ministry of Foreign Affairs issued the report containing the workshop proceedings in May 1992, see Fig. 7.2.3 (Towards a Comprehensive Test Ban Treaty, ISBN 82-7177-329-1).

This workshop and its comprehensive report demonstrated that Norway was at the forefront of the processes leading to a CTBT. As we shall see in Section 7.10, the CTBT was finally negotiated from 1994 to 1996, when it opened for signature.

7.3 Refurbishment of the NOA array

On 3 January 1991, a letter arrived from Dr. Ralph Alewine, ARPA, to NTNF Director Rolf Skår, proposing a joint modernization of the NOA array.

Dr. Alewine expressed in the letter "the appreciation from the United States to NTNF for over twenty years of cooperation, beginning with the NORSAR array in the late 1960s and early 1970s and continuing with the development of smaller high-frequency arrays – NORESS and ARCESS - in the 1980s which has resulted in developing the most advanced seismic technology in the world."

He continued: "As a measure of the immense success of this program, new seismic surveillance capabilities have been incorporated into upgraded seismic operational systems around the world and have helped form the technical basis which both the U.S. and Norway use for discussions related to nuclear testing verification within the United Nations Conference on Disarmament in Geneva. The research by Project NORSAR has been highlighted in a number of high-level international conferences organized and held in Norway, notably a NATO Advanced Study Institute in 1980, a special symposium and demonstration for the Conference on Disarmament in 1985, and a Symposium on Regional Seismic Arrays and Nuclear Test Ban Verification in 1990."

Dr. Alewine further stated that "a major contribution to this program has been the commitment of the Government of Norway. Recruitment and retention of a highly competent and internationally respected research group of physical and computer scientists by NTNF for Project NORSAR has been a key factor to the success of the program. Additionally, the acquisition by NTNF and a modern work facility at Kjeller have been important to the infrastructure of the program."

Dr. Alewine suggested in the letter to Director Rolf Skår to modernize the NOA equipment and establish a new data acquisition system at the NORSAR data center at Kjeller. The overall cost was estimated at USD 1,800,000, and the upgrade would be carried out in 1992-1993. The suggested joint funding was USD 600,000 from each of the three organizations: ARPA, AFTAC, and NTNF.

More detailed plans were discussed at the NTNF office on 15 January 1991 with the participation of Alewine, Ringdal, and Skår. On 23 January 1991, Director Skår confirmed the commitment by NTNF of USD 200,000 in 1992 and USD 400,000 in 1993 for contributing to the modernization of the NOA array, which was completed successfully in the following years.

7.4 Collapse of the Soviet Union
– A previously unknown nuclear explosion

In December 1991, the Soviet Union disintegrated into fifteen separate countries. This change was accompanied by a new openness ("Glasnost") in many areas, particularly regarding the nuclear testing history. In NORSAR's case this led to the examination of many years of NOA recordings.

The information about the activity at the main Soviet nuclear test area in Kazakhstan attracted attention. The handling of this nuclear heritage by Kazakhstan is admirable. Ever since the CTBT was signed, the Kazakhstan Government has arranged biannual seminars on "Monitoring of Nuclear Tests and Their Consequences." NORSAR seismologists have regularly attended these seminars and given technical presentations. The information on nuclear tests that has been provided has served to confirm the monitoring results by NOA and NORES.

In addition to the nuclear weapon tests, it is common knowledge that the USSR had a history of nuclear explosions for civilian purposes, usually referred to as Peaceful Nuclear Explosions (PNEs). Details about the 124 PNEs carried out during 1965-1988 became known and assisted in the location calibration of seismic stations as well as verification of the detection capability of the existing seismic network. Eventually, Sultanov et al. (1999) provided a detailed summary of these explosions. Only one of these PNEs was apparently not detected by the outside world (see Box 7.4.1).

According to Izvestiya (26 June 1992), the detonation occurred at noon Moscow time on 16 September 1979, and the yield was 1/3 kt. The location of the town, Yunokommunarsk, is approximately 48.22N, 38.30 E. It was reported that the explosion knocked a portrait of V.I. Lenin off the wall at the mine's party headquarters, suggesting that explosions of this size were not commonplace at the site. NORSAR scientists examined available seismic event lists in detail to see if this event could be confirmed. They searched for an event with an origin time close to 09.00 UTC, which corresponds to noon Moscow time. However, the event was not reported, either by agencies using global network data (ISC, NEIC) or by other available sources, including the NORSAR monthly bulletin.

However, the NOA array automatic detector operates at a very low threshold, and many small seismic events, especially at regional distances, are detected but not included in the monthly bulletins.

For this reason, NORSAR scientists decided to check the original automatic detection lists in the NORSAR archive. It turned out that the automatic (unedited) NOA bulletin for 16 September 1979 had automatically detected the explosion, which was located 2200 km from the array with the following parameters:

Origin time (UTC) 08.59.53
Location 45N, 34E, Crimea region
Magnitude (mb): 3.3

The automatic plot for this event has been saved (see Fig. 7.4.1) and shows a high-frequency signal, visible on at least four subarrays but with poor signal coherency across the full NOA array. The analyst did not consider the event to be of high enough quality to include it in the final NOA bulletin, although there is no question that the event was real (and not a noise detection).

Unfortunately, when this event occurred, NORSAR had the capacity to retain only selected raw data intervals on magnetic tape. At the time, there seemed to be no reason to save this event beyond the standard data retention interval of one year, so the digital raw data is no longer available. Only the plot and the detector listings have been retained.

BOX 7.4.1

A previously unknown nuclear explosion

On 28 June 1992, the following article appeared in the New York Times:

Excerpt from the New York Times, 28 June 1992
"(headline) Izvestiya Reports '79 A-Test in Ukraine Mine
MOSCOW, June 27 (AP) – Soviet scientists set off a nuclear blast in 1979 next to a Ukrainian coal mine, then sent thousands of miners back to the shaft a day later without telling them, the newspaper Izvestiya reported.

The article, published on Friday, may shed some light on long-standing assertions by miners that a nuclear blast caused unusually high levels of radiation around a town it identified as Yunokommunarsk.

Izvestiya said officials have previously attributed the level of radiation in the area, which has registered three or four times normal, to industrial waste and to the 1986 event in Chernobyl, 625 miles to the north-west.

Izvestiya did not report higher incidents of death, cancer or other diseases in the area near the mine, and officials could not be reached for comments today.

The report said the bomb had been detonated to see if the explosion would clear the mine of dangerous methane gas. It added that officials had disguised the incident by staging a civil defence drill and evacuating the town's 8,000 residents, most of whom were miners."

The automatic location estimate (45N, 34E) is somewhat different from the location at Yunokommunarsk but well within the uncertainty for an event with such low coherency. The estimated origin time is only seven seconds before the hour. As is well known, the traditional Soviet PNE practice has been to detonate such explosions exactly on the hour.

It is important to note that at the time this event occurred, there was no advanced regional array network in northern Europe. If such an event were to occur today, the current network would have detected, accurately located, and flagged it as a suspicious seismic event that would need further investigation.

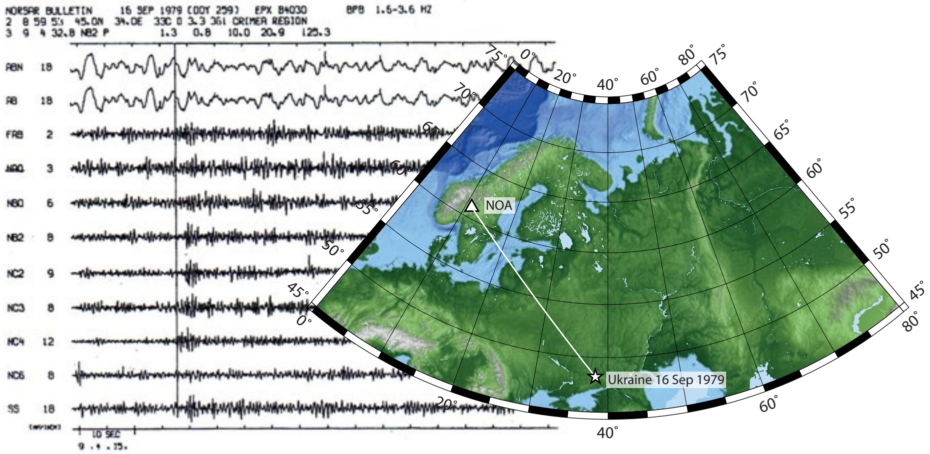


Fig. 7.4.1 NORSAR automatic bulletin plot of the Yunokommunarsk event together with a map showing the event location in relation to the NOA array.

7.5 Co-operative agreement NORSAR – Kola Regional Seismological Centre

In the post-cold-war climate, and especially following the Reagan-Gorbachev meeting in Iceland in 1987, there were many initiatives to establish cooperation between the United States and the Soviet Union. In the nuclear monitoring field, initiatives focused on establishing seismic monitoring stations in the Soviet Union and exchanging data to improve the monitoring possibilities. ARPA had an interest in establishing stations in the north (near Novaya Zemlya) and in eastern Siberia.

Dr. Alewine was especially interested in expanding the small-array network in Fennoscandia to include Spitsbergen and the Kola Peninsula. Swedish colleagues informed NORSAR scientists that Dr. Elena Kremenetskaya from the Kola Regional Seismological Centre (KRSC) in Apatity was in the fall of 1990 staying at Uppsala as a visiting scientist. Ringdal and Mykkeltveit went to Uppsala on 24 October 1990 (which happens to be the date of the last nuclear test conducted by the Soviet Union/Russia). They discussed the possibilities for establishing a small NORESS-type seismic array in Apatity. Such an array would have the additional benefit of contributing to monitoring the extensive mining activity in the nearby Khibiny Mountains. It would enable NORSAR to establish a much improved "ground truth" database for locating the numerous mining explosions carried out daily in these mountains.

These explosions were too small to be recorded at teleseismic distances but were regularly detected at regional distances by NORESS, ARCESS, and FINESA. Dr. Kremenetskaya agreed to discuss the plans with her superior, Dr. Igor Kuzmin, and he forwarded the plans to the Director of the Kola Science Center, Dr. Vladimar Kalinninkov, who was very receptive to such a project. An agreement was signed between NORSAR and KRSC. Accordingly, in 1992 a small nine-element seismic array with an aperture of about one km was established in Apatity, with satellite communication to NORSAR (see Fig. 7.5.1). Paul W. Larsen and Rune Paulsen were key participants in developing the hardware and software for the Apatity seismic array. NORSAR received three million NOK of financial support from ARPA for this project for the initial year, with investments in the seismic array and satellite communications, followed by modest annual amounts for operations, data exchange, and a scientist exchange program.

This project came about at a most favorable time, with a positive attitude towards cooperation between institutions in the two countries. The project demonstrated that a regular exchange of seismic data, previously considered a potentially sensitive activity, was indeed possible and feasible. NORSAR and KRSC kept their authorities informed about the activities, which were met with approval on both sides. The respective telecommunication authorities granted the necessary licenses for satellite communications.

Fig. 7.5.1 *A scene from Apatity in 1992 with the building housing the KRSC in the background. Note the satellite dish on the roof; it was used to exchange seismic data between the KRSC and NORSAR.*

The cooperation between NORSAR and KRSC has continued to the present, although to a more limited extent than initially. The cooperation has concentrated on the analysis of seismic data from the Arctic region (see Section 10.2), an activity that has benefited both parties: seismic bulletins of the two institutions have been combined to obtain a more precise picture of the seismicity of the Arctic than was previously possible with observations from one side only.

In 2020, regulations imposed by Russian authorities prohibited the transmission of waveform data from Russia to foreign organizations. Consequently, the data transmission from Apatity to NORSAR ceased in September 2020.

7.6 Construction of the SPITS array at Spitsbergen

The establishment of the SPITS seismic array in 1992 in Adventdalen, about 15 km east of Longyearbyen, was planned as a cooperative project between NORSAR and the oil industry and was intended to monitor earthquake activity in the Barents Sea. However, ARPA was interested in the array for nuclear monitoring purposes and agreed to fund online data transmission to NORSAR via a dedicated satellite link to integrate SPITS data processing with the other regional arrays. U.S. sources largely funded subsequent technical upgrades of SPITS. The design of SPITS was similar to that of the Apatity array, but the seismometers were placed in six-meter-deep boreholes in stable permafrost conditions.

The value of a seismic array at Spitsbergen in a future global network for test ban verification was obvious to ARPA and NORSAR. The co-funding by ARPA of online data transmission made it possible to evaluate the capabilities of SPITS fully and to demonstrate during the CTBT negotiations that this station should be included in the CTBT global seismic monitoring network, which also was achieved, as we shall see.

A further description of the SPITS array and its current status is presented in Section 10.2.

7.7 NORSAR marks its 25th anniversary

On 15 June 1993, NORSAR celebrated its 25th anniversary with an "open day" event at Kjeller, attended by NORSAR's employees, the Research Council of Norway (Norges forskningsråd - NFR), and special guests. Technical demonstrations were provided in all of NORSAR's fields of activities.

NFR was created in 1992 as a merger of NTNF and four other research councils. NFR took over the role of NTNF as the Norwegian partner in the government-to-government agreement with the United States. This seamless transition involved no changes for NORSAR.

The anniversary ceremony started with a statement by NORSAR's director Frode Ringdal. The Deputy Director of the Research Council of Norway, Kari Kveseth, also made a statement, and in particular, mentioned the presence on this occasion of the leaders of the two Norwegian technical institutions which were central in establishing the agreement 25 years ago, Mr. Finn Lied (FFI) and Mr. Robert Major (NTNF). She also noted the important contributions to the development of NORSAR by ARPA and the U.S. Air Force Technical Applications Center (AFTAC), which were also present at this anniversary. She stated that her organization had had the pleasure of following NORSAR from its initial successful establishment to a status where NORSAR was known and respected both nationally and internationally.

On the following day, NORSAR and the Ministry of Foreign Affairs hosted a continued celebration of the anniversary. The ministry wanted to demonstrate NORSAR's contributions to a future test ban. The timing of the event was optimal, as the immediate prospects for negotiating a CTBT in the CD in Geneva were very bright. Ten influential CD ambassadors, including those of all the "recognized" nuclear weapon states, attended the events that day, which started with statements delivered at NORSAR's premises at Kjeller. After a welcome address by Frode Ringdal, Ambassador and Special Advisor on Disarmament, Mr. Finn K. Fostervoll delivered the opening statement on behalf of the Norwegian Ministry of Foreign Affairs and the Advisory Council for Arms Control and Disarmament.

Recalling that NORSAR was established based on a government-to-government agreement signed between Norway and the United States of America 25 years ago, he stated that the agreement laid the foundation for establishing the original NOA array and later the sensitive high-frequency arrays NORESS and ARCESS. He recalled that one of the purposes of NORSAR was research and development concerning the survey of earthquakes and nuclear explosions. The research at NORSAR over the years, primarily financed by the United States, had focused on the development and techniques to locate and identify small seismic events and, consequently, small nuclear explosions. Mr. Fostervoll further stated that NORSAR had been a highly valuable contributor to the work of the Conference on Disarmament in Geneva through the years.

Ralph Alewine, ARPA, and Ola Dahlman, chairman of the Group of Scientific Experts, also delivered statements, followed by technical briefings and demonstrations at NORSAR's data center. State Secretary Jan Egeland hosted a luncheon following the event.

In the afternoon, the Ministry of Foreign Affairs hosted a seminar in Oslo on CTBT and NPT-related issues chaired by Norway's ambassador to the CD, Oscar Værnø. The CD ambassadors present all delivered statements. This provided a very useful stock-taking for the participants in view of the events about to unfold in Geneva.

7.8 Changes in the United States funding of NORSAR

As we foreshadowed in the section above, the 25th anniversary of NORSAR in 1993 happened to coincide with significant international progress regarding a nuclear test ban:

- The United States and the Soviet Union had each declared a moratorium on nuclear tests
- In Geneva, on 10 August 1993, the Chairman of the CD's Ad Hoc Committee on a Nuclear Test Ban, Ambassador Yoshitomo Tanaka of Japan, announced the historic decision to commence the negotiations on a comprehensive nuclear test ban (document CD/1212)
- On 12 December 1993, Tanaka succeeded in reaching a consensus on a mandate for the Ad Hoc Committee for these negotiations
- The CD made the important decision in December 1993 that the negotiations would take into account the work of the GSE.

These developments had significant financial implications for NORSAR. In particular, the United States Congress had decided in November 1993 that ARPA should discontinue its emphasis on the development and experimental operation of seismic array stations. This decision was made because the array technology was now considered mature (to a large degree thanks to NORSAR's achievements), and therefore other agencies could take over this work.

The formal United States proposal regarding the future status of the experimental arrays in Norway was outlined by acting ARPA Director Larry Lynn in a letter to NFR's director Christian Hambro on 22 March 1995. He proposed a transfer to the Norwegian Government of the NORESS, ARCESS, and Spitsbergen facilities, which had been operated and maintained by NORSAR with ARPA funding. The transfer would encompass both the ownership of these facilities and the fiscal responsibility for their operation.

Mr. Lynn proposed a generous phased transfer over a two-year period beginning in the fiscal year 1996. He suggested the following arrangement:

- NFR would be given full operational responsibility for the three arrays from October 1995. This point implied that NORSAR, as the executor of the agreement with the United States, would be in full control of these arrays
- Data from the arrays would continue to be made available to the GSETT-3 activities being carried out by the CD
- At the conclusion of the transition period, the small-aperture array facilities would no longer be covered by the Government-to-Government Agreement between Norway and the United States.

Otherwise, the 1968 agreement would remain in force as the basis for the management of the NOA array and the execution of a cooperative research program by NORSAR. Thus, the NOA array, which had been supported through funding from the U.S. Air Force, would be excluded from this arrangement, and its funding by the United States would continue unchanged.

Mr. Lynn noted that a major investment to modernize the components of the NOA array had been undertaken and equally financed through ARPA, the U.S. Air Force, and the Norwegian Research Council (see Section 7.3 above). Although not stated explicitly in the letter, there was no question that the willingness of the Norwegian Research Council to contribute USD 600.000 to the NOA array modernization effort in 1992-1993 had made a positive impact on the United States decision to contribute to this effort.

7.9 NORSAR is funded through the research program for the High North

By the mid-1990s, NORSAR was the leading European center in detection seismology. NORSAR collected and processed seismic data from a number of arrays: NOA, NORESS, ARCESS, FINESA, Hagfors, Apatity, SPITS, as well as various single seismograph stations, in support of GSETT-3. The data were transmitted by satellite to the GSETT-3 IDC in Arlington, Virginia. Some countries contributed

to their own costs, but the main expenses were carried by ARPA, which had taken on the task of developing the GSETT-3 IDC and eventually developing it into the prototype IDC, as noted in Section 7.1. As we saw in the previous section, there were signals from ARPA that the U.S. funding could be reduced and that some funding from the Norwegian Government might be required to provide support to continue these activities.

In anticipation of the announced cutbacks in funding for NORSAR by the US, NORSAR recognized that its existence depended on securing alternative financing for the operations and research program. The first attempt was simply asking for the financing of a general program at ten million NOK per year. The Ministry of Foreign Affairs did not accept this proposal.

The ministry had initiated a plan of action to implement its Report No. 34 (1993 -1994) to the parliament on nuclear activities and chemical weapons in areas adjacent to Norway's northern borders - the High North. A high priority would be given to increasing nuclear safety and preventing radioactive contamination. The efforts in connection with nuclear issues would primarily concentrate on Northwest Russia, in areas such as unsatisfactory safety standards at nuclear facilities, unsatisfactory management and storage of spent uranium fuel and radioactive waste, dumping of radioactive waste in the Barents and Kara Seas, and input into the sea from Russian rivers, as well as weapons-related environmental hazards.

Considering that in 1976 NORSAR already had experience with assessing safety relative to the siting of nuclear power plants (e.g., in Forsmark, Sweden) as well as the detection of nuclear testing activity in and near Novaya Zemlya, and cooperation with experts on nuclear-related waste, this could be a suitable route to financing for NORSAR.

The Chairman of The Advisory Council for Arms Control and Disarmament, Finn Fostervoll, suggested that NORSAR make an introductory presentation of their activities to this council. Frode Ringdal provided such a presentation, which was quite well received, and NORSAR submitted a proposal for a three-year effort in this regard.

The proposal resulted in a contract with the Ministry of Foreign Affairs for nearly 2.1 million NOK for 1995, 4.1 million NOK for 1996, 5.1 million NOK for 1997, and 8.2 million NOK for 1998. These amounts included 0.8 million NOK for each of these years for NORSAR's activities in GSE (WGB from 1997). Before 1995, the only funding from the ministry had been for GSE activities. The ministry's program for the High North thus came in handy and secured a funding level that compensated for the reductions in the U.S. funding. As we shall see in Chapter 9, the funding situation changed again with Norway's ratification of the CTBT in 1999.

7.10 CTBT negotiations in the Conference on Disarmament, 1994 - 1996

In the early 1990s, several factors created an atmosphere conducive to the negotiation of a CTBT, such as the end of the cold war and the readiness of several nuclear powers to stop testing after declaring moratoria in 1990 (USSR) and 1992 (U.S. and UK).

In August 1993, the Conference on Disarmament (CD) in Geneva decided to give its Ad Hoc Committee on a Nuclear Test Ban a mandate to negotiate a CTBT, as noted in Section 7.8. Two working groups were established, one on verification and one on legal and institutional matters. In addition, a number of Friends of the Chair, Convenors, and Moderators were appointed to handle specific issues on behalf of the working group chairs. Due to the method of work of the CD, all posts had to be filled every calendar year anew during the course of the negotiations. Diplomats at the Norwegian Permanent Mission in Geneva participated in and followed the negotiations closely, assisted by representatives of NORSAR in verification-related matters. No other Norwegian technical institutions were directly involved.

The history of the negotiations on the CTBT is covered in great detail in a very interesting book written by some of the key persons in the negotiation process (Ramaker, Mackby, Marshall, and Geil, 2003). In the following, we will concentrate on some key issues and those of special interest to Norway and NORSAR.

Before turning to verification, we will touch upon a few of the legal and institutional issues that turned out to be more difficult to solve than others. It was decided early to establish the future organization for the CTBT in Vienna, Austria, once the treaty entered into force. However, it proved more problematic to agree on the composition and decision-making in the Executive Council, the future organization's executive organ, and a solution was reached only at the last minute. The solution was to create an Executive Council comprising 51 countries elected for two-year terms among members in six regional groups. This division of the world into six regional groups (see Annex 1 to the Treaty), of which one covers the Middle East and South Asia, has brought the Middle East conflict directly into the work of the CTBT implementation phase (the PrepCom, see Section 8.2).

Perhaps the hardest-fought article in the CTBT was the one on entry into force of the Treaty. At the beginning of the negotiations, many delegations expected a simple rule requiring a certain number of ratifications, as was the case for the Chemical Weapons Convention (CWC, negotiated in the CD during 1980-1992), which requires 65 ratifications for entry into force. However, towards the end of the CTBT negotiations, the CWC was approaching 65 ratifications without including the two major possessors of chemical weapons. This caused concern for many states, and most delegations then thought that all nuclear weapon states, as well as many "threshold" states, should be on board before entry into force of the CTBT.

The negotiators tried to devise a formula to fulfill this desired goal without explicitly identifying the relevant states. In the end, the countries appearing in Annex 2 to the Treaty comprised those 44 CD members that possessed nuclear reactors when the negotiations were completed (according to a list of the IAEA). Norway is among those states. Although this formula was a diplomatic way to avoid a discussion state-by-state concerning inclusion in this list, it offers many states the potential of holding hostage the Treaty's entry into force. As we know, after 25 years, the Treaty has not entered into force, as eight required ratifications are still lacking.

A potentially difficult political issue was the question of scope: should the Treaty ban all nuclear explosions, irrespective of yield? There was some discussion about permitting tests with a yield below some low threshold. However, eventually, all states supported a "zero yield" treaty with no reservations. This means that the Treaty bans any self-sustaining chain reaction resulting in a nuclear explosion.

The CTBT includes the most elaborate international verification system ever negotiated, and a major portion of the text of the Treaty and its entire protocol are devoted to verification. The treaty negotiations on verification dealt basically with three issues: which technologies to use and the design of the corresponding networks of monitoring stations for adequate global coverage; how far the CTBT Organization should go in its analysis of the data from the monitoring stations, and finally, arrangements and technologies for on-site inspections.

It was clear from the outset that a global seismic system would be a key component in an International Monitoring System (IMS) for the CTBT. Here, the negotiators could lean heavily on the work of the GSE. As noted, even before the negotiations on the CTBT began, the CD members decided in December 1993 to take into account the work of the GSE. In particular, the CD wanted to be kept informed about the progress of the GSETT-3 experiment. Many of the stations used in the GSETT-3 were high-quality stations located in areas where the background noise was low, making them ideal for monitoring a test ban.

In March 1994, members of the GSE presented the plan for the functions and components of GSETT-3 to the treaty negotiators. The negotiators realized that the GSETT-3 concept of an international data center and its processing capabilities could be directly transferred to the CTBT Organization, resulting in significant cost savings. The GSE thus contributed not only to the design of the seismic component of IMS but also to a relatively mature design of an international data center.

The CTBT negotiating committee formed an IMS Expert Group toward the end of 1994 to consider seismic and radionuclide (particulate and noble gas), hydroacoustic, and infrasound monitoring techniques. These techniques complement each other and ensure that effects from a nuclear test in all of earth's environments, i. e., in the atmosphere, underground, and in the world's oceans, will be detected. This IMS Expert Group, chaired by UK scientific expert Peter Marshall, included many GSE members and drew heavily on their knowledge. Thus, the list of 50 primary stations in the eventual seismic network was, to a large extent, based on those arrays and single stations participating in the GSETT-3 experiment.

In addition, the GSE was specifically asked to propose a network of auxiliary seismic stations as part of the IMS. GSE's proposal was slightly modified by the negotiators, which resulted in a selection of 120 auxiliary seismic stations in the IMS. On Norwegian territory, there are two primary IMS seismic stations (the NOA array in southern Norway and the ARCES array in northern Norway) and two auxiliary IMS seismic stations (the SPITS array in Svalbard and the JMIC single station on the island of Jan Mayen). Data from IMS auxiliary seismic stations are used to refine the location of events already detected and initially located by the IMS primary seismic network.

There was little internationally shared knowledge and experience for radionuclide, hydroacoustic, and infrasound monitoring technologies. Hence, the IMS Expert Group had to focus on establishing an understanding among the experts participating in the negotiations of what could be achieved by these technologies. In the end, an agreement was reached that the IMS would be composed of networks of 80 radionuclide stations, 60 infrasound stations, and 11 hydroacoustic stations, of which six are hydrophone arrays placed in oceans in the southern hemisphere, and five are seismic single stations placed on islands. The latter are so-called T-phase stations, which detect seismic waves converted at steep shorelines from acoustic waves propagating in the ocean (see additional details in Section 7.11). There is one radionuclide station with a particulate and noble gas monitoring capability (in Svalbard) and one infrasound station (in northern Norway) on Norwegian territory. The map in Fig. 7.10.1 shows the IMS, which comprises 321 monitoring stations altogether. The map also shows 16 radionuclide laboratories for additional analysis of samples from radionuclide stations, as required.

Fig. 7.10.1 The figure shows the International Monitoring System for the CTBT, with its 321 stations around the globe and 16 radionuclide laboratories (from www.ctbto.org, August 2021).

Other monitoring technologies were also considered during the negotiations, particularly satellite observations and optical and electromagnetic pulse observations. Again, a few countries had some knowledge of all of these technologies, but little knowledge had been shared widely, and no broad international tests had been undertaken compared to those in the seismic field. At the time of the negotiations, satellite imagery was not generally available and suffered from limited coverage and resolution. A specific satellite system for the CTBT was considered but was found to have a frightening price tag. In the end, such a system was not included, and many delegations thought that satellite observations should rather be part of national technical means. The other technologies considered did not attract enough interest since the knowledge and experience at the time were too limited. After entry into force of the Treaty, changes can be made to the monitoring technologies and the IMS networks.

The main functions of the International Data Center (IDC) of the CTBT Organization are to receive, store and analyze the data from the IMS, and to disseminate the results of its analysis, as well as the raw data from the IMS, to the member states. A key question during the negotiations was how far the IDC should go in its assessment of the nature of the events it would detect and locate. In other words, what should the role of the CTBT Organization be in verifying compliance with the CTBT? Delegations made it clear early in the negotiations that the final assessment of the nature of events should rest with the member states. The role of the IDC should be to facilitate national interpretation by providing user-friendly products, most notably in bulletins containing lists of events determined by the IDC analysis.

Among these are lists of events that, based on objective criteria, depart from what can be considered natural events – so-called screened bulletins. The Treaty text is rather vague on screening, and this issue has been further explored in the Treaty implementation phase in the PrepCom. A point to note here is that it will be critical for the member states to develop and maintain their own technical competence, to be in a position to assess the nature of events reported by the IDC, and also to make use of relevant non-IMS data available to them in their assessment. This task could be particularly difficult for developing countries that might not possess the required technical expertise.

The last resort of the CTBT verification regime is the possibility of conducting an on-site inspection (OSI). OSIs can only take place after entry into force of the Treaty. The basis for an OSI may typically be an event detected by the IMS and reported by the IDC that is considered suspicious by one or more member states. In treaty language, this is expressed as “any matter which may cause concern about possible non-compliance with the basic obligations of this Treaty.”

The Treaty text contains elaborate procedures for the initiation and conduct of an OSI, including the rights and obligations of the inspected member state and the inspection team. On the technical side, the Treaty contains detailed descriptions of methods and equipment that can be used to clarify the nature of the suspicious event. More than a dozen technologies can be used to address the key question: does the suspicious event constitute a breach of the Treaty, or is it a natural event with explosion-like characteristics that have triggered the concern? The final step of an inspection, if carried thus far, could be drilling into the chamber of a suspected nuclear explosion to retrieve radioactive samples as proof of a Treaty violation. The Treaty specifies that the area for an OSI should not exceed 1,000 square kilometers. It is thus important that the uncertainty of the IDC location is small enough so that the true location, with a high probability, is within the inspection area.

A decision to conduct an OSI must be made by the Executive Council, with at least 30 affirmative votes among its 51 members. Before a member state uses its right to request the Executive Council to decide to proceed with an OSI, every effort should be made to clarify and resolve the concern of the requesting state, including efforts to obtain clarifications from the state on whose territory the suspicious event occurred. The state requesting an OSI should base its request on information from the IMS/IDC monitoring system, any relevant information from national technical means, or a combination thereof.

Information from national technical means to be presented to the Executive Council might, for example, include data from non-IMS monitoring assets, including satellite imagery. It might be problematic for a requesting state to reveal its national monitoring capacities. Hence the most likely candidates to be used in this context would be open-source data. When an OSI has been completed, an inspection report shall be prepared for review by the Executive Council, addressing whether any non-compliance with the Treaty has occurred. This may result in collective measures, such as international sanctions via the UN, against the inspected state.

In our opinion, decision-making in the Executive Council regarding the launch of OSIs will be the most critical and consequential process in the future CTBT Organization in terms of upholding the purpose of the Treaty. It will be important that the requesting state is able to present the case for an OSI in a technically solid and convincing manner to the 51 members of the Executive Council. Again, we see the importance of possessing adequate technical competence at the national level, which may be difficult for developing countries to acquire.

Many stakeholders expressed keen interest in the CTBT negotiations and urged the negotiators to conclude their business as soon as possible. Inspiration and encouragement came from, among others, the NPT Review and Extension Conference in April-May 1995, a summit between Presidents Clinton and Yeltsin in October 1995, and the UN General Assembly in December 1995. During the final stages of the negotiations, the world also witnessed the last nuclear tests by France (January 1996) and China (July 1996).

In 1996, the negotiators considered successive drafts of the Treaty text and found solutions to many remaining problematic issues. The CTBT negotiating committee started its final round of consideration of a text proposed by its Chairman, Ambassador Jaap Ramaker of the Netherlands, on 29 July. A number of countries were prepared to accept the draft, while others, in particular India and Iran, voiced their opposition. India wanted a reference in the Treaty to nuclear disarmament in a time-bound framework, disagreed with the formula for entry into force of the Treaty, and when its proposals were not accepted, refused in the end to have any IMS stations on its territory listed in the Treaty. The four stations in India listed in earlier versions of the draft Treaty text were in the final lists of IMS stations in the Treaty, replaced with the designations “to be determined” for the state, location name, and geographical coordinates. Because the lists of states appear in alphabetical order, it is clear which country these designations replaced.

After inserting a slight revision to the rule on decision-making in the Executive Council, the Chairman presented his final text on 14 August. This text enjoyed overwhelming support from the countries participating in the negotiations. However, it was held hostage by some countries that disagreed with the text, as the negotiating committee could only act by consensus. India and Iran were the most vocal countries to oppose the text. So, the question was, “what now”? The solution, and only way forward, was through national initiatives. Belgium presented to the CD the Chairman’s text of 14 August as a national paper. After that, Australia introduced the same text in a draft resolution to the UN General Assembly, where

it was adopted on 10 September 1996, as we will see in Section 8.1.

Concurrently with the end of the CTBT negotiations, the GSE held its 45th and last session in Geneva in August 1996. The last report from the GSE to the CD covered the GSETT-3 experiment and its relevance to the seismic component of the IMS. As described in Section 7.1, the GSE’s GSETT-3 experiment continued until 2000 and was integrated with the activities of the CTBTO PrepCom (see Section 8.2) in Vienna from 1997. The GSE thus succeeded in providing what was called a “seamless” transition from GSETT-3 to the eventual monitoring system for the CTBT.

7.11 NORSAR participates in the selection of monitoring stations for CTBT

As noted, NORSAR participated very actively in the verification aspects of the CTBT negotiations. In line with NORSAR’s competence and expected future role in CTBT verification, NORSAR’s representatives concentrated their efforts specifically on the IMS networks, but also participated in the IDC discussions.

For the primary seismic network of 50 stations covering the globe, there was a general acceptance of Norway’s wish to include one station in southern Norway and one station in northern Norway. NORSAR’s array stations and their track record of operational stability and detection capabilities were well known from the scientific literature, data exchange, and experiments like those of the GSE. The obvious candidate station in northern Norway was the ARCES (previously termed ARCESS) array. In southern Norway, there were two candidates: The NOA array and the NORES (previously termed NORESS) array. NOA was chosen based on its longer history and richer archive of nuclear explosions records.

As we saw in the previous section, the IMS Expert Group was to use GSE’s list of proposed stations as a basis for selecting the eventual auxiliary seismic network of the IMS. This final selection should have been a mere formality, but it turned out quite different, with the NORSAR staff having a crucial role.

Peter Marshall anticipated toward the end of 1995 that there was consensus on the primary seismic, hydroacoustic, and infrasound networks. He further considered that he had arrived at an agreed list of 119 of the 128 stations proposed by the

GSE to become part of the IMS auxiliary network. However, China, referring to the hydroacoustic network, stated that it wanted an additional hydroacoustic IMS station located north of Norway. This was not acceptable to Russia, and other countries considered that the agreed hydroacoustic network should not be changed. No solution was found, and Marshall called for a break to conduct consultations.

Ringdal and Mykkeltveit were NORSAR's representatives in the IMS Expert Group and kept close contact with colleagues at NORSAR. They discussed how a seismic station on Bjørnøya or Jan Mayen could be proposed as a substitute for a hydroacoustic station. The station of choice was Jan Mayen, which could be promoted as an IMS auxiliary station with the potential to record T-phases (see Box 7.11.1).

BOX 7.11.1

Seismic T-phases

T-phases are the third (tertiary) principal seismic arrival after an earthquake. The T-phase can only be observed on island and coastal seismic stations (that is, after the primary (P) and secondary (S) waves). At least part of their propagation path occurs in the ocean sound channel.

The use of the T-phase for recording acoustic waves from underground nuclear explosions converted to seismic waves at steeply sloped shorelines before being recorded at a seismic station is an established technology. It has, on previous occasions, been used by New Zealand to record French nuclear explosions on the Rarotonga Island.

When the session resumed, the Norwegian delegation proposed a compromise solution to include a seismic station with T-phase recording capability on the island of Jan Mayen in the auxiliary seismic network. The proposal was accepted with gratitude.

Norway also became home to an infrasound station and a radionuclide station in the IMS, and the NORSAR team was thus introduced to new technologies. The choice of Norway resulted from geography and the goal of creating networks with a reasonably even distribution of stations globally. Norway's location, bordering on large ocean areas that are difficult to cover, made it a favorable selection in this regard. The site of the infrasound station in Norway in the station table of the Treaty is identified as Karasjok in northern Norway, which is the same location as the primary seismic station ARCES.

It is interesting to note that Karasjok hosted an infrasound station during the late 1960s and early 1970s as part of technical intelligence cooperation between Norway and the United States. The existence of this station became known to the public only in 1997. As noted earlier, and as we will see in Section 11.2, the IMS infrasound station could not be established in Karasjok due to a conflict over land use, and it was installed instead in Bardufoss, some 300 km away.

Another episode from the negotiations, partly related to IMS stations on Norwegian territory, is worth mentioning. Towards the end of 1995, when the IMS networks had essentially been agreed upon, Russia announced that it reserved the right to come back with some proposals for improvement of the monitoring capacity of the IMS when the negotiations were to resume in 1996. When Russia presented its amendments to the IMS in January 1996, it became clear that they believed the IMS detection capability was better for their Novaya Zemlya test site than for any other test site. Novaya Zemlya is surrounded by many powerful seismic arrays, not least in Norway. Luckily, Russia did not propose to change the network in this region; they rather wanted to install primary seismic stations at the test sites of the five nuclear weapon states: in Nevada (U.S. and UK), Lop Nor (China), Mururoa (France), and Novaya Zemlya (Russia). The principal concern of the Russian delegation appeared to be the inferior capability of the IMS to monitor the Nevada Test Site compared to Novaya Zemlya.

Some delegations expressed concern that a new examination of the IMS capability could damage the emerging consensus on the networks. However, after some deliberations, the five nuclear weapon states reached an agreement. Instead of installing seismic stations at the test sites, they agreed to change the seismic networks around Nevada and Lop Nor: a primary station in California was re-designated as an auxiliary station, and a new primary array station was introduced at Mina, Nevada, some 250 km from the test site. In Kazakhstan, the auxiliary station at Makanchi near the border with China was converted to a primary array station, while a primary station at Aktyubinsk in the western part of the country was re-designated as an auxiliary station. With these changes, the primary seismic network remained at 50 stations, as previously agreed.

Chapter 8

1996 – 1999
Starting up the implementation of the CTBT

8.1 CTBT approved by the United Nations in 1996

On 10 September 1996, the UN General Assembly in New York adopted the CTBT based on a draft resolution introduced by Australia. As noted previously, the Australian resolution contained the Treaty text negotiated in Geneva. Decisions by the General Assembly can be taken by a majority vote, and only three states, Bhutan, India, and Libya voted against, whereas 158 states voted in favor and five abstained.

The Treaty opened for signature on 24 September 1996, during the "high-level week" of the UN General Assembly, when many heads of State were present. The first person to sign was the U.S. President, William J. Clinton. This choice was natural based on his strong initiatives to promote and complete the CTBT negotiations. He was followed by the other four nuclear weapon states (i.e., those named in the Nuclear Non-Proliferation Treaty): China, France, the United Kingdom, and the Russian Federation. By the end of that day, a total of 71 states had signed the CTBT and thus made the first step toward a commitment never to conduct a nuclear weapon test explosion or any other nuclear explosion.

Norway's Prime Minister, Gro Harlem Brundtland, was among those who signed the CTBT that day. Afterward, she said to the Norwegian newspaper Aftenposten that it was particularly satisfying to hear about the recognition of the sustained effort by Norway in the establishment of the Treaty.

Events related to international diplomacy on CTBT matters seldom reach the headlines of international news media. However, from the end game of the CTBT negotiations in August 1996 until the signing ceremony in the UN a month later, numerous media articles provided considerable insight to the public on the diplomatic maneuvering necessary to secure a fruitful output from nearly three years of negotiations in Geneva (as well as the previous efforts attempted since 1945). Fig. 8.1.1 is an example from Norway. The newspaper Aftenposten reported on the UN General Assembly's decision to adopt the CTBT and described the procedures pursued after India's rejection of the Treaty in Geneva. The Norwegian ambassador to the UN at the time, Hans Jacob Biørn Lian, expressed Norway's satisfaction with this decision, which was in line with a longstanding priority in Norwegian foreign policy, not least due to Norway's proximity to Russia's test site at Novaya Zemlya.

Utland Onsdag 11. september 1996 Aftenposten

Forbud mot atomsprengninger

Det ble hilst som et gjennombrudd da FN med overveldende flertall vedtok å forby prøvesprengninger av atomvåpen.

Aftenpostens korrespondent
ULF ANDENÆS

New York/Washington Det skal bli slutt på alle atomprøver over hele kloden, både til lands, til vanns og under jorden, ifølge vedtaket, som forelå sent i går kveld norsk tid. Blant flertallet på hele 158 land hørte alle de ledende atommaktene. Ett land - India - har motarbeidet vedtaket iherdig, men ble stående nesten alene.

SA NEI: Den indiske nedrustningsforhandleren Arundhati Ghose (i midten) fulgte spent med i avstemningen om prøvestansavtalen i FNs hovedforsamling i går kveld. Foto: SCANFOTO/EPA

– Viktig for Norge

– Prøvestansavtalen blir et viktig vern mot spredning og utvikling av atomvåpen og et skritt mot det endelige mål som er global kjernefysisk nedrustning, sier lederen for den norske FN-delegasjonen, ambassadør Hans Jacob Biørn Lian, til Aftenposten.

– Dette har vært en sak av særskilt interesse for Norge, ikke minst fordi et område hvor Russland har testet atomvåpen, Novaja Semlja, ligger nær vårt land.

På grunn av Norges erfaringer fra dette naboskapet har vi vært blant pådriverne for å få prøvestansavtalen igjennom, fremholder vår FN-ambassadør.

Arbeidet for et forbud mot atomprøver tok fart etter den enorme internasjonale opinionsbølgen som fulgte Frankrikes atomsprengninger i Stillehavet og de kinesiske prøvene kort etter. Derfor har Australia vært forslagsstiller for vedtaket. Australierne ble anførere for landene i Stillehavet som har sett på atomprøvene i sin region som en nasjonal trussel. Mye har endret seg siden Australia i tidlig etterkrigstid velvillig stilte sine ørkenområder til rådighet for britiske atomprøver.

Det ble et paradoks for mange at den store bremseklossen for en atomnedrustningsavtale var nettopp India, et land som under selvstendighetslederen Mahatma Gandhi og hans etterfølgere opptrådte som det fremste talerør for ikkevoldstanken. Dagens India ser seg selv som inneklemt mellom Kina som har atomvåpen og Pakistan som står på terskelen til å få det.

– Vi stoler ikke på våre naboer; de vil fortsette å true oss med atomvåpen og vi er nødt til å ta våre motforholdsregler, sa de indiske talsmenn i FN.

Under nedrustningskonferansen i Genève i sommer blokkerte India en avtale om stans i atomprøvene. Derfor gikk Australia til det skritt å drive avtalen gjennom på en uvanlig måte, som vedtak i FNs hovedforsamling.

India presses

Avtalen vil likevel ikke tre formelt i kraft før alle de 44 land i verden med atomreaktorer har undertegnet. Også det kan India blokkere. Men FN-vedtaket ventes å skape et overveldende internasjonalt press mot nye prøver.

Tidligere har India fått støtte i sin motstand fra andre u-land som har sett prøvestans som et forsøk fra de gamle atommakter på å «stenge klubben for nye medlemmer». Dette synspunktet ble gjentatt nå av Zimbabwes ambassadør, men da det kom til avstemningen fikk India støtte bare fra Libya og fra Bhutan, et lite indisk lydrike i Himalaya.

– Vi har grunn til å håpe at de land som undertegner vil holde seg til avtalens bestemmelser, og at også de andre til slutt vil anse dette for å være i egen interesse, sier ambassadør Lian.

Den amerikanske FN-ambassadøren Madeleine Albright omtalte vedtaket som en «milepæl». President Bill Clinton sa i en kommentar at verden er «i ferd med å virkeliggjøre en drøm» etter FN-vedtaket. Clinton ventes å undertegne på USAs vegne når han besøker Hovedforsamlingen senere i måneden.

Fig. 8.1.1 Article in the Norwegian newspaper Aftenposten on 11 September 1999, after the decision in the UN General Assembly to adopt the CTBT.

8.2 Establishment of the CTBTO Preparatory Commission and its Provisional Technical Secretariat

When the CTBT negotiations in the CD in Geneva were drawing to an end, delegations had to start thinking about the future organization's need to prepare for entry into force of the Treaty. The "Text on the Establishment of a Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization" was successfully negotiated in the CD and then adopted in a resolution in New York on 19 November 1996 by those states that had signed the Treaty by then.

This text governs and guides all activities of the CTBTO Preparatory Commission (hereafter referred to as CTBTO PrepCom or PrepCom), which has a standing as an international organization on its own. The purpose of the PrepCom is to carry out the preparations for the implementation of the CTBT and for the first session of the Conference of the States Parties, which will be the first meeting of the future CTBT Organization after entry into force of the Treaty. At this juncture in time, PrepCom will cease to exist. Fig. 8.2.1 shows organizational elements of the organization before and after entry into force of the Treaty.

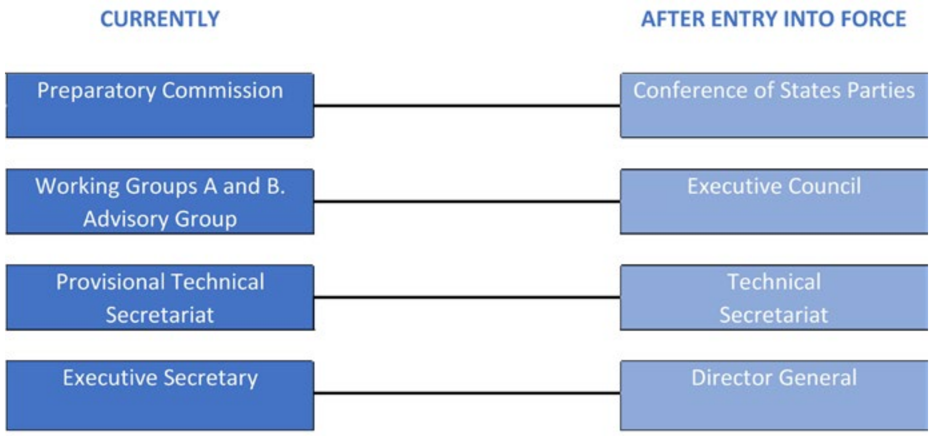


Fig. 8.2.1 The figure shows organizational elements of the CTBTO before and after entry into force of the CTBT. On the left,"Preparatory Commission" denotes the superior plenary body, which makes all decisions of the PrepCom, based on recommendations from the two working groups. The Executive Council (on the right) will make decisions in the day-to-day business of the future CTBT Organization.

The PrepCom has a strong mandate to undertake all necessary preparations to ensure the operationalization of the Treaty's verification regime upon entry into force. The PrepCom is composed of all states that sign the Treaty. The costs of the PrepCom and its activities are met annually by all States Signatories, following the UN scale of assessment, with slight adjustments for different memberships. Further, many countries, including Norway, devote considerable additional national resources to the operation of the PrepCom, and in efforts to promote the Treaty and the development of its verification system.

Decisions of the PrepCom are made in plenary sessions of States Signatories. This plenary body should operate based on consensus, but procedures are in place for voting if no consensus can be found. From September to November 1996, interested delegations met in informal discussions in Geneva and New York to prepare for decisions to be made at the first session of the PrepCom plenary body. They discussed the establishment of a secretariat of the PrepCom, called the Provisional Technical Secretariat (PTS), the secretariat's structure, the appointment of an Executive Secretary, administrative and financial rules and regulations, a budget, and a work program for the first few months, and the creation of subsidiary bodies to the PrepCom plenary body.

In the discussions leading up to the first session of the PrepCom, delegations quickly agreed on establishing two subsidiary bodies of the PrepCom plenary body: Working Group A for administrative and budgetary matters and Working Group B for verification. In addition to the two working groups, there would be an Advisory Group to advise the PrepCom plenary and working groups on financial, budgetary, and associated administrative matters. The creation of the two working groups followed logically from experience gained in the CTBT negotiations, which had formed Working Group 1 on Verification and Working Group 2 on Legal and Institutional issues. Delegations found it most useful to conduct detailed discussions in dedicated subsidiary organs. The experience from the GSE also proved useful in supporting the creation of the PrepCom Working Group B. Discussions on the structure of the PTS, however, became difficult.

The first session of the PrepCom plenary body opened in New York on 20 November 1996, the day after the States Signatories had given birth to this new organization. Ambassador Jacob S. Selebi of South Africa was elected chairman of the first session. Apart from this election and decisions on some rules and regulations, little was achieved at this three-day-long meeting. Disagreements dominated the discussions over the PTS structure, particularly the allocation of director-level positions. The PTS could not be established. An Executive Secretary could not be appointed (although German Ambassador Wolfgang Hoffmann, a key figure in the CTBT negotiations, was the only candidate and enjoyed broad support). An already approved agreement with Austria on hosting the PrepCom in Vienna could not be signed because no one had the authority to do so. The two working groups could not be established. The proposed work program and budget for the first four months were not approved. It was decided to resume the session in Geneva in March 1997.

To prepare for the resumed session, ambassador Selebi named Ola Dahlman, Sweden as a Friend of the Chair, with the task of conducting consultations to facilitate agreement on verification matters. Ola Dahlman recruited Svein Mykkeltveit and later Hein Haak from the Netherlands to advise and assist him in this task. There followed three rather intensive months of consultations in Geneva with interested delegations. Jenifer Mackby, who had served as Secretary of the negotiations, as well as the GSE, the PrepCom meeting in Geneva, and subsequently as Secretary of the Working Group on Verification in Vienna, assisted in these efforts. The consultations centered on a work program for the PTS in anticipation of its establishment and a work program for the future Working Group B and how it should be structured. The work program for the PTS included a plan for the start of the establishment of the IMS and the IDC, taking into account the status of the ongoing GSETT-3 experiment. Other consultations resolved the difficulties of the structure of the PTS and the filling of its top-level posts.

In Geneva, during 3-7 March 1997, the PrepCom successfully completed its first session. It appointed Ambassador Wolfgang Hoffmann of Germany as Executive Secretary. The PrepCom established Working Group A with Ambassador Tibor Tóth of Hungary as its Chairman, and likewise, Working Group B with Ola Dahlman as its Chairman. It approved work programs for the two working groups for the remainder of 1997. The PrepCom also established the PTS in Vienna, with an agreed structure of five divisions (Administration, Legal and External Relations, IMS, IDC, and OSI), and appointed its five directors. It further approved a program and budget for the PrepCom of 27.5 million USD for 1996-1997. With these decisions, the PrepCom was in a good position to embark on the task of establishing the CTBT verification regime.

The PTS, which executes the decisions made by the PrepCom, commenced its activities in office facilities at the Vienna International Centre on 17 March 1997, with an initial staff of 10 people. The Executive Secretary of the PrepCom also serves as the CEO of the PTS, and he developed the Organization quickly. The number of staff grew to 95 by the end of 1997 and reached about 260 over the next four years, which remains to date. The annual budget of the PrepCom grew gradually to about USD 85 million USD in 2002 and has since then only been adjusted following the principle of "zero real growth," i.e., with adjustment only to compensate for inflation, so that the budget for 2021 is close to 130 million USD.

Many people with expertise in the various CTBT verification technologies and often with backgrounds from the GSE, the CTBT negotiations, or national institutions engaged in test ban monitoring took up employment in the PTS in the early years. Among these was Bernt Kristian Hokland from NORSAR, who served in the PTS for seven years from 1998 as a lead analyst of seismic, infrasound, and hydroacoustic data.

8.3 Working Group B of the CTBTO Preparatory Commission

As we saw in Section 8.2, the PrepCom has been organized since March 1997 with its plenary body, its two working groups, and its executive arm, the PTS. The PrepCom plenary body, the superior decision-making organ, meets in relatively short sessions (two or three days) twice a year, with one-year chairmanships that rotate among the regional groups in alphabetical order (the Middle East and South Asia Group has always been bypassed, as this group is not able to nominate a candidate or to meet). The chair of the PrepCom has always been a Vienna-based ambassador. Most of the discussions and consensus building among the States Signatories takes place in the two working groups, which summarize their work at each session in reports containing recommendations for decisions by the PrepCom plenary. With a few exceptions, the PrepCom plenary has adopted the recommendations from the working groups over the years.

Working Group A (WGA) for budgetary and administrative matters meets twice a year in two or three day sessions. The chair is elected for a term of three years and has also been at the ambassador level, usually Vienna-based. WGA conducts most of its business in plenary meetings led by its chair, who at times has relied on assistance from "Friends of the Chair" or "focal points" appointed by the chair to deal with specific issues. Participants in WGA sessions are typically diplomats from the permanent missions in Vienna.

Working Group B (WGB), which deals with verification matters, is the key venue for NORSAR's efforts on behalf of the Ministry of Foreign Affairs. After a busy schedule during the first ten years, with three sessions each year, the WGB meets for two-week sessions twice a year. There have been three past chairmen of the WGB: Ola Dahlman from 1997 to 2006, Hein Haak from 2006 to 2015, and Joachim Schulze, Germany from 2015 until the end of 2020. All three are technical experts with long careers in CTBT verification technologies in their home countries. The term of office of the WGB chair changed to three years, renewable once. In 2021, Erlan Batyrbekov from Kazakhstan was elected to chair the WGB for 2021 - 2023. Another candidate for this election was NORSAR's Anne Lycke, but Norway withdrew her candidacy to enable the PrepCom plenary to make a consensus decision.

WGB held its first session in Geneva during the first session of the PrepCom in March 1997. This enabled the PrepCom to immediately adopt the WGB's recommendations for its method of work and work program for the remainder of 1997, and WGB was off to a flying start.

The key element of the WGB's method of work is the division of WGB's portfolio into separate tasks and reliance on task leaders to chair the discussions in separate meetings for each task. The findings and conclusions of these meetings, which take up most of the time allotted to WGB, are presented in the plenary meetings of WGB for discussion and eventual incorporation into WGB's report to the PrepCom. Task leaders are selected by the WGB chair (usually after consultations with delegations) based on their technical expertise and with a view to geographical balance. It was initially relatively easy to find people who were able and willing to take on the responsibility of being task leaders and eager to implement the complex verification regime for the new treaty. Task leaders are members of their respective delegations to WGB and are supported by their own countries to fulfill their functions on behalf of all States Signatories. This voluntary commitment of resources by States Signatories for the common good has been very substantial, considering all the work the task leaders have accomplished over the years.

The PrepCom, at its initial session, assigned WGB a very active work program, and WGB held its second session in Vienna from 7-18 April 1997. There was a widespread sense of urgency, stemming from a wish to implement the verification regime as quickly as possible, to be ready for an early entry into force of the Treaty. Agreement was found, e. g., on initial plans for IMS and IDC commissioning, as well as on technical requirements and specifications for stations in all four IMS monitoring technologies. This allowed the PTS to start procurement processes for the acquisition and installation of IMS station equipment, and hardware and software for the IDC. All in all, the first years were extremely busy in WGB, with, at times, up to three meetings under the guidance of task leaders taking place in parallel. It was only in 2013 that a principle of no parallel meetings was adopted, primarily to allow small delegations to participate in all activities of WGB.

States Signatories considered commissioning plans and station specifications as matters of policy, and they were dealt with in WGB and the PrepCom before the PTS started executing its work. However, in the first few years, when the PTS was in its infancy and had limited personnel resources, work in the policy-making organs also included issues of a nature that the PTS subsequently handled. Over time, a division of work between the PTS and the PrepCom's organs emerged as the PTS grew in capacity. The PTS executes the work program mandated by the PrepCom, under the approved budget, and the PrepCom organs provide oversight, feedback, and guidance on policy matters. This is an art of balance, with challenges on both sides: for the PTS to be transparent about all their activities and for the States Signatories to resist the temptation of resorting to micromanagement of the PTS. In our assessment, both sides have in general understood their roles well and contributed constructively to advancing the implementation of the CTBT verification regime.

Norway has devoted significant resources to the efforts in WGB through the participation of representatives of NORSAR. The delegates to the WGB have two basic tasks: to promote the interests of their own country in technical matters and to contribute to moving the installation of the CTBT verification regime forward. The Ministry of Foreign Affairs has stressed the importance to Norway of both aspects. Frode Ringdal and Svein Mykkeltveit took on heavy duties on behalf of the three first WGB chairs. Frode Ringdal was task leader during 2001-2016 for a range of tasks related to the IDC, National Data Centers and Testing and Provisional Operation. Svein Mykkeltveit assisted the chairs from the first session of WGB until 2016 as a Friend of the Chair, with a duty to serve as their closest adviser in organizing and conducting the work of the working group.

From 1997 until 2016, Jan Fyen attended to Norway's interests in WGB. This included follow-up on a range of issues related to installation, operation and maintenance of IMS stations, data communication, data quality management and processing of data at the IDC, as well as participation in drafting of IMS and IDC operation manuals. In addition, Jan Fyen worked closely with many delegations to promote technical solutions for the common good. He was key in developing a Command and Control structure for IMS stations and led an expert group on this topic. Ulf Baadshaug and Michael Roth joined Jan Fyen to follow National Data Center issues. During the first years of the PrepCom, all NORSAR employees involved in operations or research in the test-ban monitoring area attended at least one session of WGB to gain insight into the diplomatic context of their daily work. NORSAR's representation and activities in WGB during recent years are dealt with in Chapter 11.

NORSAR's cooperation with the Norwegian permanent mission in Vienna has always been excellent. The diplomats there have consistently taken a keen interest in the PrepCom and its activities, and they have to a large extent attended the WGB plenary sessions along with NORSAR's representatives. A highlight in their engagement was in 2013 when Ambassador Jan Petersen served as the Chair of the PrepCom. Likewise, the Ministry of Foreign Affairs has continually supported NORSAR's activities in the PrepCom. There has always been a deep-rooted common understanding of the objectives and goals of NORSAR's participation and activities in the PrepCom, and this has left little room for doubt about what should be the Norwegian position on issues dealt with by NORSAR. Only very exceptionally has there been a need to ask for instructions on matters that have been up for discussion. One such case was the question of which country, out of three candidates, should be chosen as host for a major OSI field exercise.

It might be worthwhile to reflect in hindsight on the first few years of the life of the PrepCom. This was a period of widespread enthusiasm among the delegations. Many individuals, especially on the technical side, had worked persistently over a long time - some for more than 30 years - to achieve a CTBT. They wanted to contribute, as PrepCom delegates or PTS employees, in this new era with a long-awaited opportunity to implement the verification regime and witness the start and evolution of a new organization. They put aside disagreements from the CTBT negotiations, with conflicting national positions and the need for compromises, and a spirit of cooperation to achieve common goals prevailed. As we have noted, delegates and employees in the PTS needed to work side by side on the same issues in the beginning. This all fostered a “family feeling,” from which the work benefitted greatly.

In our assessment, a sense and culture of ownership developed among the stakeholders in the PrepCom early on. This culture was visible in the consensus-building processes and applied to every decision made by the policy-making organs. Most importantly, a robust decision-making process developed during these early years that allowed all delegations to have their say. In general, there has been a willingness to accommodate the concerns of others to facilitate consensus.

However, over time, the mood in the policy-making organs has gradually changed towards becoming more confrontational for several reasons. Changes in personnel, both in the delegations and in the PTS, brought in people with less background in CTBT matters. Debates in the PrepCom plenary and its working groups tended to become more political, with controversies over disarmament issues other than the CTBT. And the prospects for entry into force of the CTBT diminished after the U.S. Senate's decision in October 1999 not to give its consent to ratify it (see Section 8.9).

At the start of the work in 1997, experts in the four technologies expected a timeframe of only three to four years to essentially complete the IMS, provided that adequate budgets would be made available and that the countries hosting IMS stations would cooperate fully to overcome legal and other administrative obstacles. This thinking was partly a result of the early enthusiasm and probably also colored by the prospects of early entry into force of the Treaty; nevertheless, the experts saw it as possible, from a technical point of view, to install the IMS within a few years. However, this optimism faded soon when non-technical and political realities emerged, like the rejection in the U.S. of the Treaty's ratification. With increasing strength, delegations argued that they should adapt the pace of installation of IMS stations to the prospects of the entry into force of the CTBT. After 25 years in the PrepCom phase, the IMS is about 90 percent complete. Also, it should be added that technological advancements have been adopted over the years to the extent that the detection capability of the IMS supersedes what was projected at the outset of its establishment.

At a very early stage, indications emerged that certain issues might present difficulties for the WGB and the PrepCom plenary body. Among these were the mode of operation of the IMS and the IDC (should it be for testing purposes only or more regular operation under some agreed requirements), the development of the noble gas component of the IMS radionuclide network, and the ability of technical experts from developing countries to participate fully in WGB. We will revert to these and other issues in Chapter 11 as part of an overall assessment of the developments in the WGB until today and their implications for Norway and NORSAR.

8.4 Challenging the test ban

Although the United States president was the first to sign the CTBT in 1996, there was no political agreement in the U.S. that the Treaty should be ratified. In fact, an unusual seismic event in Russia, which could be interpreted as a nuclear explosion, occurred less than a year after the signature.

On 16 August 1997, the GSETT-3 system detected a low-magnitude seismic event in the vicinity of the former Novaya Zemlya test site. This event triggered an official query by the United States to the Russian Federation.

NORSAR was questioned by ARPA (Ralph Alewine) about the event and could inform him that the event was not on Novaya Zemlya but about 100 km east of the island. In addition, an aftershock occurred some hours later at the same location (see Fig. 8.4.1). Such aftershocks are not unusual for earthquakes.

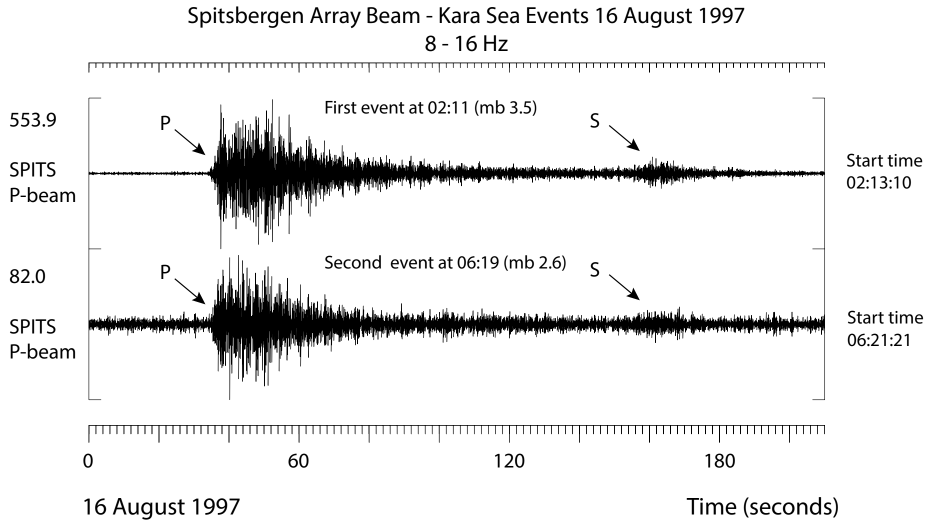


Fig. 8.4.1 The SPITS plots of the two seismic events on August 16, 1997. The second event was a magnitude unit smaller than the first event.

The Russian government stated officially that no nuclear explosion had taken place, and that the event was a small earthquake, most likely under the Kara Sea.

The Washington Times reported that U.S. officials suspected that Russia had conducted an underground nuclear test at Novaya Zemlya. Although Russia strongly denied conducting such a test, there was no consensus within the U.S. government at that time as to either the nature of the event or its location.

As a U.S. investigation on the matter proceeded, however, it became clear that the seismic event did not occur at Novaya Zemlya but rather 130 kilometers away, below the Kara Sea.

According to the 4 November 1997 statement summarizing the conclusions of an independent U.S. panel, Russia had conducted nuclear weapons-related experiments at Novaya Zemlya in mid-August 1997. The panel concluded, however, that the seismic event "was almost certainly not associated with the activities at Novaya Zemlya and was not nuclear." Nevertheless, it asserted that, based on the seismic data, "experts cannot say with certainty whether the Kara Sea event was an explosion or an earthquake."

The panel also maintained that the activity at Novaya Zemlya, and the simultaneous event in the Kara Sea "demonstrate the difficulty of accurately identifying and assessing weapons experiments or tests with very low yields."

8.5 India and Pakistan carry out nuclear tests in 1998

Neither India nor Pakistan signed the CTBT following the negotiations in 1996. They were, therefore, not legally bound to adhere to the CTBT. They were not members of the CTBT organization, although Pakistan has attended some WGB meetings as an observer. However, their breaking the international norm of no nuclear testing caused worldwide concern.

India had previously carried out one nuclear explosion. On 18 May 1974, the Indian authorities announced that the country had carried out its first nuclear test explosion in the Pokhran region (Fig. 8.5.1). It was declared to be a "Peaceful nuclear explosion" (PNE), meaning that it was not intended for development or improvement of weapon technology. The explosion was fully contained (i.e., there was no release of radioactivity into the atmosphere).

The Indian Government stated at the time that the PNE explosion had a yield of 10-15 kilotons. This estimate was consistent with worldwide seismic recordings of the event, and NORSAR concurred with this estimate.

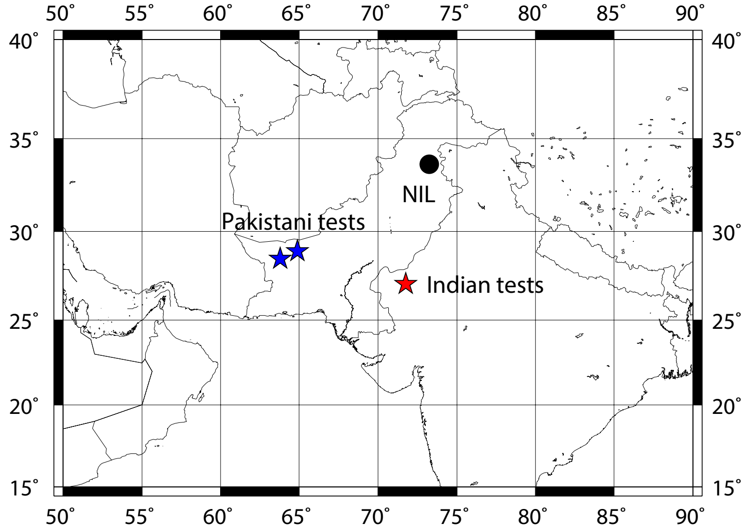


Fig. 8.5.1 Locations of the Indian and Pakistani nuclear tests in May 1998. The site of the Indian tests was identical to the Indian PNE test in 1974. The station NIL is a station that was transmitting data by satellite to NORSAR during the Indian tests in 1998. The station was not transmitting data during the Pakistani tests.

The NOA array recorded the 1974 PNE event and reported it in its monthly bulletin. The high-quality digital recordings produced by NOA were essential in estimating the yields of the Indian nuclear explosions carried out 24 years later, after the CTBT was negotiated.

The NOA array is to our knowledge the only seismic station in the world that has retained high quality digital recordings of both the 1974 and 1998 Indian nuclear explosions. In 1974, NOA had 132 short-period and 22 three-component long-period seismometers. In 1998, after the reduction of the array in 1976, NOA had retained 42 short-period and seven three-component long-period seismometers.

In May 1998 India stated that it had conducted five underground nuclear tests on 11 and 13 May 1998. India declared these explosions as nuclear weapon tests. According to the Indian authorities, the series of explosions involved:

- On 11 May, two large explosions with yields of 12 and 43 kilotons and one small explosion (0.2 kilotons)
- On 13 May, two small explosions with yields of 0.5 and 0.3 kilotons.

The Indian nuclear explosions on 11 May 1998

The three explosions on 11 May were conducted simultaneously and were located in the Pokhran region. The origin time was 10.13.44 UTC, and the seismic waves were detected and automatically processed by the NOA array processing system within a few minutes. The prototype IDC in Arlington, Virginia, also detected and located the event. The location was close to the 1974 test.

It should be noted that when several co-located explosions are detonated simultaneously, the largest explosion will dominate the seismic recordings. It is, therefore, not possible, from NOA data, to confirm whether or not the smaller explosions were carried out as planned.

NORSAR reported a magnitude of 5.1 for the 11 May 1998 test, indicating a yield of 15-20 kt, which is not consistent with a total yield of 55 kt claimed by the Indian authorities. Fig. 8.5.2 shows that the waveforms of the 11 May 1998 and the 1974 events are essentially identical (there is a scaling factor between them, with the 1998 event being slightly larger). NORSAR reported to the Norwegian Ministry of Foreign Affairs that its estimate was 15-20 kt for the 11 May 1998 nuclear explosion.

The Indian nuclear explosion on 13 May 1998

The explosions reported by Indian authorities (two explosions of 0.5 kt and 0.3 kt) took place on 13 May 1998 at 06.51 UTC. None of the IMS stations detected seismic signals.

NORSAR had arranged with Pakistan in 1997 to receive seismic data from the Nilore station (NIL), which was not in the IMS, and could apply the site-specific Threshold Monitoring (TM) method to its regular network augmented by the station NIL. NIL is situated less than seven degrees from the Indian test site. We will illustrate the effectiveness of the TM method by applying it to the announced Indian nuclear explosions at 06.51 UTC on 13 May 1998.

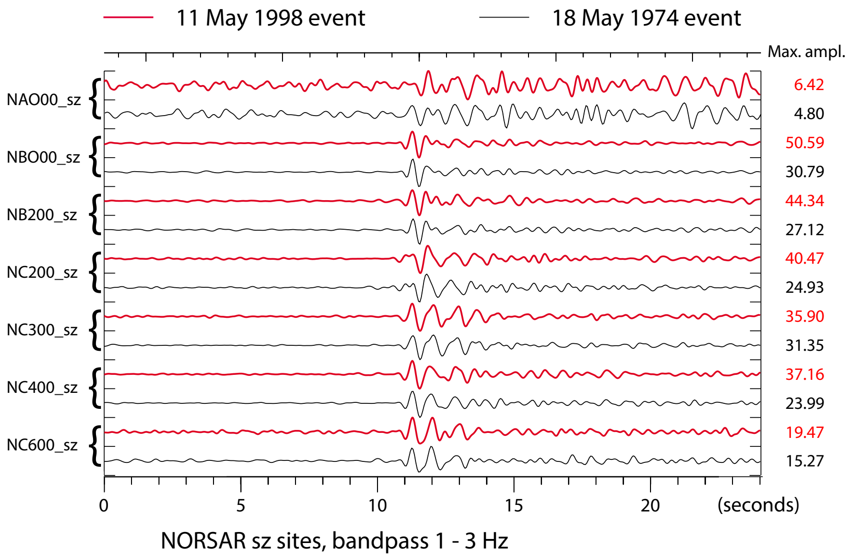


Fig. 8.5.2 *Comparison of the 1974 and 1998 Indian nuclear tests. The individual waveforms are essentially identical. (Note that the NOA array was upgraded with new seismometers in the early 1990s).*

Fig. 8.5.3 is adapted from Kværna et al. (2002b). It illustrates results from analysis of a four-hour time interval around the announced nuclear test, and it is instructive to compare the two traces in the figure. The upper trace corresponds to the GSETT-3 90 percent network detection capability, requiring at least three P detections. The lower trace is the TM results for the same 11 stations (i.e., the upper 90% limit for any seismic event that could have occurred at the site).

For this comparison, we included the NIL station in the detection capability estimation for two hours, as shown in the figure. Including one favorably located station does not significantly improve the three-station network detection capability, which is, in effect, governed not by the best station but by the third-best station in the network. In contrast, the TM approach makes full use of the NIL capabilities, which cause the monitoring threshold to be lowered by about 0.4 magnitudes when data from this station are available.

From the estimated upper magnitude limit of 2.5 (see Fig. 8.5.3), India is unlikely to have set off the claimed 0.5 and 0.3 kiloton nuclear explosions on 13 May 1998.

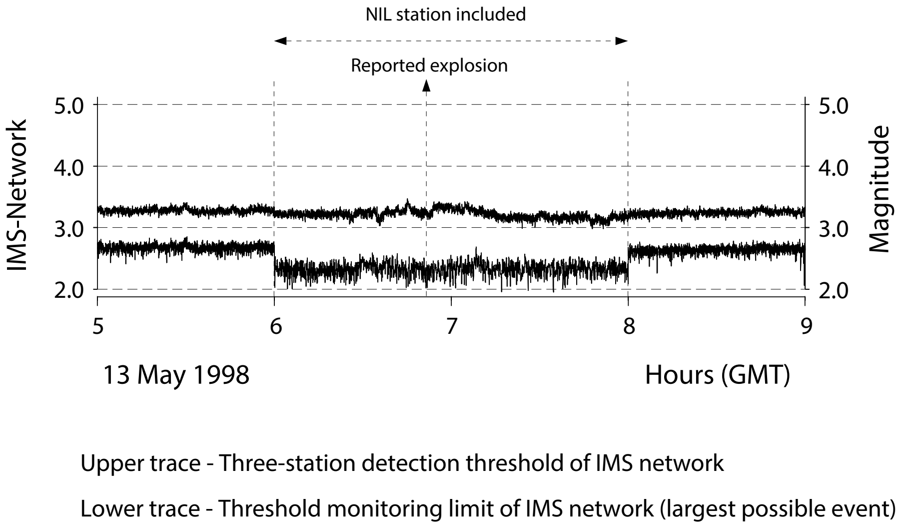


Fig. 8.5.3 *The site-specific threshold monitoring result around the reported time of the nuclear explosions by India on 13 May 1998.*

The Pakistani nuclear explosions on 28 May 1998

The explosions (announced as five separate explosions carried out simultaneously) took place near the border with Iran on 28 May 1998, with an origin time of 10.16.17 UTC. The Pakistan Energy Commission reported that the five nuclear tests generated a seismic signal of 5.0 on the Richter scale, with a total yield of up to 40 kt. As expected, both the NORSAR array processing system and the Prototype IDC detected and automatically processed the event using data from the network of IMS primary stations.

The plot in Fig. 8.5.4 illustrates the effectiveness of the site-specific threshold monitoring. The individual traces of each array show several spikes unrelated to the event, while the threshold trace shows one clear maximum at the explosion time.

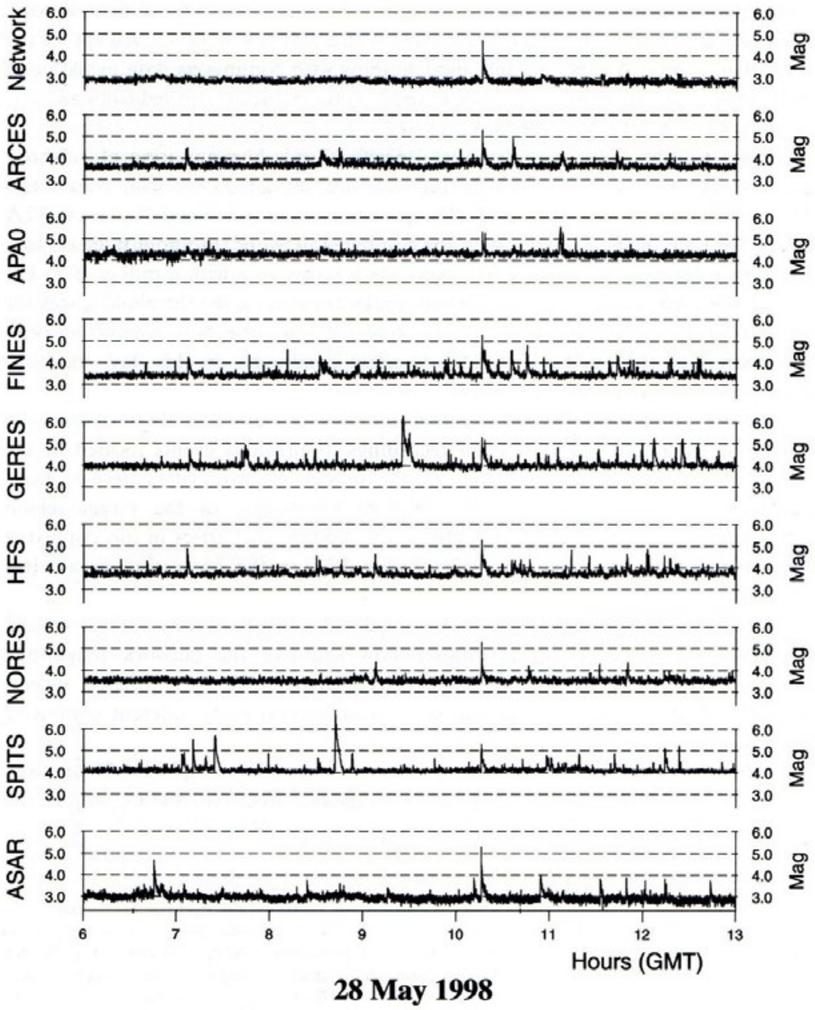


Fig. 8.5.4 *Site-specific threshold monitoring of a seven-hour time interval around the first Pakistani nuclear explosion on 28 May 1998. The plot shows individual continuous threshold traces for each of eight arrays, with the combined network threshold trace on top.*

The Paksistani nuclear explosion on 30 May 1998

This event was announced as a single explosion with a reported yield of 12 kt and took place about 100 km northeast of the explosion on 28 May. Again, NORSAR and the prototype IDC reported it. This explosion followed a large earthquake in Afghanistan (magnitude MS 6.7) about 30 minutes before the test, with several aftershocks. Although there was some degradation of the signal-to-noise ratio caused by the aftershock sequence, the nuclear test was clearly detected.

A detailed discussion of the Indian and Pakistani nuclear tests and other aspects of threshold monitoring has been presented by Kværna et al. (2002a, 2002b).

The magnitudes determined at NORSAR of the two Pakistani events on 28 and 30 May 1998, as reported to the Norwegian Ministry of Foreign Affairs, were 4.8 and 4.6. NORSAR estimated the simultaneous Pakistani explosions on 28 May 1998 to have a total yield of 5-10 kt and the 30 May 1998 explosion to have a yield of 3-5 kt.

Concluding remarks

India and Pakistan demonstrated without any doubt that they both possess nuclear weapons. The yields of the three detected nuclear explosions in May 1998 (one by India and two by Pakistan) were considerably exaggerated by both countries.

8.6 Estimating seismic network detection capability

Traditionally, seismic network detection capabilities assessments are based upon assuming statistical models for the noise and signal distributions. These models include station corrections for signal attenuation and a combinational procedure to determine the detection threshold as a function of the number of phase detections required for reliable location (Sykes and Evernden (1982) and many others).

The National Research Council (NRC) of the National Academies of the United States published in 2012 a detailed review and assessment of the CTBT with the title: “The Comprehensive Nuclear Test Ban Treaty: Technical Issues for the United States.” The world-renowned seismological experts Lynn R. Sykes, Hans Hartse, Paul G. Richards, Gregory van der Vink, and William R. Walter contributed to this study. The NRC study shows, in Figure 8.6.1, the magnitude of the smallest seismic event that would be detected with a 90 percent probability at three or more stations by the IMS primary seismic network in late 2007. Three detecting stations are generally enough to locate an event reliably.

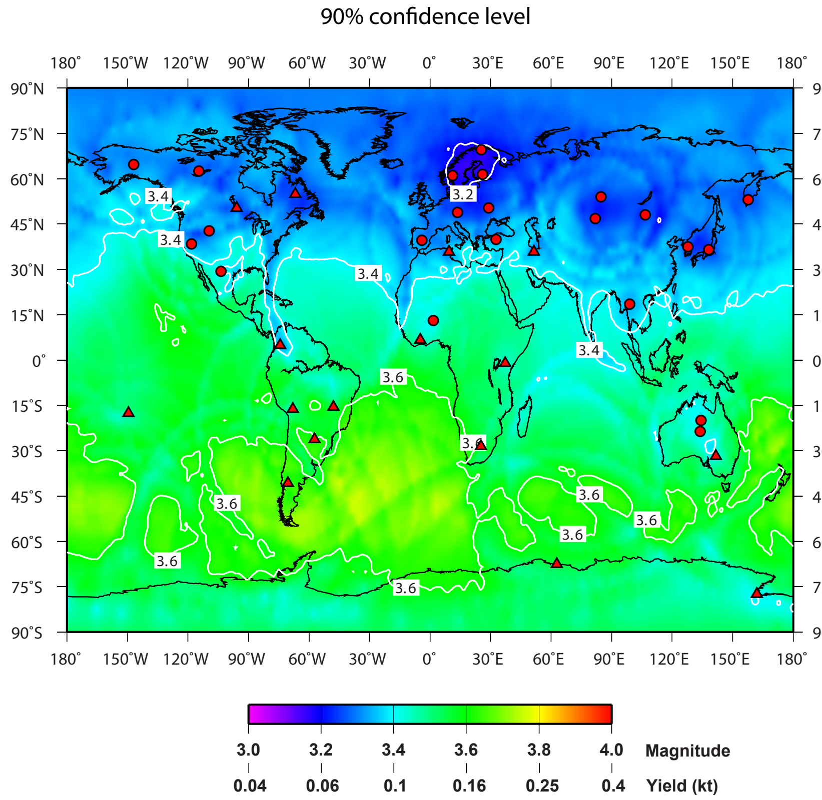


Fig. 8.6.1 *The figure is adapted from the NRC study and shows the detection capability of the global IMS network as of late 2007, with 38 stations sending data to the IDC. Contours designate the smallest seismic event that would be detected by three or more stations in the network.*

Fig. 8.6.1 was originally developed at NORSAR (by Tormod Kværna and Frode Ringdal) and was provided to the NRC study panel upon request.

We have already described the usefulness of the TM technique in discussing the nuclear tests by India and Pakistan. The above-mentioned NRC report focused on the Russian Federation and the possibilities of clandestine testing at its test site on Novaya Zemlya. As shown in Fig. 8.6.1, the detection capability (using conventional procedures) at Novaya Zemlya is in the magnitude range of 3.2-3.4.

In the NRC report, it was noted that Kværna et al. (2002a) examined data from the seismic array network in Norway and Finland (NORES, ARCES, SPITS, and FINES) using the threshold monitoring technique (which the Americans have named “smart monitoring”) for the last two months of 1997 and all of 1998.

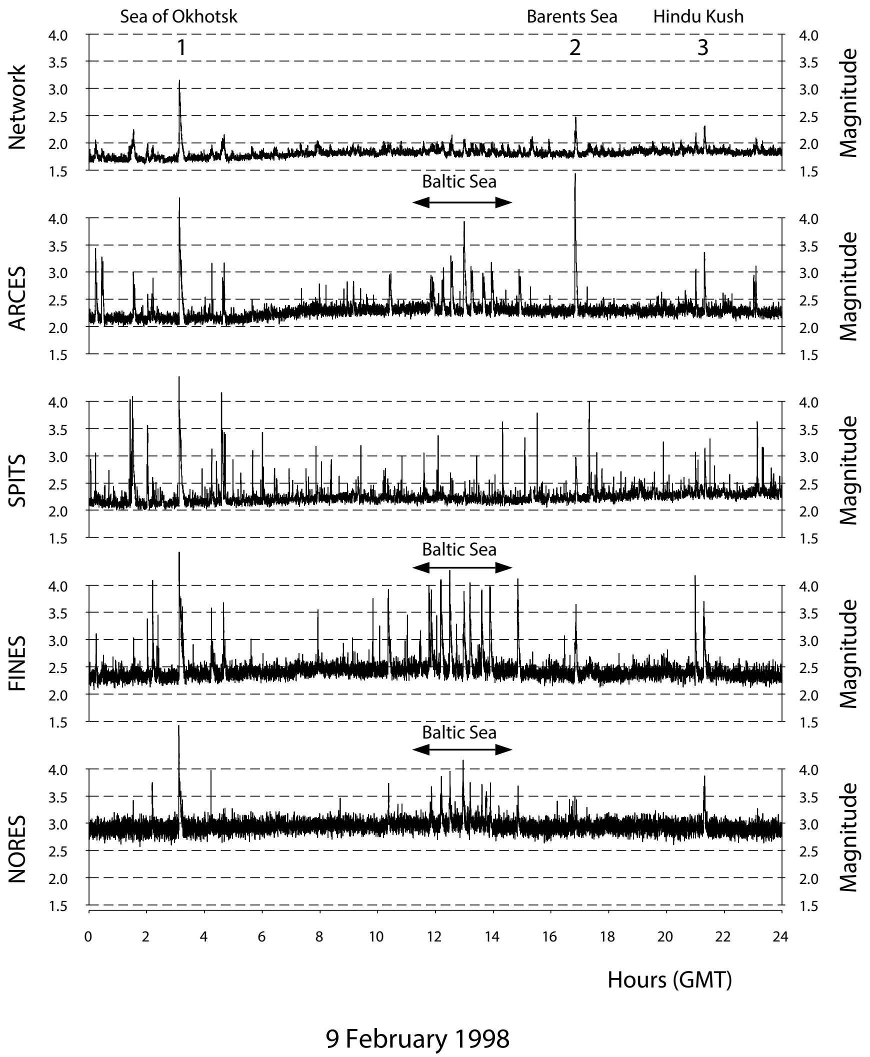


Fig. 8.6.2 Example of a site-specific threshold monitoring plot (the top trace) using the four arrays ARCES, SPITS, FINES, and NORES steered to the Russian test site at Novaya Zemlya for 24 hours on 9 February 1998.

The NRC report noted that most of the time, the threshold monitoring capability was about 2.0, corresponding to a yield of approximately one ton of TNT. For November and December 1997, all occurrences exceeding 2.5 were visually analyzed by the NORSAR authors. Kværna et al. (2002a) found that all of these threshold peaks could be explained by teleseismic, regional, or local signals from seismic events outside the Novaya Zemlya testing area. The year 1998 was not analyzed in the same detail but had similar results. See Fig. 8.6.2 for results for 9 February 1998.

In summary, the NRC panel concluded that, at 90 percent confidence, seismic events can be detected at the Russian test site at Novaya Zemlya down to magnitudes in the range of 2.0 to 2.5 corresponding to fully coupled explosions of about 5 to 15 tons (0.005 to 0.15 kilotons). The TM techniques contributes to this particularly low detection level.

We should note that only ARCES and FINES are primary stations in the CTBT network. It will be the responsibility of Norway to maintain continuous operation of SPITS and NORES without PTS support. On 16 December 1997, there was a SPITS outage, together with a severe storm across northern Norway, causing an unusually large increase in the background noise level at the other key array, ARCES (shown in Fig. 8 in Kværna et al. (2002a)). This is close to a worst-case scenario, but even so, the TM thresholds were still close to 2.5.

More recently, Tormod Kværna has developed software for a live display of seismic thresholds, which can be used either for real-time data or selected data intervals in the past. It was demonstrated on a special globe during the 2019 Science and Technology Conference in Vienna; see Fig 8.6.3.

***Fig. 8.6.3** TThe photo on the left shows the globe as demonstrated in Vienna in 2019, showing in this case an application of atmospheric transport modelling (from www.ctbto.org). To the right, the same globe during an interactive demonstration of TM, showing how a large earthquake reduces the detection capability of the IMS primary seismic network.*

A similar, somewhat smaller globe is displayed at the NORSAR data center.

8.7 Norway ratifies the CTBT in 1999

In 1999, Norway ratified the CTBT. This marked the culmination of work over several decades during which Norwegian foreign ministers had consistently called for a treaty banning nuclear tests and repeatedly stated Norway's readiness to provide NORSAR's monitoring assets to support verification of such a treaty.

Officials at the Ministry of Foreign Affairs worked hard during the autumn of 1998 and early 1999 to prepare the bill (proposition) to the parliament on Norway's ratification of the CTBT. The bill included the complete Treaty text, translated into Norwegian. Frode Ringdal advised the ministry in this regard, specifically on translating many technical terms used in the Treaty. The ministry also included in the bill an appropriation for NORSAR's expenses for 1999 concerning the CTBT, arguing that this was a consequence of Norway's ratification. The appropriation was proposed as an addition to the annual fiscal budget for 1999, which the parliament had approved in December 1998. The cabinet approved the bill on 12 March 1999 and it was subsequently forwarded to the parliament for its consideration.

The foreign relations committee of the parliament recommended that the parliament plenary give its consent to Norway's ratification of the Treaty and agree on the appropriation of the funding for NORSAR. However, the committee asked the Foreign Ministry in a formal letter why this funding was not included already in the regular budget proposal for 1999 adopted in December 1998, given that it ought to be known to the Ministry, according to the committee, that such expenses would be incurred. The Ministry responded that at the time of submitting the budget proposal for 1999, there were uncertainties about the budget implication of Norway's ratification. In the committee's recommendation, some representatives signaled that they would propose in the plenary's consideration to delay the appropriation of funds until the parliament, at a later time in 1999, would consider revisions to the 1999 budget. The decision in the parliament on 26 April 1999 was unanimous and fully in accordance with the government's bill. Fortunately for NORSAR, there was eventually no proposal to delay the appropriation of funds.

The parliament's decision on the ratification clarified NORSAR's role. The parliament designated NORSAR as Norway's National Data Center (NDC) for CTBT verification. This implies a responsibility for establishing, operating, and maintaining IMS facilities on Norwegian territory. According to this decision, NORSAR shall also advise Norwegian authorities on CTBT compliance and other technical matters related to the CTBT. NORSAR was asked to develop and maintain the competence needed to assist the authorities in conducting these CTBT verification tasks. Cutting-edge research activities in support of seismological verification were not included. These would need to be financed independently, particularly through open competition for research contract opportunities announced by United States authorities.

The parliament decided to increase the expenses in the budget for 1999 for Chapter 100, Ministry of Foreign Affairs, Item 71, Miscellaneous expenses, by 15.3 million NOK. NORSAR subsequently received this amount for 1999 from the Ministry of Foreign Affairs after confirming that the institution would take on the tasks assigned to it by the parliament. This new funding mechanism for NORSAR's test ban-related activities was the final solution after several years of interim funding from the ministry in anticipation of Norway's ratification of the CTBT. This milestone marked the end of the dependence on U.S. government funds to operate and maintain seismic arrays in Norway. It was vital to NORSAR that the CTBT-related funding be dealt with as part of Norway's ratification process. Several colleagues in other countries later informed NORSAR's representatives that the assignment of their institutions' roles had not been part of their countries' ratification processes. These colleagues had then struggled very hard to secure the funding required for their NDC tasks.

The CTBT obligates states not to carry out nuclear explosions. Ratifiers also need to pass legislation to give domestic effect to the Treaty. This implies that measures should be taken to prohibit persons anywhere on a state's territory from undertaking a nuclear explosion and its citizens from carrying out nuclear explosions elsewhere. The Norwegian parliament passed a law to this effect on 18 June 1999 (Law no. 40, 1999). Violations result in fines or imprisonment of up to five years.

The parliament emphasized in its ratification decision that, for political reasons and to promote progress in the implementation of the CTBT, Norway should act as if the Treaty had entered into force. This attitude has guided NORSAR on how to act during the PrepCom period in relation to a broad range of issues. For example, the mode of operation of IMS stations on Norwegian territory follows the operational manuals for seismic, radionuclide, and infrasound stations, which are being developed in Working Group B and contain operational requirements for the period after entry into force of the Treaty. Another example is NORSAR's response to indications that a nuclear test has been conducted. Over the years, NORSAR's analysis has gradually come closer to the arrangements foreseen for the period after entry into force of the Treaty concerning providing Norwegian authorities advice in a timely manner.

Even though the allocations in the Ministry of Foreign Affair's budget are provided for one year at a time, the positive experience from the ratification process in 1999 gave NORSAR strong hopes that NORSAR's CTBT-related activities would be funded at an adequate level in years to come. However, already for the year 2000, the funding was cut back to 13.3 million NOK. There were further cuts over the years so that the annual funding after 15 years was only about 50 percent of the amount for 1999 in real terms, i.e., after correcting for inflation and salary increases, and even after considering income to NORSAR from the PrepCom for IMS station operation (see Section 8.8). NORSAR faced this reality despite considerable lobbying in the parliament, particularly during 2000-2006, to remedy the financial situation. NORSAR's lobbyists found considerable sympathy, and many politicians from the opposition and the government sides took initiatives to improve the situation. But in the final rounds of the parliament's annual budget discussions, the amounts allocated to NORSAR were never adjusted from those in the government's proposal. Similarly, during this period of 15 years, NORSAR did not successfully convince the ministry to increase the funding level in its budget proposals to the parliament, with a few exceptions of moderate annual adjustments after 2010. As we shall see in Chapter 11, it is only from 2017 that this funding has improved and has become comparable to the level of 1999 in real terms.

8.8 NORSAR obtains status as an independent research foundation in 1999 and organizes to support CTBT verification activities

On 1 July 1999, NORSAR obtained its current status as an independent research foundation. Anders Dahle, who had succeeded Frode Ringdal in 1997 as Director of NORSAR, became the first Chief Executive Officer (CEO) of the NORSAR Foundation. As we have seen in previous chapters, NORSAR started as a project under the Royal Norwegian Council for Scientific and Industrial Research (NTNF). NORSAR later became a department of NTNF and, in 1993, a department of The Research Council of Norway (NFR), which resulted from a merger of NTNF and four other research councils in Norway.

For some time, NORSAR followed a strategy to become an independent institution when appropriate long-term arrangements could be found to fund its activities in nuclear test-ban verification. Other research institutions in the technology sector in Norway had gained such status already in the 1980s as a result of policies of NTNF. In anticipation of a solution to the funding issue, NFR and NORSAR worked together in 1998 on the formal framework for NORSAR to become an independent institution, including procedural arrangements, bylaws, and financial arrangements. With the CTBT ratification decision in the parliament in April 1999 and the funding accompanying that decision, only formalities remained for it to become an independent foundation. With the independence came an extraordinary five-year grant from NFR for strategic programs and a guarantee from NFR of a minimum level of basic funding during the same period. NORSAR became part of the group of institutes qualified to receive base funding from NFR.

The tasks assigned to NORSAR by the parliament were summarized in broad terms in Section 8.7 and are detailed below. Some of the tasks derive from Norway's obligations to the PrepCom. In contrast, others relate to national functions, such as advising and assisting Norwegian authorities and participating in meetings of the PrepCom's policy-making organs in Vienna. Employees across NORSAR's departments cooperate in executing these tasks. The Norwegian National Data Center (NDC) was established as a department at NORSAR to support operational aspects of CTBT verification, with Jan Fyen as the NDC manager.

The main CTBT verification tasks conducted by NORSAR include the following:

Establishment, operation, and maintenance of IMS stations on Norwegian territory: The six monitoring stations in Norway are shown in Fig. 8.8.1. NORSAR has established stations, or upgraded pre-existing stations, under contracts with the PrepCom (handled by the PTS), with full recovery of expenses. Contracts with the PrepCom provide partial funding for the operation and maintenance of the primary seismic stations. PrepCom covers the operation and maintenance costs in full for the radionuclide and infrasound stations. For the two seismic auxiliary stations, operational costs are borne by Norway. Operating and maintaining Norwegian IMS stations according to contractual standards place high demands on the NDC staff, who work to ensure data quality and availability meet the requirements.

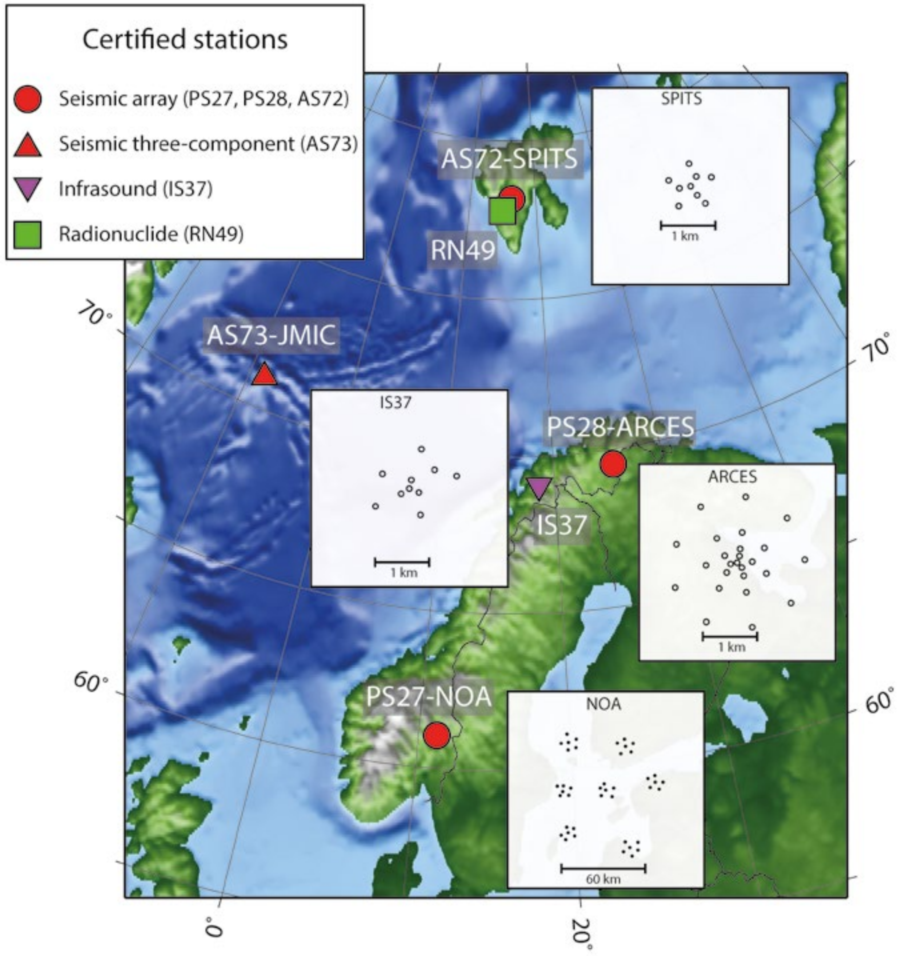


Fig. 8.8.1 The figure shows the six IMS stations on Norwegian territory. The geometrical configuration of the three seismic arrays and the infrasound station are shown.

Data transmission:
Data from the six stations are transmitted to NORSAR at Kjeller using links established by NORSAR and then forwarded to Vienna using a dedicated communications infrastructure established by the PTS. It is NORSAR's responsibility to ensure that data from these stations are transmitted to the IDC in Vienna without delay. In case of failure of some communication link, NDC staff will initiate repair and transmit the data (from a buffer at the station or at NORSAR) as soon as the link is restored. All data from Norwegian IMS stations are permanently archived at NORSAR.

Maintain contact with the PTS:
NORSAR communicates with the PTS on all technical aspects of Norway's participation in establishing and operating CTBT verification arrangements. The focus is on the performance of IMS stations in Norway and corrective actions whenever needed.

Advice and assistance to Norwegian authorities on events of special interest:
NORSAR receives information regularly from the IDC on events detected and located by the IMS. For events of particular interest to Norway, NORSAR performs independent analyses, including assessments of data from available non-IMS seismic stations. Adding such stations for events in and close to Norway, including the Arctic, can considerably improve the event detectability and location accuracy relative to events determined by the IMS alone. For announced and suspected nuclear tests, the priority is on providing detailed and timely information to the Ministry of Foreign Affairs.

Participation in technical meetings of the CTBTO PrepCom:
NORSAR represents Norway in Working Group B, as described in Section 8.3. In addition, NORSAR participates in related activities, such as specialized technical workshops on CTBT verification, some of which have been hosted by NORSAR. Bilateral or multilateral cooperation with other countries is another activity from which all parties gain advantages in their efforts to improve their capabilities.

As we saw in Section 8.7, seismological verification-related research activities did not become part of the CTBT mission for the Ministry of Foreign Affairs. Such research had been performed under sole-source contracts with ARPA and AFTAC as part of the government-to-government agreement with the United States. But from the late 1990s, funding for such research from these two U. S. agencies was drying out, and NORSAR had to look for other opportunities. The solution was to enter annual competitions for research contracts with other U.S. Department of Defense and Department of Energy agencies. From 1999 until this writing, NORSAR succeeded more or less annually in winning such contracts, typically for two years, and in competition with U.S. universities and U.S.-based industrial contractors.

On several occasions, NORSAR teamed with co-workers at the Lawrence Livermore National Laboratory on these contracts, which typically provided funds for one to two full-time employees at NORSAR annually. These contracts have covered a wide range of topics within cutting-edge verification research and have helped NORSAR stay visibly at the forefront of nuclear explosion monitoring activities.

8.9 The United States Senate rejects ratification of the CTBT in 1999

As we have noted earlier, events related to the CTBT seldom reach the headlines of international news media. An exception occurred again after the U.S. Senate, on 13 October 1999, declined to consent to U.S. ratification of the CTBT. After a short debate in the Senate, 51 senators voted "no," 48 "yes," and one abstained. Sixty-seven votes in favor were needed for a positive outcome for the Treaty proponents. Leaders in many countries, including China, France, and Russia, expressed their disappointment, as did the Norwegian Minister of Foreign Affairs, Knut Vollebæk.

Fig 8.9.1 shows part of an article in the Norwegian newspaper Aftenposten on 15 October 1999, focusing on President Clinton's ambition to eventually obtain U.S. ratification despite this setback. It is interesting to note the picture of Senator Joseph Biden, despairing over the outcome of the vote. Will he make another attempt during his presidency, more than 20 years later?

As we have commented earlier, the US Senate's "no" to the CTBT diminished much of the enthusiasm of those looking forward to an early entry into the force of the CTBT. Completing the IMS and the IDC was no longer perceived as urgent. The view that one should adapt the pace of establishing the verification regime to the prospects of entry into force of the Treaty was gradually gaining support. The new U.S. administration in 2001 under President George W. Bush did not want to pursue ratification of entry into force of the CTBT. The U.S. delegates in the PrepCom and WGB stated that they would support the further development of the IMS and the IDC and continue their involvement in these matters.

On the other hand, they announced that they would not participate in activities related to the OSI program since on-site inspections can only occur after entry into force of the Treaty. It was a great loss to the OSI discussions in WGB not to have access to the U.S. expertise during 2001-2008. However, under the Obama administration, which began in 2009, the U.S. delegation was back in full force on all subjects of WGB, which helped the OSI discussions

gain momentum. The United States also paid outstanding dues accumulated during the Bush administration.

UTLAND

Fredag 15. oktober 1999 Aftenp

Clinton vil kjempe videre for prøvestans

USAs president ber andre land om å godta prøvestansavtalen, og sier at USA til slutt også vil gjøre det.

Aftenpostens korrespondent
MORTEN FYHN
Washington

Bill Clinton advarte i går, dagen etter at Senatet hadde sagt nei til å ratifisere traktaten som forbyr alle atomprøver, mot tegn til isolasjonisme i det republikanske parti.

– Flertallet sier med sitt nei at USA ikke trenger å lede an i verden, at USA ikke trenger venner og allierte, sa presidenten. Han stemplet det republikanske flertallsvedtaket som partipolitikk av verste slag, og lovet at han ikke vil slutte å kjempe for traktaten.

– Jeg er ikke i tvil om at USA til slutt vil ratifisere traktaten, sa presidenten, som innstendig ba andre land om også å gjøre det.

Usikker fremtid

Men etter det forsmedelige nederlaget vil det i praksis være helt nytteløst for Clinton og demokratene å gjøre et nytt forsøk på å få Senatet til å vedta prøvestansavtalen. Og det trengs et formidabelt demokratisk valgskred neste år, dersom Senatet skal endre oppfatning. Et slikt skred regnes i dag som utenkelig.

– Visepresident Al Gore lovet etter voteringen å arbeide hardt for traktatens godkjennelse, dersom han blir USAs neste president. Også hans utfordrer, Bill Bradley, støtter traktaten. Den republikanske favoritten, George W. Bush, er imidlertid imot den, selv om han støtter USAs frivil-

Nederlag. *Senator Joseph Biden må innse at slaget er tapt for demokratene, som i likhet med USAs president Bill Clinton kjempet for ratifisering av prøvestansavtalen.*
FOTO: SCANPIX/REUTERS

fakta

CTBT-avtalen

▼ Internasjonalt totalforbud mot atomprøvesprengninger er et nøkkelelement for å kontrollere utvikling og spredning av atomvåpen.

▼ CTBT-avtalen – den utvidede prøvestansavtalen – ble vedtatt i 1996 og har som mål å stanse spredningen av atomvåpen.

▼ Forbud mot atomprøvesprengninger, både i atmosfæren og underjordisk.

▼ Omfatter ikke tester som fører til små eksplosjoner som ikke utløser en kjernefysisk kjedereaksjon.

▼ Med CTBT-avtalen forplikter de fem atom-stormaktene USA, Frankrike, Storbritannia, Kina og Russland seg til å redusere sine arsenaler.

▼ Alle fem stormaktene har undertegnet avtalen, men bare

«Atomsopp». *Amerikanerne vil ikke forby fremtidige prøvesprengninger. Dette er en av de mange som ble foretatt i USA på 50-tallet.*
FOTO: SCANPIX/REUTERS

tive republikanere anført av utenrikskomitéens leder Jesse Helms sa nei. Etter deres mening er traktaten skadelig for USA. De ga klar beskjed om at de ikke synes det er i USAs sikkerhetspolitiske interesse å binde seg til ikke i fremtiden å foreta tester av sine atomvåpen. De hadde heller ingen tro på at et amerikansk ja til traktaten ville få noen som helst positivt effekt i land som Irak. Iran

Forrige gang var i 1919, da Senatet avviste Versailles-traktaten til tross for at president Woodrow Wilson sterkt anbefalte et ja.

Dårlig håndverk

I analyser og kommentarer i går i USA ble det påpekt at både presidenten og demokratene gjorde et dårlig politisk håndverk. Hvorfor ville man ha traktaten behandlet i Senatet når man visste at den ikke hadde en

Solana
skal
avvikl
Vest-
unione

Javier Solana,
nyutnevnt koor
nator for EUs f
sikkerhets- og u
rikspolitikk, bli
generalsekretæ
i Vestunionen.

JAN-ANDER
EKSTRØM
Helsingfors

I sin nye rolle
mer Solana i
til å avvikle Ve
nen og overføre
av funksjonene
Dette fremgår
forslag som Fi
egenskap av fo
i EU dette ha
har utarbeidet
nas fullmakter
mer trolig til å
kutert på EUs
ordinære topp
Tammerfors i d
morgen.
Det skal ha v
store EU-la
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ke som tok initi
å koble Solana
spørsmålet om
fremtid. Sake
lenge kontro
fordi blant
Storbritannia
et kritisk syn
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Vestunionen
grunnlagt åre
NATO, i 1948, o
allianse uten
styrker. 10 av
medlemsland e
lemmer i VE
andre har obse
status, mens N
assosiert medle
Etter det
som Finland
ger frem i sam
med Luxem
skal Solanas sa
ningsoppdrag

Fig. 8.9.1 Article in Aftenposten after the U.S. Senate rejected the CTBT.

Chapter 9

2000 - 2005
Station certifications, the Kursk accident and a tsunami

9.1 The NOA array (PS27) certified as the first station in IMS

A proud moment for the NORSAR staff occurred when the PTS on 28 July 2000 selected the station NOA (PS27) to be the first of 337 technical facilities of the International Monitoring System (IMS) to be officially certified! Two other IMS seismic primary stations, at Yellowknife, Northwest Territories, Canada, and at Mina, Nevada, U.S., were certified in the same meeting of the PTS. This selection was a recognition of Norway's substantial contributions to the work that led to the Treaty. The PTS wrote in a press release a few days later:

"For 30 years, the array station at Hamar has demonstrated some of the best capabilities in the world for detecting seismological events and, through Norwegian research programmes, has contributed significantly to the development of seismological verification techniques. The Hamar station, like the Yellowknife station, can detect seismic events occurring up to 10,000 kilometres away down to a seismic magnitude of less than 4 (equivalent to a yield of 1 kiloton). These excellent results led, during the negotiations on the CTBT, to the selection of many other seismic array stations to form part of the seismological network to monitor compliance with the Treaty's ban on nuclear explosive tests."

The certification process for stations of the IMS involves a collaboration between the PTS and station operators. It is designed to ensure the fulfillment of the stringent requirements of the CTBT's global verification regime. These include both hardware specifications and operational standards. The issuance of a certificate is thus a formal confirmation that the station is ready to fulfill its mission after entry into force of the Treaty.

An in-situ visit to the station by PTS personnel may be conducted as part of the certification process to check and assess infrastructure and equipment, carry out tests of various kinds, and communicate with personnel at the IDC in Vienna to verify that data received there are in accordance with the expectations. For example, opening a lid or a door to gain access to a seismometer in the field shall result in an immediate alarm clearly noticeable at the IDC.

The NOA array was modernized in the 1990s in a cooperative effort between Norway and the United States, as described in Section 7.3. It turned out that this upgrade met the basic technical specifications that were later determined for IMS stations. NOA could thus be certified following some specific further enhancements, which included installing tamper detectors at all seismometer and central subarray vaults, providing for the authentication of data throughout the array, ensuring a connection to the Global Communications Infrastructure of the CTBT verification regime, and installing one Güralp CMG-3T broadband seismometer.

Equipment and software at IMS stations will become obsolete over time and need to be replaced or refurbished at intervals of typically ten to fifteen years, or possibly longer in some instances. The CTBTO PrepCom covers the costs for such replacements for all IMS networks except the auxiliary seismic stations. Thus since 2010, the CTBTO PrepCom budget has provided for the recapitalization of IMS stations.

NOA was one of the first stations to receive funding from this budget chapter. A contract between NORSAR and the PTS provided for a full replacement of seismometers and digitizers of the NOA array during 2011-2012. Seismometers from Teledyne Geotech and digitizers from Science Horizons were replaced by equipment from Güralp Systems. Following such substantial changes, the station was subjected to a formal revalidation process with the PTS to retain its certificate.

NOA is by far the largest array in the IMS. A unique feature of the NOA array is its library of digital data that has been retained for numerous nuclear explosions and earthquakes dating back to 1970. The data were originally stored on magnetic tapes but were later converted to mass storage facilities for convenient access and permanent storage. The pictures in Figs. 9.1.1-9.1.3 show some features of the array after the last modernization effort in 2011-2012.

Fig 9.1.1 *Winter-time inspection of the center of subarray 01A (see Fig. 4.2.1 for map).*

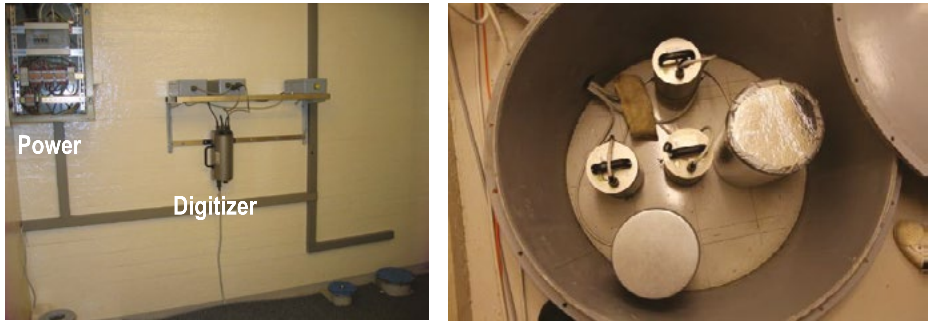


Fig 9.1.2 *Photos from inside the central vault at subarray 06C.*

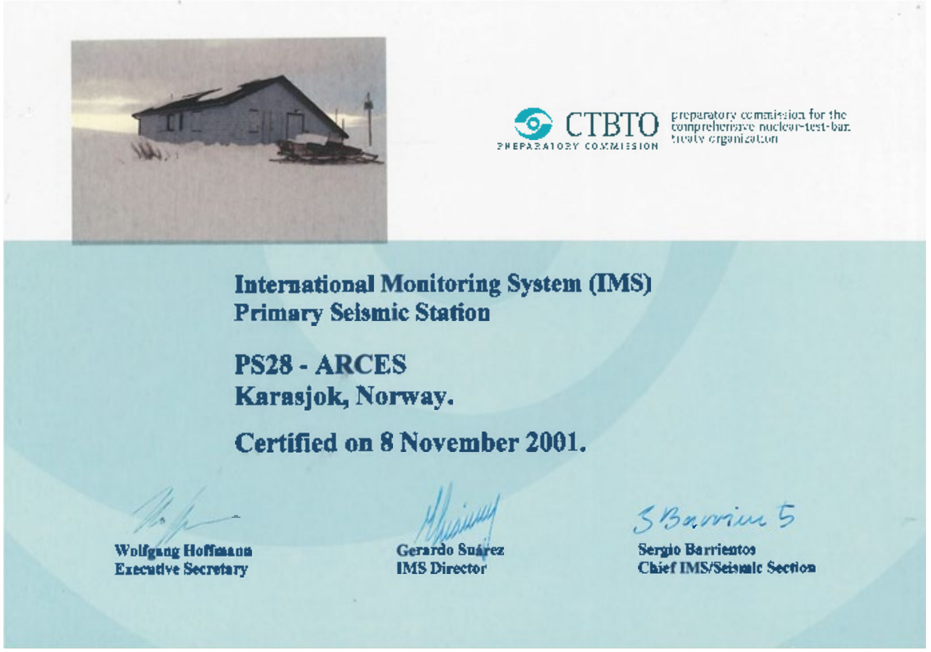
Fig 9.1.3 *The picture shows Dr. Cansun Güralp at the Stendammen test facility, in a seismic vault next to Güralp seismometers, of which he was the inventor.*

When an IMS station has been certified, it qualifies for funding from the CTBTO PrepCom for operation and maintenance through so-called Post-Certification Activities (PCA) contracts. As noted previously, the CTBTO PrepCom does not cover operational expenses for stations in the auxiliary seismic network, which in Norway includes stations on Jan Mayen (AS73) and at Longyearbyen, Svalbard (AS72). The respective host countries must fund the operation of stations in this particular network.

In 2003, the PTS asked Norway to contribute to the costs for NOA (PS27) and ARCES (PS28) in order to save money in the PrepCom's budget. After negotiations with the Norwegian Ministry of Foreign Affairs, it was agreed that the PrepCom would contribute 61% and 69%, respectively, of the actual operating costs of these stations. This cost-sharing model has been applied until the time of completion of this manuscript and may be revisited in the future. For the radionuclide station at Longyearbyen (RN49) and the infrasound station at Bardufoss (IS37), the PrepCom's budget provides for the full operational costs.

9.2 ARCES (PS 28) certified in 2001

ARCES (PS28) was initially constructed in 1987 and was selected in 1999 by the PTS for an upgrade in preparation for its certification. This effort was funded by the IMS station installation program and was completed in 2001. The modernization amounted to replacing all digitizers and seismometers and installing a centralized authentication process. After a period of testing and evaluation, the PTS formally certified the station on 8 November 2001 (see Fig. 9.2.1).



CTBTO
PREPARATORY COMMISSION
preparatory commission for the comprehensive nuclear-test-ban treaty organization

International Monitoring System (IMS)
Primary Seismic Station

PS28 - ARCES
Karasjok, Norway.

Certified on 8 November 2001.

Wolfgang Hoffmann
Executive Secretary

Gerardo Suárez
IMS Director

Sergio Barrientos
Chief IMS/Seismic Section

Fig 9.2.1 *Certificate for ARCES (PS28) issued by the PTS on 8 November 2001.*

After ARCES (PS28) certification, the array was refurbished during 2014-2016 through a contract with the PTS. This modernization involved a substantial effort (see Box 9.2.1).

ARCES (PS28) was revalidated by the PTS in October 2016, following a mandatory period of testing after the completion of the refurbishment. The pictures in Figs. 9.2.2-9.2.4 are taken during this refurbishment effort.

BOX 9.2.1

Elements of the ARCES refurbishment 2014-2016

- *New Güralp hybrid surface sensors*
- *The same Güralp digitizer as used for PS27, IS37, and AS72*
- *75 channels sampled at 40 Hz transmitted to the Norwegian NDC, the IDC and AFTAC*
- *Data sampled at 80 Hz for the nine sensor sites closest to the array center were transmitted to the Norwegian NDC*
- *All pit boxes inside the 25 seismic vaults were replaced; new lightning protection and grounding were implemented*
- *The cabin at the center of the array was completely renovated, and a new UPS system with seven-day power backup was installed*
- *A new central data acquisition system was installed in the cabin.*

Fig 9.2.2 *Preparing for the refurbishment of instrumentation at one of the seismometer sites by uncovering the vault.*

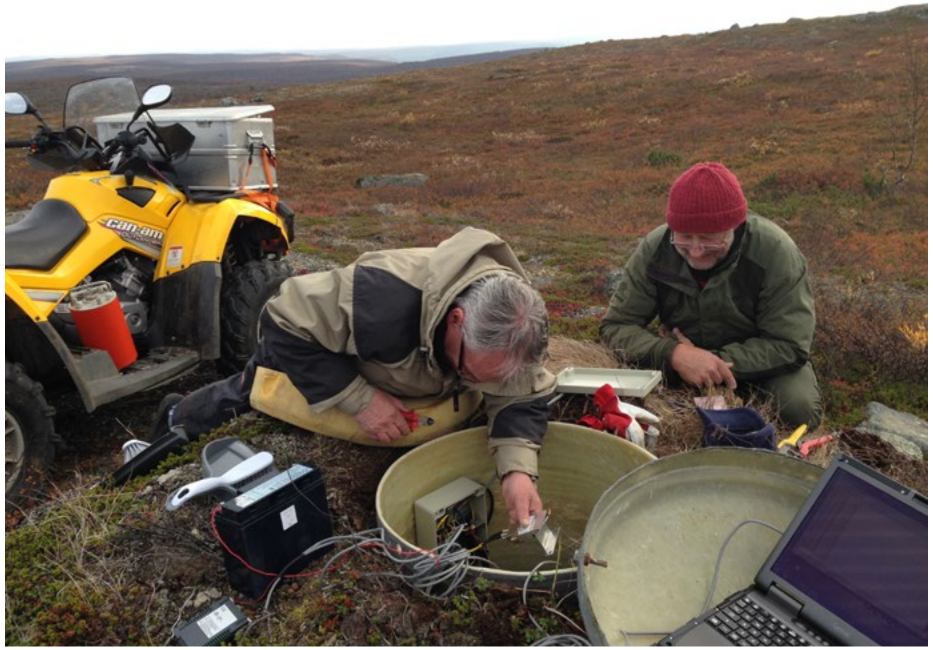


Fig 9.2.3 *The picture shows NORSAR's field engineers, Paul W. Larsen and Kjell Arne Løken, upgrading the instrumentation inside one of the vaults.*

Fig 9.2.4 *Photo taken inside the ARCES central building during the refurbishment of the data acquisition system.*

9.3 Radionuclide station in Longyearbyen (RN49): Particulate component certified in 2003, noble gas component certified in 2012

The 80-station IMS radionuclide network includes a station near Longyearbyen in Svalbard. The PrepCom selected this station to be among those 40 IMS radionuclide stations that will also monitor for the presence of relevant noble gases upon entry into force of the CTBT. The presence of specific radioactive xenon isotopes is strongly indicative of a nuclear explosion.

NORSAR, in cooperation with the Norwegian Radiation and Nuclear Safety Authority, conducted a site survey for this station in August 1999. The site survey report to the PTS contained a recommendation to establish this station at Platåberget, near Longyearbyen. The company Kongsberg Satellite Services (KSAT) had established the Svalbard Satellite Station (see Fig. 9.3.1), a ground station for controlling and acquiring data from polar-orbiting satellites at Platåberget in 1997, and had available indoor space for rent for the radionuclide station. Moreover, the topography at Platåberget is favorable for capturing airborne radionuclides. The PTS accepted NORSAR's recommendation for the location of the radionuclide station RN49 at KSAT's facility.

The infrastructure for housing the station equipment was established in early 2001. Based on the Swedish "SAUNA" design, a noble gas detection system was installed at this site in May 2001 as part of the PrepCom's noble gas experiment. A particulate station ("ARAME" design) was installed at the same location in September 2001 (see Fig. 9.3.2). A certification visit to the particulate station took place in October 2002, and the particulate station was certified on 10 June 2003. Both systems underwent substantial upgrading in May/June 2006. The noble gas system was certified on 21 December 2012. The equipment at RN49 is being maintained and operated under a PCA contract with the PTS. NORSAR has engaged KSAT as a subcontractor to deliver services related to the daily operation of RN49.

Fig 9.3.1 *Aerial photo of KSAT's facility at Platåberget in Longyearbyen. The IMS radionuclide station RN49 is hosted within the main building at the center-right of the photo.*

Fig 9.3.2 *The picture shows the particulate component of the IMS radionuclide station in Longyearbyen, with its air sampler and detector. Paper filters are exposed for 24 hours, then rested for 24 hours, and then measured for the content of radioactive isotopes.*

9.4 The Kursk accident

The tragic accident of the Russian submarine Kursk in the Barents Sea on 12 August 2000 was one of the events that year that created the most international attention. On that day, the ARCES array sensors recorded two unusual seismic disturbances off the coast of the Kola Peninsula. The first one, at 07.28.27 UTC, was relatively weak and had a Richter magnitude of 1.5. The second disturbance, occurring 2 minutes and 15 seconds later, was far more powerful and measured 3.5 on the Richter scale.

It soon became clear that these two seismic events were located in the area where the sinking of the Kursk had occurred and that they were connected with the accident. NORSAR's interactive analysis gave a location within five km of the site of the accident.

A detailed analysis of the seismic signals showed that both of the events, in all likelihood, were underwater explosions. The first explosion was relatively weak and could be observed only at the closest station (ARCES) in Finnmark, northern Norway, at a distance of about 500 km. The second, much more powerful explosion, was observed on all the Norwegian IMS seismic stations, from Spitsbergen in the north to Hedmark in the south, and was also recorded at some monitoring stations outside the Nordic countries (see Fig. 9.4.1).

The accident first became known to the general public on Monday, 14 August, although the initial Russian statement indicated that the accident had occurred on Sunday, 13 August. NORSAR reported the preliminary results of its analyses to the Ministry of Foreign Affairs on Tuesday, 15 August, and submitted a press release to the public on Friday, 18 August.

The most important information NORSAR could provide on this matter was the presentation of specific evidence of the characteristics and timing of the recordings. This material was extensively used in subsequent media coverage.

The official Russian report on the accident, issued in 2002, concluded that one of Kursk's torpedoes exploded onboard. This explosion led to a fire in the foremost torpedo room, which triggered a larger explosion of torpedoes. NORSAR's observations are consistent with the descriptions in this report.

Moore (2002) presents a detailed description of the Kursk disaster and the failed rescue attempts. The book also describes NORSAR's role in detecting the disaster.

Later in 2000, NORSAR recorded a sequence of underwater explosions in the Barents Sea. These explosions had no counterparts in all the years preceding the Kursk accident. The events caused much concern, especially in northern Norway. NORSAR issued a press release indicating the possibility that the explosions were intended to keep foreign submarines away from the Kursk wreck. The Russian Government finally published a statement indicating that these explosions were intended to "protect" the submarine without going into details.

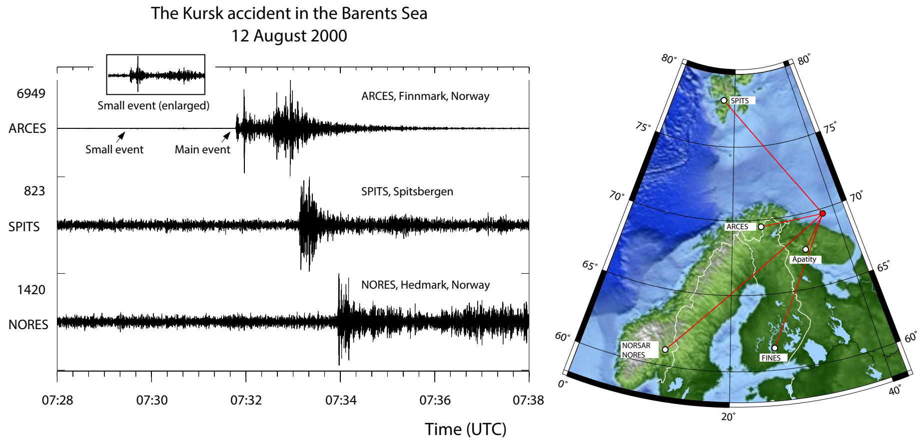


Fig. 9.4.1 Following the Kursk accident, two seismic signals were recorded at the ARCES array. The first signal was from the initial explosion, while the second, much larger explosion was recorded by many of the CTBTO IMS stations.

9.5 The devastating tsunami earthquake in Indonesia (26 December 2004)

At about 0100 UTC on 26 December 2004, a magnitude 9.1 earthquake occurred 30 km below the sea floor near Ache on Sumatra in northern Indonesia, generating a powerful wave resulting in the strongest tsunami the world had seen in over 40 years.

A tsunami - Japanese for "harbor wave" - is a series of powerful waves caused by the displacement of a large body of water. Most tsunamis, like the one that formed off Indonesia, are triggered by underwater tectonic activity, such as earthquakes and volcanic eruptions.

The tsunami and its aftermath resulted in immense destruction and loss on the rim of the Indian Ocean. The tsunami is estimated to have killed at least 240,000 people across a dozen countries. There is little doubt that thousands of lives could have been saved if an alert system similar to that operating in the Pacific Ocean since 1965 had been in place in the Indian Ocean region.

As a consequence of the tsunami, the PrepCom took the initiative to provide IMS real-time data on a test and experimental basis to tsunami warning centers in Japan and Hawaii. This was implemented, and the PTS conducted tests in 2005 and 2006. The Member States then agreed in November 2006 to regularly provide real-time, continuous IMS data to tsunami warning organizations, based on individual agreements with the PrepCom. As of 2020, 18 tsunami warning centers in 17 countries receive data from about 100 seismic and hydroacoustic IMS stations. There is no question that such access to IMS data for tsunami warnings represents a major contribution by the PrepCom, as such data may help reduce the loss of lives and property due to natural disasters.

Providing access to IMS data and IDC products (especially bulletins) for scientific and civil use has been a contentious issue with WGB since the beginning of the PrepCom in 1997. Several member states believe that, in principle, IMS data should be available only to the designated CTBT national data centers for their use concerning their CTBT mission. Other states promote the view that IMS data should be openly available. Over the years, it has been very challenging for Working Group B to unite these views and find agreement. Even for the noble cause of providing data to tsunami warning centers, it took nearly two years to agree on a solution, as we saw above. Nevertheless, a step-by-step approach has yielded some successes, examples of which are the provision of IDC bulletins to the International Seismological Centre in the UK for use in the production of its own seismic bulletin and the creation by the PTS of its Virtual Data Exploitation Centre (vDEC) arrangement for access to IMS data by researchers who sign a legal data confidentiality agreement with the CTBTO PrepCom.

Norway and NORSAR have consistently promoted open access to IMS data and worked with others in various capacities towards this end, with some limited success, as we saw above. One way to inspire openness is to make data from one's own IMS stations available to all that request the data. Norway adopted this approach at an early date and has never been challenged regarding this practice. NORSAR, as the host of the National Data Center for Norway, has access to data from IMS stations in all countries. However, requests to NORSAR for data from a non-Norwegian IMS station are referred to the station's host country unless NORSAR has an agreement with that country to redistribute data on its behalf.

9.6 Workshops on location calibration

An on-site inspection (OSI) is the final verification measure under the CTBT. It follows up on suspicious but inconclusive evidence of a nuclear explosion obtained by the CTBTO global network of monitoring stations (IMS). The area of an on-site inspection is restricted to the following: it shall be continuous, it shall not exceed 1000 square kilometers, and there shall be no linear distance greater than 50 kilometers in any direction.

Once the CTBT has entered into force, a State Party can request an on-site inspection if it suspects another State has conducted a nuclear explosion. The inspection is authorized to proceed if approved by at least 30 of the 51 States Members of the organization's executive body, the Executive Council.

The limitation in the size of the area for an on-site inspection means that a suspicious seismic event must be located with an accuracy of 18 kilometers or less (a circle with a radius of 18 kilometers covers an area of about 1,000 square kilometers). When a small seismic event occurs, usually there will be only a few seismic stations that detect the event, and the event location can therefore be quite uncertain. However, by calibrating the network, it is possible to reduce the uncertainty in the location procedure significantly.

The first location calibration effort for IMS seismic stations was arranged by NORSAR at a workshop in Oslo in 1999. Another four such workshops took place in Norway in the following years (see photo from the 2003 workshop in Fig. 9.6.1). Up to 60 experts from 15 countries attended the workshops. The conclusions of each workshop were presented to Working Group B in Vienna. Gradually, the results found their way into the IDC processing and contributed to reducing the location errors.

Fig 9.6.1 Participants at the calibration workshop at the Holmenkollen Park Hotel in Oslo in May 2003.

Besides the location and calibration efforts, the CTBT has caused seismologists to redouble their efforts in other areas. For example, Brian J. Mitchell from Saint Louis university in the USA took an initiative to establish a series of seven volumes in the journal Pure and Applied Geophysics under the heading "Monitoring the Comprehensive Nuclear-Test-Ban Treaty". The volume on "Seismic Event Location" (see Fig. 9.6.2) was edited by Frode Ringdal and Brian Kennett from the Australian National University in Canberra. The volume contains 20 papers and led to an improvement in the methodologies used for estimating seismic event locations in most parts of the world.

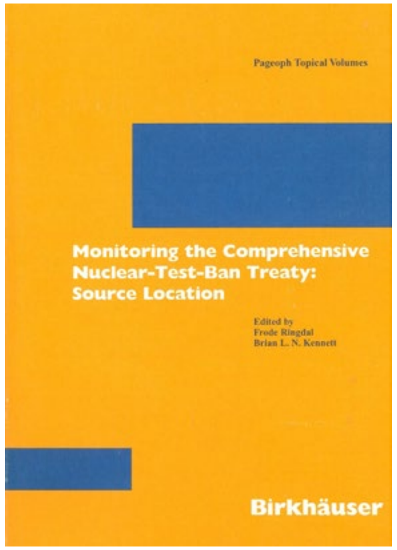


Fig 9.6.2 Front page of the special volume of the journal Pure and Applied Geophysics, containing 20 papers on source location.

9.7 Additional technical support by NORSAR to the PrepCom

It was clear from the beginning that the operation of the monitoring systems would require substantial technical assistance from the States Signatories. NORSAR staff were key participants in a number of such activities, such as the workshops on the operation and maintenance of the IMS, the biannual scientific and technical meetings ("SnT" conferences) in Vienna, annual NDC workshops in member countries, and work on more specialized topics such as reviews of computer technology and assessments of the daily bulletin production.

In particular, Jan Fyen was chairperson for an expert group that considered computer technology. The mandate of this group was:

- Based on material to be provided by the IDC, review the adequacy of the existing hardware at the IDC for carrying out the testing and evaluation functions currently envisaged for the PTS, and assess the needs for improvements and modernizations.
- Consider various options that would improve the cost/effectiveness of the IDC hardware/software, taking into account recent developments in computer technology.
- Make recommendations for changes that would support both the short- term and long-term needs of the IDC. These suggestions should take into account that any changes will need to take place in well-defined stages, to assure the availability of an operational system at the IDC at all times.

The group delivered its report in 2004, and its recommendations set the direction for the improvements and modernizations of the IDC hardware and software.

The PTS is also issuing contracts, on a commercial basis, to support its activities. NORSAR has pursued such opportunities and has performed work for the PTS on several topics, such as seismic array tuning and threshold monitoring. Also, based on contracts with the PTS, NORSAR hosted training courses for operators of IMS seismic stations around the world in 1998 and 1999 and an NDC workshop in 2002.

Chapter 10

2006 - 2010
Nuclear tests by North Korea and international cooperation on many fronts

10.1 North Korea's nuclear tests

On 9 October 2006, North Korea (DPRK) announced that it had conducted a nuclear weapon explosion at its test site at Punggye-ri near Kimchaek (see Fig. 10.1.1). This first DPRK test was detected by several stations in IMS, including NORSAR's arrays, and reported by the IDC of the PTS with an origin time of 01.35.27.6 UTC and a magnitude of 4.1 on the Richter scale.

The first information received by the National Earthquake Information Center (NEIC) of the USGS in the United States regarding the event came from a major media outlet in Japan approximately 30 minutes after the reported occurrence. Consequently, the staff of the NEIC was able to locate and report the event independently of the PTS IDC and assign a magnitude of 4.2 to the explosion. NORSAR informed the Ministry of Foreign Affairs in the morning and issued a press release, which resulted in several interviews with national media during the day. At the time of this first nuclear test by North Korea, NORSAR had not yet implemented a specific alert system with automatic alarms around the clock. Today, an alert team at NORSAR provides a timely response to such events, as described in Section 11.3.

The event in the DPRK presented a real-life test case for the CTBT verification system. Although the verification regime was only partially completed and operating in test mode, it proved that it was capable of meeting the expectations set for it. The automatic process correctly associated the event and reported it in its initial standard event list within one hour (LeBras et al., 2007) of the event. The Reviewed Event Bulletin (REB) accurately located the event, and the PrepCom's

Executive Secretary informed the States Signatories of the event the same day. It is important to note that the IDC did not depend on the announcement by North Korea of the explosion in order to process and report the data.

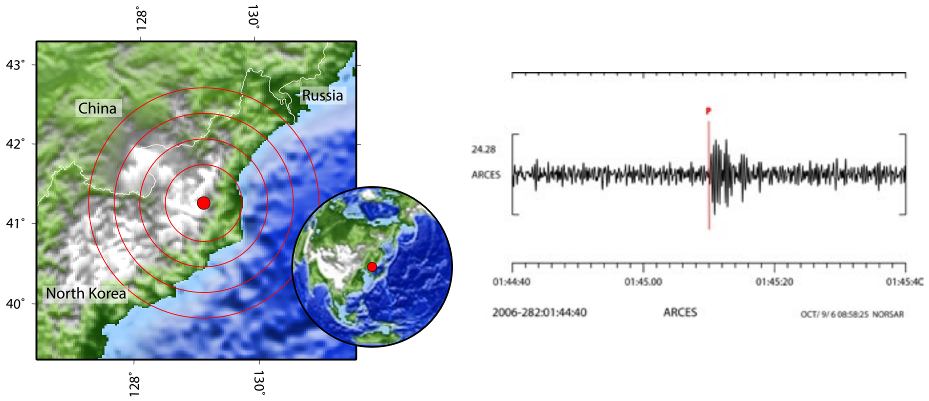


***Fig. 10.1.1** North Korea's first nuclear test with its signal as recorded by ARCES.*

NORSAR estimated the capability of the global seismic network to monitor the DPRK test site for possible future explosions. NORSAR's analysis was based on the Site-Specific Threshold Monitoring (SSTM) approach (Kværna et al., 2007). Using actual seismic data recorded by a given network, SSTM calculates a continuous "threshold trace," which provides, at any instance in time, an upper magnitude limit on any seismic event that could have occurred at the target site at that time. It is estimated that during periods with normal background noise conditions at the key IMS stations (KSRS in South Korea and USRK in eastern Russia) used for monitoring the DPRK test site, the SSTM method would impose an upper magnitude limit of about 2.0 on any hypothetical event which might have occurred at the test site.

How could it be verified that the 9 October 2006 event was, in fact, nuclear, independent of the DPRK's announcement? The seismic data strongly indicated that the event was an explosion, not an earthquake. But could it have been an underground chemical explosion with all explosive material detonated simultaneously? Such chemical explosions, even of magnitude 4 (i.e., approximately 0.5 kiloton TNT equivalents), are feasible and have been carried out in the past. As we have seen earlier, radioactive noble gases like xenon are diagnostic of underground nuclear explosions. In the days and weeks following the event, atmospheric transport modeling was used to backtrack observations of radioactive xenon, which led to the area of the DPRK's test site, thus strongly indicating that the DPRK had, in fact, carried out a nuclear explosion. The test was condemned by political leaders worldwide, and the DPRK was subject to sanctions imposed by the UN Security Council.

As is now well known, the DPRK has carried out an additional five nuclear tests (see Fig. 10.1.2), the last one (as of this writing) in 2017. The DPRK claimed that the 2017 test was a thermonuclear explosion with a much higher yield than the previous ones. NORSAR estimated the power of the 2017 test to be about 250 kilotons. Radionuclide xenon gases that might be attributed to releases from nuclear tests in the DPRK were also detected at various stations following the explosions in 2013 and 2017.

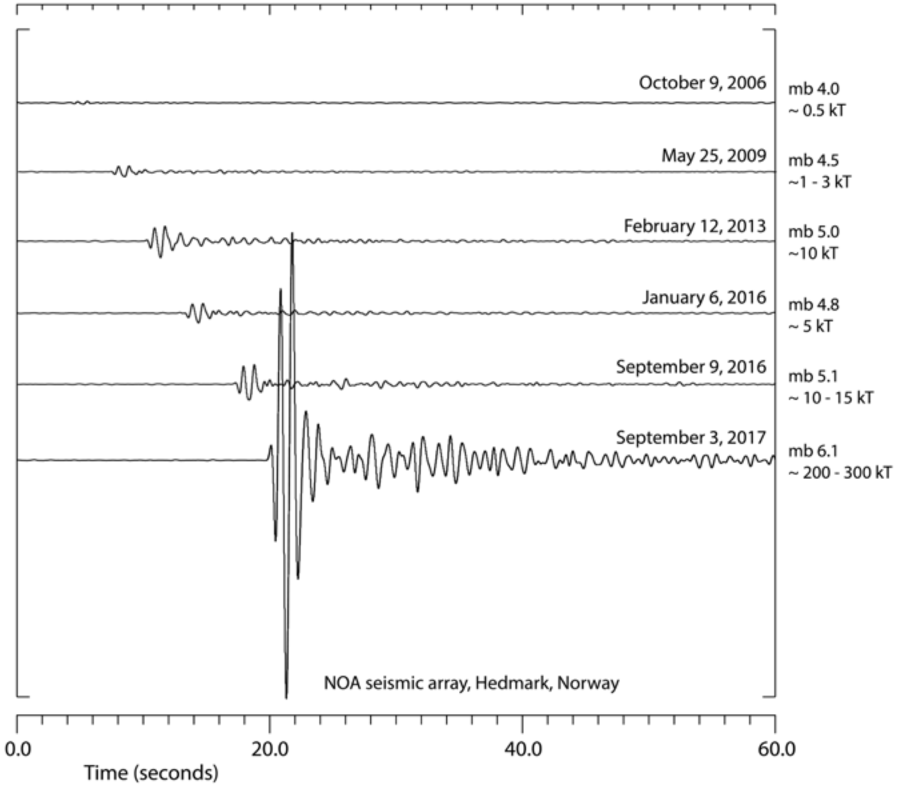


***Fig. 10.1.2** The increasing size of DPRK nuclear tests from 2006 through 2017. Magnitudes and yields to the right of each trace are NORSAR's estimates based on its own analyses.*

NORSAR scientists have investigated the relative locations of the DPRK nuclear tests using empirical slowness corrections and have published the results in the Geophysical Journal International (Gibbons et al., 2017). Fig. 10.1.3 shows NORSAR's locations of the six explosions at the test site and the portals (from satellite imagery) of the tunnels leading into the mountain complex.

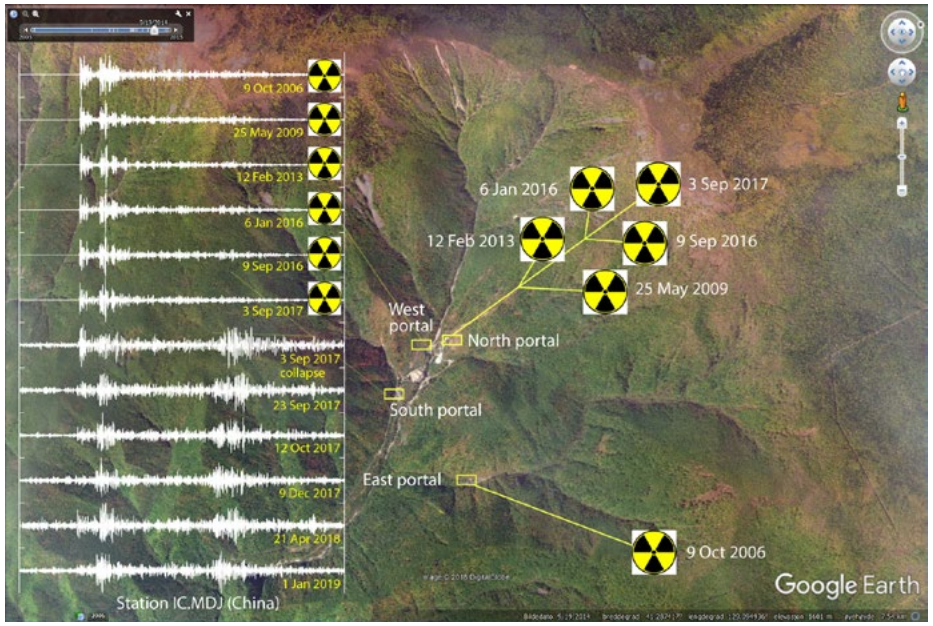


Fig. 10.1.3 The figure shows the locations of the six DPRK nuclear tests, as estimated by NORSAR. Also shown are seismograms from station MDJ in China for the six nuclear tests (top) and six aftershocks following the large test on 3 September 2017. Note the difference in the seismograms between the tests and the aftershocks.

Following the first DPRK nuclear tests in 2006 and 2009, NORSAR developed and implemented a new data processing framework to provide alerts for any seismic activity at or near the test site. Within this framework, data from IMS- and open stations in the East Asian region are downloaded to NORSAR in real time and subjected to detection processing using both classical array methodology and waveform correlation analysis. Any automatic detections are instantaneously reported to NORSAR's alert team (see Section 11.3), which manually assesses the validity of the detected signals as originating from the region of the DPRK test site or close to it.

The large mb 6.1 underground nuclear explosion on 3 September 2017 initiated an extensive sequence of smaller earthquakes in the region around the test site. As of this writing (November 2021), NORSAR's automatic detection processing has identified more than 100 such small earthquakes. The sequence is still ongoing but at a lower intensity level than observed in the first months after the 3 September 2017 nuclear test.

On 24 May 2018, surface explosions at the portals were carried out as part of the DPRK's claimed destruction of its test site. On that occasion, a DPRK officer showed a map of the test site, with explosion locations and portals of the tunnels; see Fig. 10.1.4. There are some small differences between actual locations in Figs. 10.1.3 and 10.1.4, but the relative locations match very well (note the different orientation of the maps in these two figures).

Fig. 10.1.4 Map of nuclear explosion locations and tunnel portals, shown by a DPRK officer on 24 May 2018 (photo taken by Michael Greenfeld, Sky News, and acquired from the web site of 38 North, a project of the Henry L. Stimson Center).

The explosions on 24 May 2018 were very small and were not detected by any accessible seismic station, and it is unclear whether the tunnels can be reused.

Presidents Kim Jung-un of DPRK and Donald Trump of the United States met three times during June 2018 - June 2019 to discuss DPRK's nuclear program. In the end, no progress was made in their negotiations, and NORSAR and others actively continue to monitor the DPRK.

10.2 Monitoring of seismicity in the European Arctic region

The PrepCom's Provisional Technical Secretariat continued its effort to certify the IMS stations. The priority among the seismological IMS stations was on certifying the stations in the primary network, but then it turned to the auxiliary seismic network. The Jan Mayen station (JMIC-AS73) was in 2006 the first Norwegian auxiliary seismic station to be certified.

The reader may recall that, at the time of the CTBT negotiations, the Jan Mayen station was added to the IMS network during the expert deliberations in Geneva because of a successful effort by the Norwegian delegation, as described in Section 7.11.

Fig. 10.2.1 shows the location and characteristics of JMIC (AS73). Fig. 10.2.2 shows a photo from the JMIC site.

The auxiliary seismic station SPITS (AS72) was the next Norwegian station to be certified. This certification was achieved in 2007. Compared to the initial array installed in 1992 (see Section 7.6), several new features had been implemented for AS72 in a complete refurbishment during 2004-2005, funded by AFTAC. Fig. 10.2.3 shows the location of SPITS and the characteristics of this refurbishment. The pictures in Figs. 10.2.4 and 10.2.5 are from the SPITS site.

The AS72 array was further modernized in 2014-2015, featuring:

- New windmill
- Exchange of Sterling engine
- New Güralp digitizers and pit boxes
- Solar panels
- GSM modem for redundant communication.

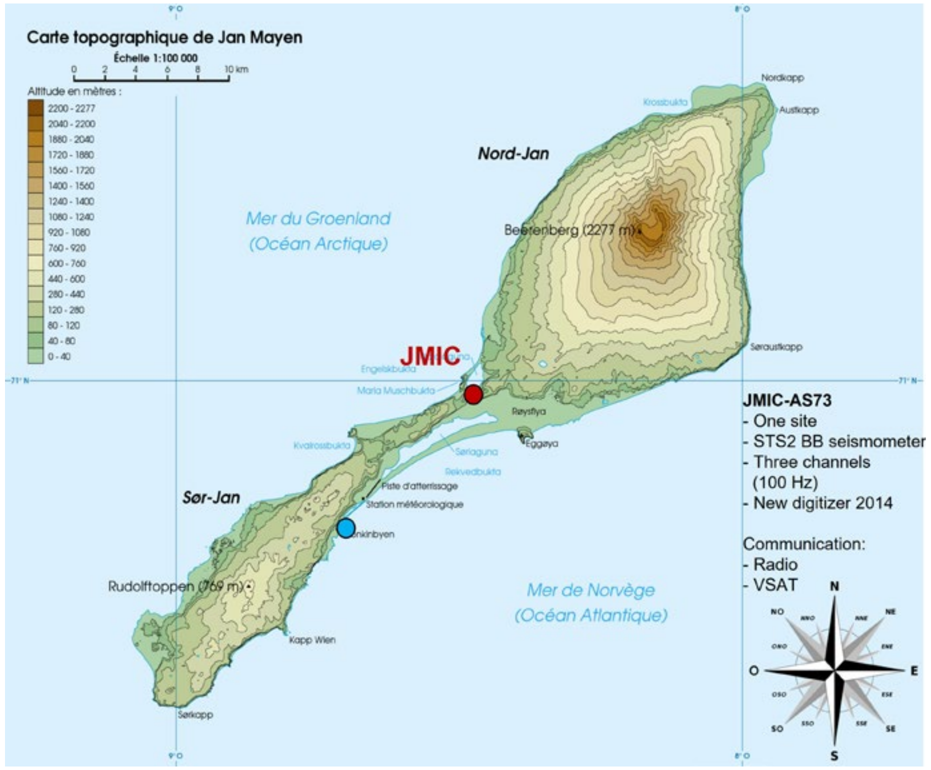


Fig. 10.2.1 *The map shows the location of the IMS auxiliary seismic station JMIC (AS73) on Jan Mayen.*

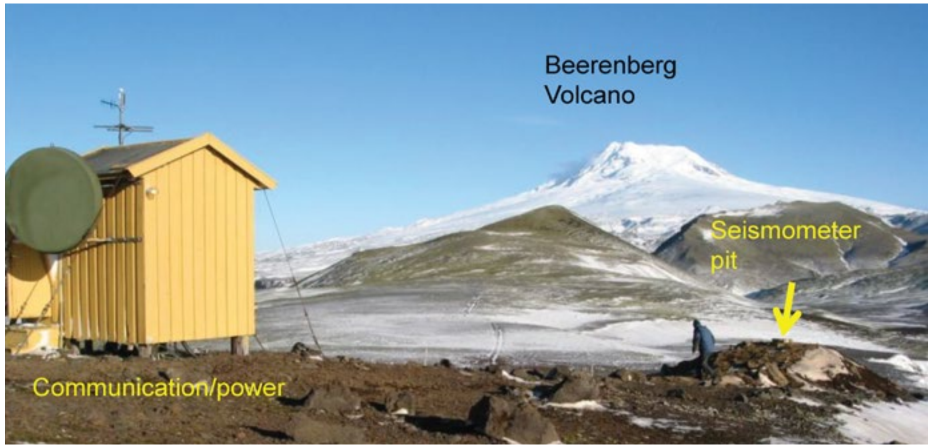
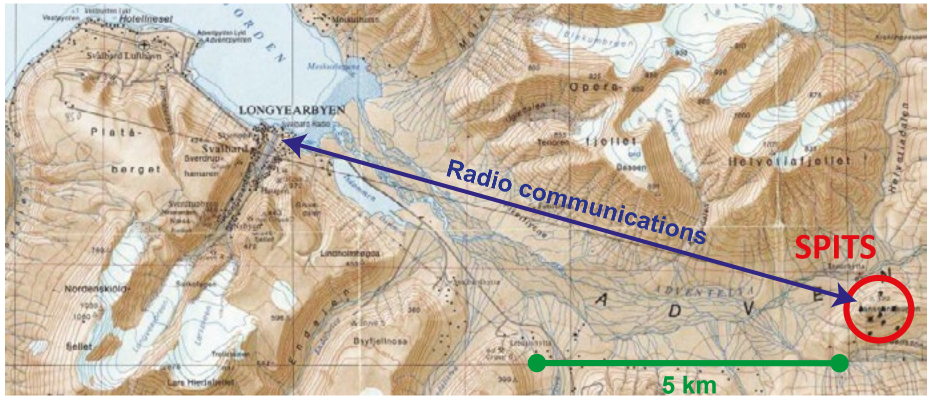


Fig. 10.2.2 *The photo is from the JMIC site, showing the building for power and communications. The seismic vault is located to the right of the person. The Beerenberg active volcano is seen in the background.*



SPITS-AS72	**Power:**	**Communication:**

- One km diameter
- Nine sites (boreholes)
- Nine instruments
  - Three Güralp-BB (vertical)
  - Six Güralp-BB (three-component)
- 21 channels
- Data acquisition in the boreholes
	- Windmill
	- Sterling engine
	
	Central building:
	- Power distribution
	- Communication
		- Modem/cables (intra-array)
		- Radiolink to UNIS
		- Internet to NORSAR

Fig. 10.2.3 *The location of SPITS about 15 km outside Longyearbyen and the characteristics if its refurbishment during 2004-2005.*

For a long time, the characteristics of earthquake activity in the European Arctic were poorly known, mainly due to the scarcity of high-quality seismic stations in many parts of this region. However, a number of significant earthquakes have been recorded in the last decades. The event occurring on 21 February 2008 in Storfjorden, Spitsbergen (Pirli et al., 2010) attracted particular attention. This earthquake had a magnitude of 6.1, which made it one of the largest instrumentally recorded earthquakes on Norwegian territory. Several thousands of aftershocks were recorded after this earthquake (see Fig. 10.2.6), and the aftershock sequence was slowly progressing toward its end more than five years later (Pirli et al., 2013). Fortunately, the earthquake occurred offshore, and no injuries or substantial damage to infrastructure was reported. However, its nucleation on a previously unmapped fault underlines the necessity for improved mapping of seismic sources in the region.

Fig. 10.2.4 *The photo shows one of the instrument vaults of SPITS. The seismometer is placed in a borehole at a depth of 6 m. The photo is taken during work to align the horizontal components of the three-component seismometer in the north-south and east-west directions.*

Fig. 10.2.5 *Photo of the central site of SPITS, with the central building and the windmill taken during a visit in April 2015.*

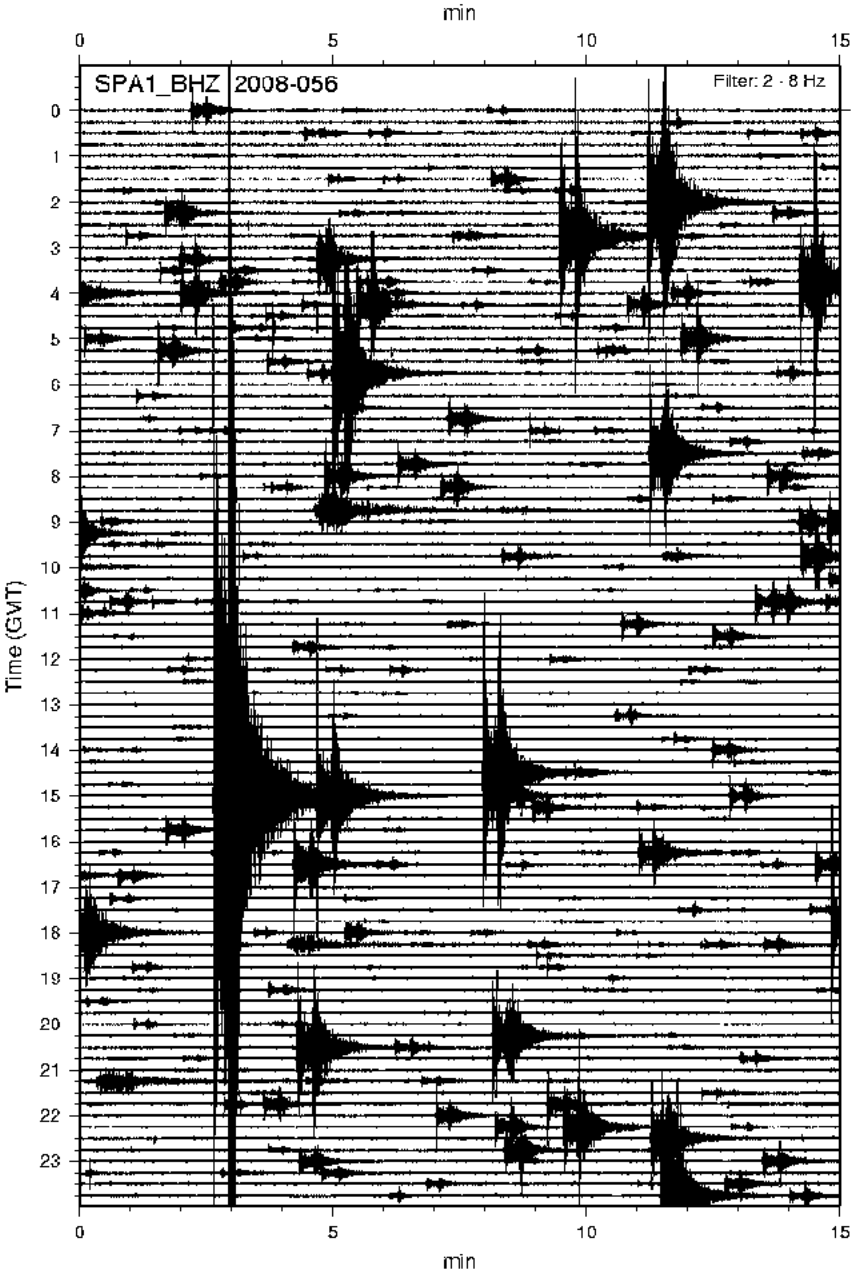


Fig. 10.2.6 A one-day seismogram for the Spitsbergen array (center sensor) for 25 February 2008, four days after the magnitude 6.1 Storfjorden earthquake. It shows more than 100 aftershocks. The aftershock sequence lasted for several years.

Moreover, this earthquake was a reminder that the Svalbard Archipelago and surrounding regions are far more exposed to seismic hazards than the northern European mainland. Active earthquake zones are found in Heerland and Nordaustlandet. In addition, there is significant earthquake activity along the Mid-Atlantic Ridge (Knipovich Ridge) about 100-200 km west of Spitsbergen, and along the Gakkel Ridge, north of the Barents Sea. The western Barents Sea south of Svalbard also exhibits frequent earthquake activity (see Fig. 10.2.7).

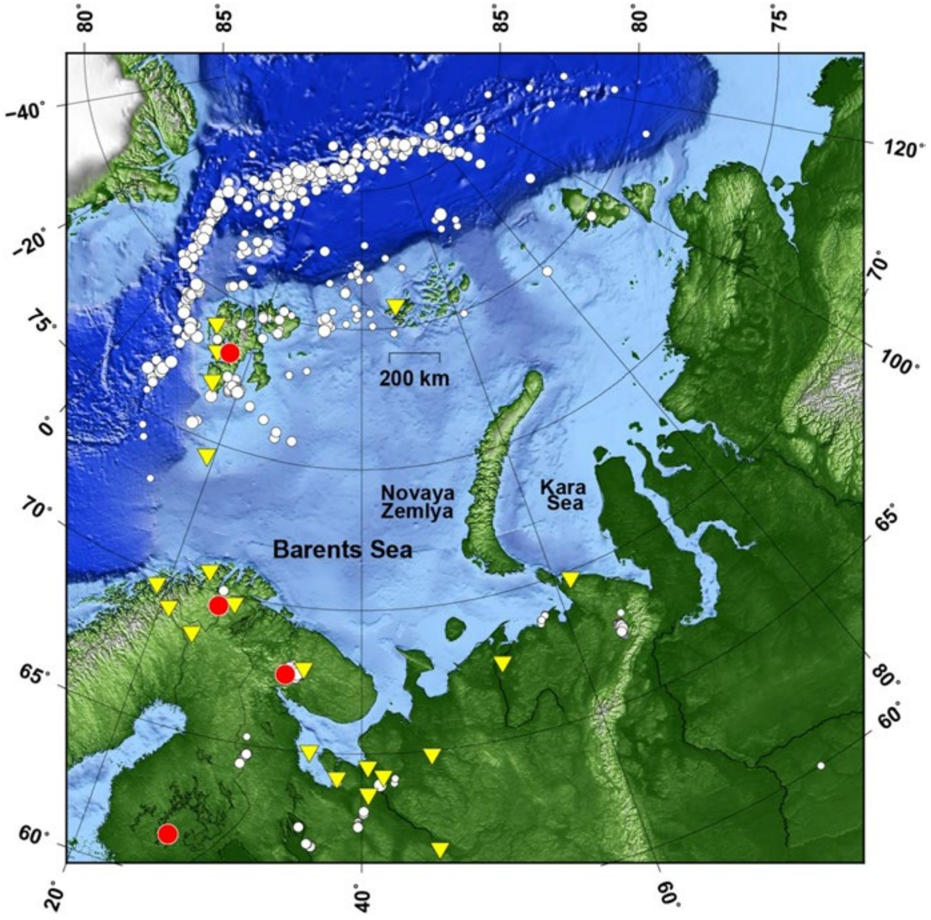


Fig. 10.2.7 Seismic events (white dots) showing results obtained during a Norwegian-Russian project using the combined seismic networks of NORSAR and Russian seismological institutions in Apatity and Arkhangelsk. The figure covers data from the first six months of 2013. The red dots denote seismic arrays, and the yellow triangles denote three-component seismic stations.

The eastern part of the Barents Sea is somewhat less exposed to earthquake activity. However, an interesting event, with a magnitude of 4.6, which is uncharacteristic for the particular region, occurred on 11 October 2010 in the north part of Novaya Zemlya (Gibbons et al., 2016). It should be noted that the monitoring of earthquakes in the eastern Barents Sea until recently has suffered from a shortage of high-quality seismic stations east of the Norwegian border. The situation is now changing, as is further discussed below.

Since its beginning, NORSAR has experienced excellent scientific cooperation with scientists from the Soviet Union, in particular, experts from the Institute of Physics of the Earth (see Section 3.4). Many of these scientists had participated in extended research stays at NORSAR and cooperated in NORSAR publications.

With the collapse of the Soviet Union, it became possible to establish research cooperation with Russian scientists in Apatity on the Kola peninsula (see Section 7.5), which made more detailed monitoring of the Arctic possible. The Khibiny mountain mining explosions were a very useful source of ground truth event information for the regional arrays in Norway and Finland.

Several years later, NORSAR also established cooperation with a research group in Arkhangelsk, which operated a network of seismic stations in northwestern Russia. This network provided a useful supplement to the Nordic array network, particularly for mapping the Lomonosov Ridge. Research cooperation with the Kola and Arkhangelsk groups has been based on joint projects, for which NORSAR has received funding from NFR, while NFR's counterpart in Russia has funded the Russian groups.

During the International Polar Year 2007 - 2008, Johannes Schweitzer of NORSAR led a project on seismological investigations in the Arctic. In cooperation with German and Polish institutions and the universities of Bergen and Oslo, a set of ocean-bottom seismometers was deployed to the west of Bjørnøya (Bear Island) to supplement the land-based stations. Schweitzer also obtained permission to install a temporary seismic array on Bjørnøya. This deployment provided data that became useful in the design efforts many years later for a permanent seismic array station on the island (see Section 11.7).

NFR and the U.S. Department of Energy contributed to funding NORSAR's seismological projects in the Arctic. In addition, the Ministry of Foreign Affairs (MFA) supported a small project on monitoring of seismic events in this region, including the Russian test site at Novaya Zemlya. To a certain extent, this money alleviated the funding problems for the CTBT program described in Section 8.6. The same applies to the MFA-funded activities described in the next two sections. Through these activities, NORSAR could maintain its experts instead of laying off personnel as a possible consequence of the reduction in the MFA funding for CTBT-related activities. Officials at the MFA were helpful in pointing to alternative options for funding from other parts of MFA's project portfolio.

10.3 Cooperation on verification of nuclear disarmament

In early 2007, NORSAR took the first step in expanding its scope of work to the broader nuclear disarmament issues beyond CTBT verification. Three Norwegian institutions, the Norwegian Defence Research Establishment (FFI), the Institute for Energy Technology (IFE), and the Norwegian Radiation and Nuclear Safety Authority (DSA), had formed a network, "NorNed," to address technical issues related to nuclear disarmament. They invited NORSAR to join in recognition of NORSAR's experience in negotiating and implementing the CTBT verification regime. With support from the MFA, NorNed embarked on bilateral, technical cooperation with the UK. This cooperation has been referred to as the UK-Norway Initiative (UKNI) and is described below. The UK was represented by its Ministry of Defence and the Atomic Weapons Establishment (AWE). Svein Mykkeltveit participated in these activities for NORSAR.

Both the UK and Norway, as signatories to the Nuclear Non-Proliferation Treaty (NPT), are committed to the long-term goal of a world without nuclear weapons. NPT's Article VI requires all state parties to the NPT to undertake to pursue "negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a Treaty on general and complete disarmament under strict and effective international control." Future disarmament processes will need to be underpinned by a verification regime that can demonstrate with confidence that nuclear disarmament has occurred. With this principle in mind, the UK and Norway worked together in UKNI to address some of the technical and procedural challenges that verifying the dismantlement of nuclear warheads could pose. UKNI has included both technical development and several unique, ground-breaking exercises.

UKNI has comprised a process of building trust and cooperation in an area that presents significant technical and political challenges to both parties. The principal objectives for the collaboration were:

- To promote understanding between a Nuclear Weapon State (NWS) and a Non-Nuclear Weapon State (NNWS) on the issues faced by the other party
- To create scenarios in which Norwegian and United Kingdom participants could explore issues relating to nuclear arms control verification without the risk of proliferation (Norway, as an NNWS, is obliged by the NPT not to seek any knowledge of nuclear weapons from the UK, and the UK, as an NWS, is obliged not to provide such knowledge to Norway)
- To promote discussion on how an NNWS can be involved in a nuclear arms control verification process.

Under UKNI, two main areas of research were pursued: Information Barriers and Managed Access:

- In its simplest state, an Information Barrier takes data from a measurement device, processes the data relative to predetermined criteria, and provides a pass/fail output. Crucially, the Information Barrier must prevent the disclosure of sensitive measurement data to "uncleared" personnel. The United Kingdom and Norway jointly developed a robust, simple and relatively inexpensive Information Barrier system capable of identifying radiological sources. The use of an Information Barrier system enables the parties in inspection activities to meet the requirements of the NPT
- In a future verification regime for nuclear warhead dismantlement, inspecting parties will likely request access to highly sensitive facilities and weapon components. Such access will have to be managed carefully by the inspected party to prevent the disclosure of sensitive information, both in compliance with the NPT and in consideration of national security. At the same time, it will be incumbent on the inspectors not to gain proliferation-sensitive information. Managed Access is the process by which "uncleared" personnel are given access to such sensitive facilities, or supervised areas, under the terms of an agreed procedure or protocol.

UKNI conducted practical exercises to address the feasibility of the use of Information Barriers and the concept of Managed Access. We will focus here on an exercise in Norway in 2009, which was the first of its kind ever, involving an NWS and an NNWS. For the purpose of this exercise, it was decided that the United Kingdom and Norway would swap roles: Norway would play the NWS while the United Kingdom would play the NNWS. Facilities at FFI and IFE mimicked the nuclear weapons complex of a hypothetical NWS, while AWE provided inspectors from a hypothetical NNWS.

Fig. 10.3.1 *The picture shows the inspectors (in orange coats) in their first contact with the "nuclear weapon", held within a transport container.*

The exercise scenario follows: A nuclear weapon ready for retirement was received at the complex to undergo dismantlement, with the fissile material of the weapon ending up in a monitored storage facility. The task of the inspectors was to verify the integrity of the dismantlement process under an agreed protocol and, in particular, to ensure that no fissile material could be diverted by the NWS, for reuse in its nuclear weapons program. The exercise lasted for a full week, with the inspectors following the dismantlement process closely, using the Information Barrier to verify the presence of the fissile material at the various steps in the process and with the use of a range of other techniques to ensure a so-called "chain-of-custody" for the nuclear weapon. For example, tags, seals, and video surveillance were used to monitor the weapon and its disassembled components when these were out of sight of the inspectors. See Figs. 10.3.1-10.3.3 for pictures from the exercise.

The main conclusion from the exercise was that the United Kingdom and Norway believed that it should be possible to maintain a chain of custody for nuclear warhead dismantlement to a high degree of confidence when the relevant technologies have been developed to the necessary level of functionality. None of the verification measures used, however, could confirm that the object was a weapon, as declared. The Information Barrier measurements and documentary evidence built confidence but were not definitive proof. It was not the intention of the exercise to solve this "initialization problem," but the exercise highlighted the issue. Participants also concluded that an NWS and an NNWS could collaborate within this field and successfully manage any proliferation risks.

Fig. 10.3.2 *An inspector watches as a measurement is performed using the Information Barrier system. Measurements are performed on the nuclear weapon inside the transport container to the left.*

Fig. 10.3.3 *The picture shows the participants from Norwegian and UK institutions after the completion of the exercise in Norway in June 2009.*

An exercise with a narrower scope was held in the UK in 2010 within the boundaries of one of the AWE sites to provide increased realism. In this exercise, there was an emphasis on security as a priority. The facility was staffed with exercise participants who were inexperienced in dealing with inspection activities and were reactive rather than proactive. The exercise provided a common understanding within the UKNI collaboration of the impact that host security and safety could have on an inspection regime. This understanding is essential for technology and procedural development in the future.

This cooperation was expanded when Sweden and the United States joined Norway and the United Kingdom in 2015 in pursuit of further advances in nuclear disarmament verification in the Quad Nuclear Verification Partnership. This initiative seeks to solve the challenges associated with verifying that nuclear disarmament has occurred. It has identified a broad range of lessons from an exercise relevant to the future development of verification technologies and procedures hosted in 2017 by the United Kingdom at a Royal Air Force base. NORSAR also participates in the work of the International Partnership for Nuclear Disarmament Verification, which was formed in 2014 by the United States and the Nuclear Threat Initiative and includes 25 member countries. This initiative has explored the physical dismantlement of a nuclear weapon, verification of declarations and reduction of weapon arsenals, and various technologies for verification. Helene Ruud has been NORSAR's key participant in these activities since 2018.

All initiatives described in this section have already led to substantial progress in understanding key issues for nuclear disarmament verification and will continue to engage participants in further development of verification procedures. The next step should be to bring this work into a multilateral forum for both nuclear-armed and non-nuclear-armed states. Norway's MFA has promoted this idea in the context of the work of the United Nations Group of Governmental Experts on nuclear disarmament verification. After the first round of meetings in 2018 - 2019, this group will meet again in 2021 - 2022 "to further consider nuclear disarmament verification issues, including, inter alia, the concept of a Group of Scientific and Technical Experts." Such a group could draw upon the experience of the GSE, which prepared successfully for the negotiations on the CTBT, as we have seen.

10.4 Cooperation with countries in Central Asia on CTBT verification

NORSAR has cooperated with seismological institutions in countries in Central Asia for more than 25 years. The cooperation started with the participation of Dr. Nadezhda Belyashova from the Institute of Geophysical Research (IGR), Kazakhstan, in the GSE in Geneva in 1995. Norway and Kazakhstan, both keen promotors of nuclear disarmament, have many common interests at the technical level. For example, the seismic networks of the IMS include four stations in each country, out of which three in each country are arrays. NORSAR and IGR specialists visited the other party, and NORSAR installed elements of its array processing package at the Kazakh NDC at IGR's premises in Almaty. Close contact has been maintained during Working Group B sessions in Vienna since 1997.

NORSAR approached the MFA in 2002 with a sketch of a project proposal for capacity building on CTBT verification in Central Asia. The sketch was well received, but it took until 2006 to sort out all the details before the first MFA-funded effort in the region became a reality. This was a project in Kyrgyzstan to install digital seismic stations to replace old ones that recorded seismograms on paper, install PCs with basic data analysis software at these stations, and equip the NDC at the Institute of Seismology (IS) in the capital Bishkek with adequate hardware and software.

A seminar on Norway - Kazakhstan cooperation, with high-level political attendance, was held in Oslo in early 2009. Presentations at this seminar by the IGR and NORSAR paved the way for an MFA-funded project to benefit all of the countries in Central Asia. Kazakhstan was the key partner and liaison with the other countries in the region. From 2009 until 2021 (except for the period 2015 - 2017, when MFA's relevant budgets focused on the migration crisis in Europe), this project has provided for the following:

- The establishment of an international training center at the IGR in Almaty in 2010 (see Fig. 10.4.1). At this center, trainees from Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan, and Turkmenistan receive hands-on training in month-long courses on all aspects of NDC operation, including analysis of IMS and other data for CTBT verification purposes. The competent staff at IGR instruct the courses, which have been attended by more than 100 participants to date, with an almost equal share of women and men. The project also provided for the restoration of two small houses in the garden of IGR for use as living quarters for the trainees. Workstations for trainees, as well as a complete seismic station for training and demonstration purposes, have been acquired through this project.
- Travel grants for personnel at the NDCs in Kazakhstan and Kyrgyzstan. These grants have enabled participation from these countries in technical activities of the CTBTO PrepCom, such as workshops and the biannual Science and Technology (SnT) conferences held in Vienna, as well as participation in other international scientific conferences.
- Cooperation between NORSAR, IGR, and IS on research projects in seismology and infrasound. This activity has resulted in joint presentations at the SnT conferences in Vienna.
- Saving historical seismograms on paper for future use. Paper seismograms stored at IS in Bishkek have been scanned and converted to digital form with the assistance of personnel at IGR in Almaty. The project provided some of the equipment needed. The seismograms include records of nuclear explosions worldwide and devastating earthquakes in Central Asia.
- A joint seismological bulletin is established for Central Asia. The participating countries contribute data from their national seismic networks, which are used to compile a joint seismic bulletin for Central Asia. Such a bulletin provides a more precise and complete picture of the seismicity of this earthquake-prone region than can be obtained from individual national bulletins. It is thus an important contribution to proper assessments of seismic risk and mitigation of damage to infrastructure and buildings, including loss of lives.

NORSAR has enjoyed fruitful and long-lasting collaboration with colleagues in Central Asian countries, who have spared no effort to fulfill the objectives of this project. The competence built in the region contributes to a strengthening of the CTBT verification regime. The credibility and legitimacy of this regime depend on active participation from countries all around the world.

Fig. 10.4.1 *The picture is from the opening in 2010 of the international training center for CTBT verification at IGR in Almaty.*

10.5 International cooperation on infrasound research

After it became clear that Norway would host an infrasound station of the IMS monitoring network (see Section 7.11), NORSAR seismologists started to take a closer look at the state-of-the-art of infrasound technology. Prof. Ludwik Liszka from the Swedish Institute of Space Physics (IRF) had since the 1970s operated several smaller infrasound arrays in Sweden and northern Finland, and NORSAR initiated cooperation with him and the IRF focusing on instrumentation and data processing methodology.

Also, as part of the cooperation with the Kola Regional Seismological Centre in Russia (see Section 7.5) a small three-element array of microbarographs was installed within the already existing seismic array in Apatity. The infrasound data were shared with NORSAR and provided valuable insight into the infrasound signal characteristics from a wide variety of man-made sources.

It was well known that acoustic signals in the atmosphere from sonic booms and surface explosions would couple to ground and generate signals at seismometers. The seismic sensors of the ARCES array were in 1987 installed in shallow vaults close to the Earth's surface and showed to record clear infrasound signals from industrial and military sources up to distances of several hundred kilometers. To widen NORSAR's observational basis, three infrasound sensors were in 2008 deployed within the inner ring of the ARCES seismic array. The deployment was further expanded to nine infrasound sensors in 2015. In 2013, the IMS infrasound array IS37 was installed in northern Norway (see Section 11.2).

Of particular interest were observations from the Hukkakero site in northern Finland where the Finnish military carried out repeating explosions to destroy expired ammunition (see Fig. 10.5.1). These explosions were, and are still carried out every summer in August/September at the same location and with approximately the same yields. As shown in Fig. 10.5.2, the seismic signals observed at the ARCES array are practically identical, whereas the infrasound signals show a high degree of variability caused by temporal changes in the atmospheric conditions. Infrasound observations of such repeating explosions provide an excellent database for research on infrasound wave propagation and studies on the properties of the atmosphere. The paper by Gibbons et al. (2015), with co-authors from Norway, Sweden, Finland, and Russia, gives a thorough overview of stations and infrasound sources in the European Arctic region and their usefulness in seismo-acoustic studies.

Fig. 10.5.1 *This map shows sources of repeating explosions, and arrays in the European Arctic region that have recorded acoustic signals from these explosions. Except for the ammunition destruction site at Hukkakero, the explosion sources shown correspond to large open-pit mines in northwestern Russia and Sweden. KIR, JAM and LYC are operated by the Swedish Institute of Space Physics (IRF). SDK is operated by Sodankylä Geophysical Observatory and IRF. ARCES, ARCI, and IS37 are operated by NORSAR, and APA/APAI is operated by the Kola Regional Seismological Centre.*

During the years 2005 to 2010 a large part of NORSAR's infrasound research was funded through a 5-year contract with the US Army Space and Missile Defence Command. The contract with the title "Basic Research on Seismic and Infrasound Monitoring of the European Arctic" allowed NORSAR's scientists to experiment with and develop different seismic and infrasound methods, and to conduct case studies relevant to nuclear explosion monitoring and the CTBT. An important part of this project was participation at the annual Monitoring Research Review meetings in the US, organized jointly by the US Departments of Defense and Energy. At these meetings the NORSAR team had the opportunity to meet strong international research teams and to present and discuss results from recent studies.

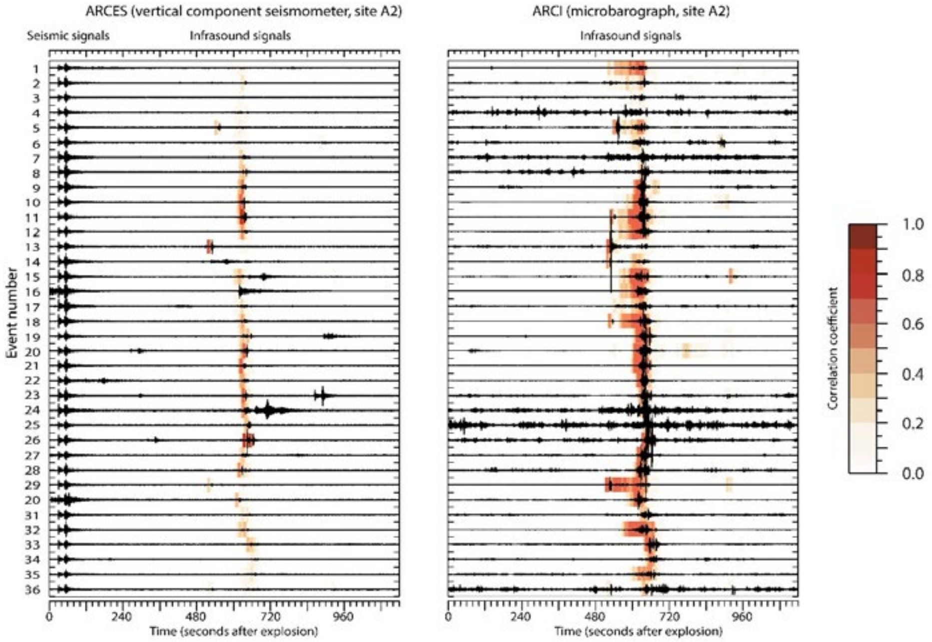


Fig. 10.5.2 *Seismic (left) and infrasound (right) data at collocated sensors of the ARCES/ARCI arrays for each of 36 explosions at Hukkakero between 13 August and 11 September 2008, filtered between 2 and 7 Hz. Time intervals with coherent infrasound signals are indicated in red. Notice the high similarity among the seismic observations of the different events, seen in the leftmost part of the left-hand panel. In contrast, the infrasound signals seen in both panels show significant variability among the events, both in terms of propagation time and amplitude.*

In 1996, when the CTBT was adopted by the UN, there were no existing infrasound arrays which could become part of the IMS monitoring network. Consequently all 60 infrasound arrays had to be built, one-by-one. As the number of installed and certified IMS infrasound arrays gradually increased, it was realized that the data they provided to support monitoring of the CTBT, were also very useful for scientific and civilian applications. Dr. Elisabeth Blanc from the French NDC at CEA took the initiative to establish a consortium of research institutions, including NORSAR, to prepare an infrastructure proposal to the European Union. The proposal, called ARISE (Atmospheric Research Infrastructure in Europe), was awarded in 2011 with a 3-year project having 12 different partners. In 2015, a follow-up project called ARISE2 was awarded, then with 24 partners. The participation in the ARISE and ARISE2 projects further strengthened NORSAR's ability to conduct infrasound-related research in support of the CTBT, but also opened the way for engagements into more general atmospheric research. In 2010, a book with the title “Infrasound Monitoring for Atmospheric Studies” was published (Le Pichon et al., 2010). This book included contributions from many of the participants which later became part of the ARISE and ARISE2 projects and provided an excellent overview of the state-of-the art of infrasound in atmospheric studies. In 2018, a follow-up book (see Fig. 10.5.3) was published with subtitle “Challenges in Middle Atmospheric Dynamics and Societal Benefits” (Le Pichon et al., 2018), in which NORSAR contributed with a section entitled “Characterization of the Infrasonic Wavefield from Repeating Seismo-Acoustic Events.”

NORSAR’s contributions to infrasound monitoring and the CTBT are additionally documented in NORSAR’s Semiannual Technical Summaries after 2000, as well as in presentations held at the CTBTO’s Science and Technology Conferences and Infrasound Technology Workshops (e.g., see section 11.2).

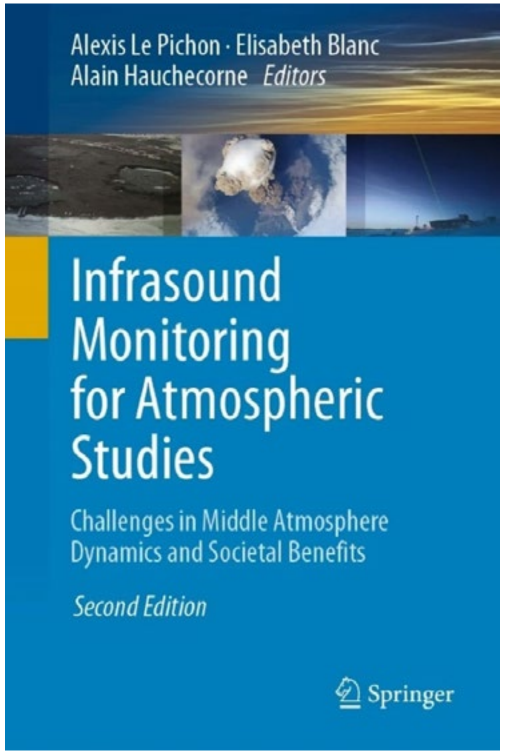

Alexis Le Pichon · Elisabeth Blanc
Alain Hauchecorne *Editors*
Infrasound Monitoring for Atmospheric Studies
Challenges in Middle Atmosphere Dynamics and Societal Benefits
Second Edition
Springer

Fig. 10.5.3 Front page of the book “Infrasound Monitoring for Atmospheric Studies”, published by Springer in 2018.

Chapter 11

2011 - 2020
New times, new people, new initiatives

11.1 The Tohoku earthquake in Japan in 2011 – radionuclide registrations globally

On 11 March 2011, Japan experienced the strongest earthquake in its recorded history. The earthquake, with a magnitude of 9.1 and a depth of 29 km, struck below the North Pacific Ocean, 130 kilometres east of Sendai, the largest city in the Tohoku region, a northern part of the island of Honshu.

The Tohoku earthquake was the fourth largest in the world since 1900. Stations of the seismic, hydroacoustic and infrasound networks of the IMS contributed important data during this earthquake and its aftershocks. The IDC registered about 800 aftershocks on 11 March alone, and approximately 10,000 during the following month. Fig. 11.1.1 shows records of the main shock at four IMS seismic stations on Norwegian territory. The high frequency P waves propagating through the interior of the earth were followed at each station by surface waves some 20 - 30 minutes later. These waves propagate along the surface of the earth at much lower speed than the P waves.

The Tohoku earthquake caused a tsunami with observed peak water run-up heights on land of up to 39 meters. More than 450,000 people became homeless as a result of the tsunami, and more than 15,000 people died.

The tsunami also severely crippled the infrastructure of the country. In addition to the thousands of destroyed homes, businesses, roads, and railways, the tsunami flooded the Fukushima Daiichi Nuclear Power Plant and caused the meltdown of three nuclear reactors. The Fukushima nuclear disaster released toxic, radioactive materials into the environment and forced thousands of people to evacuate their homes and businesses.

The Tohoku earthquake, like the 2004 Indian Ocean earthquake was yet another stress test for the IDC processing. Similar to the case of the 2004 Indian Ocean earthquake and the following tsunami, the automatic processing was able to cope with the large data volume, but in this case, the timeliness of the interactive analysis at the IDC was much better than it was for the 2004 event.

Of special importance were the world-wide detections by the radionuclide stations of the International Monitoring System of the release of both radioactive noble gases and radioactive particulates, such as iodine-131 and cesium-137, from the Fukushima nuclear accident. The first detection, in this case of iodine-131, at the Norwegian station RN49 at Longyearbyen in Svalbard occurred two weeks after the accident. This was followed by detections of cesium-134, cesium-137 and tellurium-132. By mid-April 2011 the release had reached all IMS radionuclide stations in the northern hemisphere and some stations in the southern hemisphere.

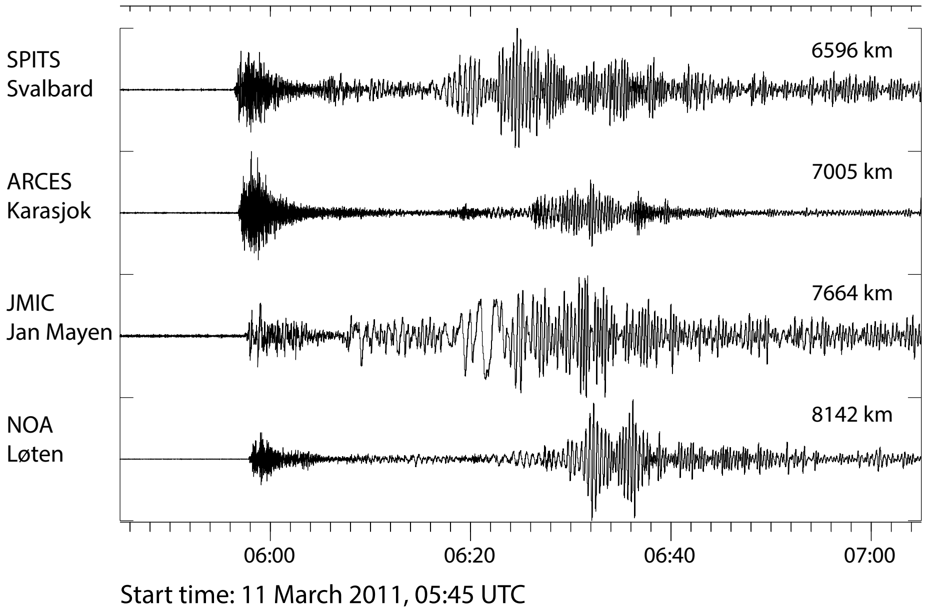


Fig. 11.1.1 Records of the Tohoku 2011 earthquake in Japan at four Norwegian IMS stations. The distance from each station to the epicenter is shown to the right.

The detections continued for three months and were carefully analysed by the IDC, and results were made available to designated National Data Centers of the States Signatories, as well as to other recipients, as we shall see below.

As described in section 9.5, the PTS of the CTBTO PrepCom started providing seismic and hydroacoustic IMS data to tsunami waning centers after the Indian Ocean tsunami in 2004. During the very early phase of the 2011 disaster in Japan, such data from the IMS were sent directly and in real time to seven tsunami warning centers in Japan and the Pacific region and contributed to rapid alerts issued by these centers. These alerts and evacuation plans that were in place saved many lives.

Because of the potential sensitivity of IMS radionuclide data, a number of States Signatories have been reluctant to agree to the distribution of such data to any other than the designated recipients. However, six days after the Fukushima accident, the International Atomic Energy Agency and the World Health Organization requested access to IMS data for their assessment of the dispersion of radioactive substances in Japan and the wider region. The following day, States Signatories agreed to such access, as well as to technical cooperation, with these two and other international organizations. This cooperation included sharing of analysis reports. All stakeholders realized the usefulness in this challenging situation of the IMS radionuclide network as the only global network of its kind.

This use of IMS radionuclide data is another example of the benefits the IMS can offer to civil society in emergency situations. Data and analysis results provided by the PTS allowed users around the world to monitor the dispersion of radioactivity and conduct contingency planning, as necessary. This facilitated regional and global efforts to assess radionuclide risks. Also, diagnostic information was made available through the radionuclide detections, such as reactor temperature, fuel burn-up, and the change in the mixture of released material due to radioactive decay.

11.2 Certification of IS37 (Bardufoss) in 2013, opening in 2014

As mentioned in Sections 6.3 and 7.11, the original plan to establish the IMS infrasound monitoring station in Karasjok, co-located with the seismic array (PS28), was not approved. Instead, IS37 was placed in Bardufoss, also in northern Norway. It took 15 years from the time the site survey was conducted in Karasjok in 1998 until the array was finally built in Bardufoss. It might be worthwhile to look into what happened and why it took so long.

NORSAR has established seismic single stations and arrays for more than 50 years. The general experience is that unless an installation is planned in a protected area, such as a national park or a nature reserve, obtaining the necessary permissions is usually fairly straightforward. Seismic stations are typically placed in remote areas, are not very visible in the terrain, have little environmental impact, and landowners usually see few problems as station hosts. This is very different, however, when it comes to infrasound stations for the IMS network. The technology favored for IMS relies on steel pipe arrays placed on the ground at each of the array elements to reduce the effect of wind noise on the measurement of infrasound signals. These pipe arrays typically cover an area of 20x20 meters, which in most places must be fenced to prevent people and animals from stepping on the pipes and harming themselves or the pipes. In addition to standing out as very visible, these fences may be seen as impediments to free movement in the terrain.

The survey in Karasjok in 1998, a cooperative effort between NORSAR and the PTS, checked various sites in the area to the south of PS28, at lower altitudes and with more favorable vegetation. It included the sites of the four elements of the infrasound array operated in Karasjok in the late 1960s and the early 1970s. The survey recommended to establish a two kilometers wide four-element array in a pine forest to the south of the village of Karasjok, where the noise level was found to be very favorable. During the following years up to 2005, NORSAR did not push actively for the installation of the station, primarily because the infrasound community at large was pursuing investigations into fundamental issues of this technology, such as array configuration and the effects of various wind noise reduction systems. These discussions revealed that a standard IMS infrasound station should be a nine-element array instead of a four-element array.

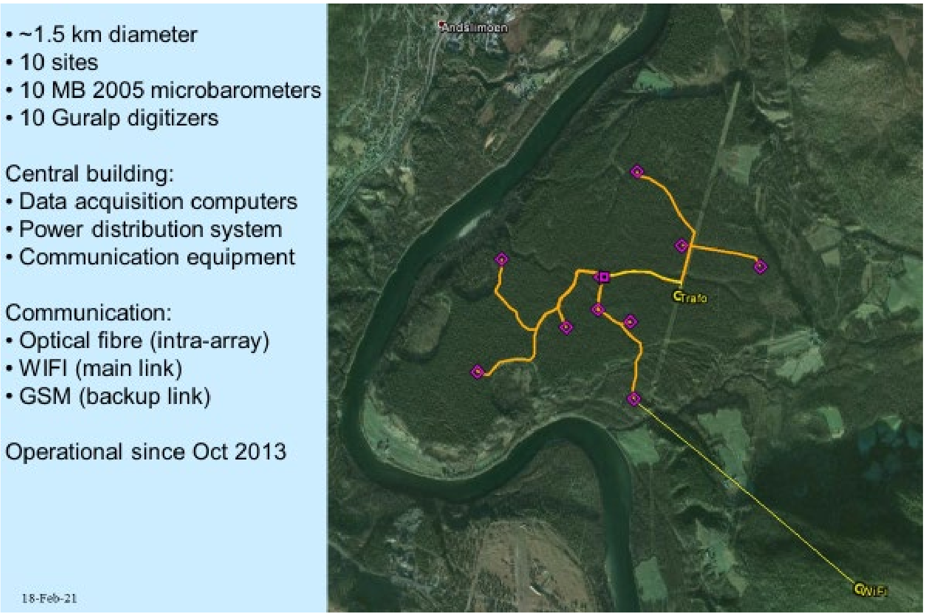
NORSAR submitted its application to the municipal authorities in Karasjok in 2005 for permission to establish IS37 at the site recommended by the site survey. It became clear, however, that permission would not be granted for this location, mainly because the fences could obstruct feeding grounds and migration routes for the reindeer. NORSAR then developed plans for two alternative locations in Karasjok, with the hope that one of them might be acceptable to the local authorities. However, in June 2007 the Karasjok municipal community board in its final decision on the matter rejected both plans. NORSAR then started the search for alternative locations for IS37 elsewhere in northern Norway.

Promising locations for IS37 were identified in 2008 around Bardufoss in the municipality of Målselv, about 280 km to the west-southwest of Karasjok. Early signals from the local authorities indicated a positive attitude towards NORSAR's plans, and site survey measurements resulted in 2009 in a preferred location at Brannmoen, a flat, pine forested riverbank. The landowners affected by the plans were willing to sign agreements with NORSAR, and NORSAR started the development of the mandatory zoning plan for the station area. A zoning plan describes in great detail the planned installation and its consequences for the environment and society at large. Developing such a plan is a very demanding task, in which NORSAR could draw upon the experience from Karasjok. The plan was submitted to the local authorities as well as to authorities at the county level, and it was subject to a public hearing. Comments and objections to the plan were received and they required new modified versions, but eventually the local authorities approved the plan in December 2012. During this process, the PrepCom plenary approved the location change from Karasjok to Bardufoss; such approval is required when locations are moved more than 10 km from the IMS station locations provided in the protocol to the CTBT.

Finally, in May 2013, civil works started at IS37. The station equipment was installed at the central recording facility and at the ten elements of the array. The complete station was in place by mid-October. The CTBTO PrepCom funded the whole effort through a contract with NORSAR signed in 2006 (in anticipation of an installation in Karasjok), and all work was carried out by NORSAR and its subcontractors. NORSAR employees Jan Fyen (project leader), Michael Roth, Paul W. Larsen, and Kjell Arne Løken handled all aspects of this effort and cooperated well with the PTS. IS37 was certified by the PTS in December 2013. This completed the certification of all six of Norway's IMS stations.

Features of IS37 are shown in Figs. 11.2.1 and 11.2.2.

IS37 was officially opened in a dedication ceremony held at the station site on 8 September 2014. State Secretary Bård Glad Pedersen from the Ministry of Foreign Affairs cut the ribbon, and many of NORSAR's collaborators, including representatives of the PTS, attended the event.



- ~1.5 km diameter
- 10 sites
- 10 MB 2005 microbarometers
- 10 Guralp digitizers

Central building:
- Data acquisition computers
- Power distribution system
- Communication equipment

Communication:
- Optical fibre (intra-array)
- WIFI (main link)
- GSM (backup link)

Operational since Oct 2013

18-Feb-21

Fig. 11.2.1 The figure shows the layout of infrasound station IS37 at Brannmoen in Bardufoss, northern Norway. The instrument sites of the array are shown in red.

***Fig. 11.2.2** Photo of one of the four steel pipe arrays at one of the ten instrument sites of IS37. As explained in the text, this design aims to reduce the effect of wind noise on the infrasound signals of interest. Note the inlet ports, looking like shower heads.*

In 2016, NORSAR in cooperation with the PTS installed parallel instruments at each of the ten elements of the station. The main objective of this installation was to facilitate regular calibration of the infrasound stations by providing data recorded both with and without the use of the wind noise reduction systems.

In 2017, NORSAR hosted the annual CTBT Infrasound Technology Workshop in Tromsø in cooperation with the PTS. There was a total of 85 participants from 33 countries (see Fig. 11.2.3). The program included a full-day field trip to the nearby IMS infrasound station IS37 in Bardufoss and a special session on atmospheric and space sciences to create a link to related research areas, and to attract local and regional R&D communities to this workshop. The workshop was very successful, and NORSAR expressed its thanks to the PTS for their excellent cooperation in organizing the event.

***Fig. 11.2.3** Participants at the 2017 CTBT Infrasound Technology Workshop in Tromsø, Norway.*

11.3 Strengthening of the CTBT mission

The funding of the CTBT related tasks for the Ministry of Foreign Affairs declined over the 10-15 years that followed Norway's ratification and assignment of the role of NDC to NORSAR in 1999, resulting in a reduction of 50 percent in real terms, in spite of the efforts by the director Anders Dahle and his colleagues to reverse this trend.

Upon Dahle's retirement, on 1 January 2014 Anne Strømmen Lycke became CEO of NORSAR. She brought new energy to the efforts to increase the budget for the CTBT mission for the Ministry of Foreign Affairs, through persistent and systematic work to document the funding shortfall and define a modified program of work that responded to the needs of the authorities, keeping in mind the will expressed by the parliament when Norway ratified the CTBT in 1999.

Emphasis on robustness in the organization has included various initiatives among the personnel as well as the physical infrastructure. This has included ensuring that critical knowledge for all verification-related tasks is maintained by several persons to reduce the dependency on individuals. In addition, detailed documentation of all physical installations at the monitoring stations, "as built," has been secured to facilitate operations and maintenance. The efforts to enhance robustness have included improved data and physical security at the monitoring stations and additional redundancy of critical components and data transmission lines.

CTBT verification-related activities have been extended and modified. The software package used since the early 1980s for real-time seismic event detection and interactive analysis has been modernized and made more user-friendly and accessible to a wider group of users. An alert team from across departments at NORSAR has been created to receive, around the clock, alarms of potentially interesting events resulting from NORSAR's real-time processing of seismic and infrasound data and/or indications of such events contained in the automatic bulletins produced by the IDC. Such alarms initiate an assessment of the detected event without delay to provide timely advice to the Ministry of Foreign Affairs. In addition, some special geographical locations are subject to detailed online monitoring for events of interest. Among these locations are the test site in the DPKR (see Section 10.1) and other sites previously used for underground nuclear tests.

NORSAR has developed considerable competence in the field of infrasound and has also acquired capabilities to analyze radionuclide data. Hydroacoustics data are sufficiently similar to those of seismology and infrasound, and can easily be handled adequately by NORSAR's specialists. Thus, NORSAR now possesses in-house competence in all four IMS technologies to perform independent analysis. In addition, NORSAR has expanded its engagement with the CTBTO PrepCom in the area of On-Site Inspection.

Since 2017, the funding of the CTBT mission for the Ministry of Foreign Affairs has increased. It is now comparable to the 1999 funding level in real terms, i.e., with inflation and salary increases since then taken into account. However, the scope of the mission has changed over these years to include additional elements, such as the operation of three additional IMS stations. There have been savings from making some of the operations more effective. In addition, the Ministry of Foreign Affairs provided during 2017-2021 extraordinary funds for the modernization of the software package for real-time event detection and interactive analysis.

11.4 Recent developments and status of activities of Working Group B

In Section 8.3, we described the work of the CTBTO PrepCom's WGB up to about 2016. In this section, we will summarize changes in NORSAR's WGB delegation over the last five years, describe an initiative by Norway for the younger generation of verification specialists, touch on some issues currently dealt with in WGB and reflect on the developments.

The last five years saw substantial changes in NORSAR's WGB delegation. On 25 February 2016, the Norwegian Ambassador to Austria, Bente Angell-Hansen, held a reception in her residence in honor of the retirement of Frode Ringdal and Jan Fyen (see Fig. 11.4.1). NORSAR's CEO Anne Lycke pointed to their contributions over many years in Geneva and Vienna to the technical work in the international development of verification technologies and their roles in the CTBTO PrepCom. The Executive Secretary of the CTBTO PrepCom, Lassina Zerbo, emphasized their contributions to the establishment and activities of the PTS and their role in international seismological cooperation.

Fig. 11.4.1 In the residence of Norway's ambassador in Vienna on 25 February 2016. From left to right in the foreground; Frode Ringdal, Jan Fyen, Lassina Zerbo, and Anne Lycke.

Fig. 11.4.2 In the garden of the residence of Norway's ambassador in Vienna on 28 August 2019. From left to right; Robert Kemerait (U.S. delegate to WGB), Kjersti E. Andersen, Svein Mykkeltveit, and Anne Lycke.

Tormod Kværna was appointed by the WGB Chair to succeed Frode Ringdal as Task Leader for Testing, Provisional Operation and Performance Assessment. This task is very demanding and comprehensive, in which discussions among

States Signatories are conducted in WGB on key aspects of the development and operation of the IMS and the IDC, with the purpose of reaching consensus on the way forward for the PTS to progress its work. In 2019, Svein Mykkeltveit retired from WGB, and this was marked by a reception in the residence of Norway's ambassador Kjersti E. Andersen (see Fig. 11.4.2). Helene Ruud from NORSAR, who has attended WGB since August 2018, was named Task Leader for WGB Cross-Cutting Issues upon Svein Mykkeltveit's retirement from WGB. Norway thus maintained the number of task leader assignments in WGB. Anne Lycke, Jon Magnus Christensen and Morten Sickel from NORSAR have attended WGB sessions regularly in recent years.

In 2020, Svein Mykkeltveit was appointed Commander of the Royal Norwegian Order of Merit for his contributions to nuclear disarmament and in particular his work in relation to the CTBT (Fig. 11.4.3).

***Fig. 11.4.3** Svein Mykkeltveit with the Royal Norwegian Order of Merit, at an award ceremony in Oslo on 21 August 2020, flanked by colleagues Tormod Kværna and Helene Ruud.*

A WGB-related activity was started by Anne Lycke when she took the initiative in 2018 to create the Young Professionals Network (YPN), a community of skilled and motivated young scientists and technical professionals working on technical aspects of verification of compliance with the CTBT. The YPN is a network and meeting place where the next-generation members of the CTBT National Data Centers (NDCs) and the Provisional Technical Secretariat (PTS) can meet, discuss and establish relationships to strengthen collaborations within the PrepCom (see Fig. 11.4.4).

The YPN aims to enable the next generation to take on formal positions at the NDCs and the PTS and to qualify for Task Leader assignments in WGB through the exchange of knowledge within the network, including the transfer of knowledge from senior stakeholders. The YPN has the ambition to serve as a meeting place for free-thinking, where new solutions from a new generation can emerge. The network is open to young staff having a scientific or technical background and scope of work and a formal, long-term employment relationship with either an NDC or the PTS. Young, in the context of the YPN, is below the age of 40 years.

The network meets virtually and at the PrepCom-related events and meetings where the participants get to know their peers from around the world. Network members develop joint projects, share knowledge and receive guidance from senior experts. The network has more than 50 active members from 27 countries worldwide.

Fig. 11.4.4 *The photo on the left shows the Chair of WGB, Joachim Schulze of Germany, addressing YPN members and stakeholders at a gathering in Vienna in March 2019. Photo to the right: Schulze, Anne Lycke, and Patrick Grenard, Director of Administration at the PTS, taken at the same gathering.*

In section 8.3, we mentioned some issues that presented difficulties to the WGB and the PrepCom. We will revert to these issues here. We will see how the controversies have developed over time and what solutions have been found for some of the problems.

The mode of operation of the IMS and the IDC before entry into force of the CTBT early became a contentious issue in WGB. Delegations had very differing ambitions for this operation, ranging from the requirements agreed by PrepCom for post-entry into force to a much less demanding operational mode. A decision by the PrepCom plenary in 2001 states that the mode of operation shall be provisional and for testing purposes only, with minimum requirements that are relaxed relative to those of the agreed draft operational manuals, which apply to operations after entry into force. Still, we see that many IMS stations are operated to very high standards and fulfil the operational manuals' requirement of 98% for IMS station data availability. Most stations are operated under contracts with the PTS. These contracts require the standards stated in the operational manuals. However, in line with the 2001 PrepCom decision, failure to meet the operational manuals' requirements does not lead to reductions in payments to IMS station operators. After 20 years, the 2001 PrepCom decision still holds, and there are no signs that it will be reconsidered. Nevertheless, some countries have indicated that they consider the provision of data from IMS stations as voluntary during the PrepCom phase.

The IDC is being developed under a commissioning plan initially adopted by the PrepCom plenary in 1997, containing six phases. Currently, the development is in the later stages of phase five, preparing for phase 6, which is validation and acceptance of the IDC before entry into force of the CTBT. In recent years, the execution of this plan by the PTS has created much discussion in WGB, mostly related to the pace of development. Several countries feel there is no urgency, given the current prospects for entry into force of the CTBT, and have argued that the sequence of experiments making up the later stages of phase five should be planned, conducted and evaluated in concert between the PTS and WGB before starting on the next experiment. As a result of hard work by the Task Leaders and the PTS, as well as constructive discussions in WGB, an understanding was reached that is bringing the IDC commissioning forward in an orderly way. The PTS will, as part of this commissioning process, conduct experiments it considers to be technically necessary for the final acceptance of the IDC. As requested by States Signatories, the PTS should maintain a balance between new experiments and addressing recommendations emerging from previous experiments.

Radioactive noble gas monitoring has presented challenges to WGB ever since 1997. The protocol to the CTBT states that the IMS radionuclide network shall comprise 80 stations, all of which should measure the presence of relevant particulate matter in the atmosphere. In addition, according to the Treaty text: "Forty of these stations shall also be capable of monitoring for the presence of relevant noble gases upon the entry into force of this Treaty." Different interpretations of the word "upon" in this sentence in the English and Chinese texts of the Treaty (which are equally authentic) gave rise to discussions in WGB about the pace of the establishment of the noble gas component of the IMS. The solution was to establish in 1999 the International Noble Gas Experiment (INGE) to test the measuring of radionuclide noble gases released by nuclear explosions. Through INGE activities, delegations familiarized themselves with the noble gas technology. They gained sufficient confidence to proceed with the stations, so in 2010, the first noble gas system was certified and formally integrated into the IMS. Currently (in 2021), 25 of these 40 systems are certified (including the noble gas system at RN49 in Longyearbyen), six are installed, and the remaining nine are under construction. INGE is thus an excellent example of collegial cooperation at a technical level (including in WGB expert groups) that has brought the CTBT verification regime closer to completion.

Another difficult issue in WGB has been the use by the PTS of mobile equipment to map background levels of radionuclide noble gases. The EU has funded these efforts. The background levels of gases can, for instance, increase because of releases from medical isotope production plants, affecting the detection capability of the IMS noble gas network. For various reasons, such measurements by the PTS became controversial, as several WGB delegations held the view that discussion of their countries' emissions was outside the mandate of the PrepCom. Other WGB delegations found these PTS activities to be within the mandate. The PrepCom plenary stated in 2018 that it is not within WGB's authority to discuss the mandate of the PrepCom. Accordingly, the PrepCom plenary itself will attempt to resolve this controversy in 2021 or later. The process in WGB could perhaps have been organized differently to avoid ending up in a discussion on the mandate of the PrepCom.

The decision to participate in WGB sessions is up to each member state, and expenses must be borne by each state sending delegates. Over the years, many countries could not afford to send technical experts from their National Data Centers to Vienna and felt that the presence of experts in WGB became unbalanced, with very few representatives from developing countries. Proposals were made to use funds from the regular budget of the PrepCom to support WGB participants from developing countries to rectify this situation. Other delegations turned down this proposal, and the situation threatened the mood and, to some extent, the credibility of the work of WGB. The solution was found in 2006 when the Project for the Participation of Technical Experts from Developing Countries in Official Technical Meetings of the Preparatory Commission was established. This project is based on voluntary financial contributions, which by 2020 were received from 23 member states, OPEC, and the EU. So far, more than 1.6 million USD have been donated, and the single largest donor is Norway, which has contributed about 320,000 USD. The project has enabled the participation of about ten technical experts from developing countries in every WGB session since 2006, which has helped restore the balance in the group. This funding mechanism has also been instrumental in the recruitment of Task Leaders for WGB from developing countries.

As intended, WGB has become the organ where member states, through active participation, can promote the development and effectiveness of the international means to verify compliance with the CTBT. Other venues may be more innovative in their search for new methods, but in the end, all new approaches must be introduced in WGB if they are to be considered for implementation in the IMS, the IDC, or for use in OSIs. In our assessment, WGB has fulfilled its role reasonably well and contributed to implementing and advancing the verification mechanisms of the CTBT through cooperation among delegations and willingness to compromise. WGB has, in our view, handled its cooperation with the PTS constructively and, in this regard, tried to avoid micromanagement. However, it must also be noted that WGB has become increasingly politicized, which is not entirely surprising, as verification in its nature is not only technical but also political. For this reason, it has been challenging to move technical matters forward. There may be a need to organize the work in WGB slightly differently to become more productive on the technical side and, simultaneously, not shy away from tackling the more politically oriented verification issues.

For Norway, NORSAR's active participation in WGB, including in the roles as Task Leaders, has provided both influence on and detailed insight into all processes related to the implementation of the CTBT verification regime. This participation has also provided insight into the delegations' considerations of the political aspects of the CTBT. NORSAR has thus been in a position to convey to Norwegian authorities a full picture of the status of CTBT implementation. Also, as we have seen, NORSAR's engagement has enabled it to take part in work on broader aspects of nuclear disarmament verification.

11.5 NORSAR's 50th anniversary in 2018

NORSAR celebrated its 50th anniversary on several occasions in 2018. Most notably, HRH Crown Prince Haakon visited NORSAR's office facilities at Kjeller on 15 June (see Fig. 11.5.1), the actual anniversary date. He was presented with some of NORSAR's contributions to a safer society:

- Nuclear test ban verification: this area was highlighted through the large nuclear explosion by the DPRK in September 2017 and NORSAR's assessment of the high number of aftershocks as tectonic and not nuclear in origin
- Earthquake zonation map for Norway: this is important for proper assessment of seismic risk
- Microseismic monitoring for safe exploration of oil and gas: safe exploration can be achieved through mapping and understanding of earthquakes induced by subsidence or injection in the underground
- Microseismic monitoring for safe storage of CO2: in order to prevent leakages from underground stores, it is necessary to understand the geological responses to the CO2 injection, and microseismic monitoring is the solution
- Further development of an alarm system for natural hazards: monitoring of rockslide-prone mountain slopes is an important contribution to safeguarding settlements and infrastructure
- Seismic modeling software: software developed and marketed by NORSAR provides cost-effective oil and gas exploration.

All of these services have emerged from expertise and competence originally developed for nuclear test ban monitoring.

In August, NORSAR invited collaborators, its own staff, and other guests to viewing in Oslo of the movie "Skjelvet" ("The quake") before its official release. This movie's theme is a large future earthquake that hits Oslo. NORSAR, and in particular Conrad Lindholm, acted as an adviser to the production team on scientific matters. Public attention around this movie presented NORSAR an opportunity to communicate the story of its 50 years. At the time of the movie's release, this was achieved through posters displayed in a pedestrian area in downtown Oslo (see Fig. 11.5.2).

***Fig. 11.5.1** The photo on the left shows HRH Crown Prince Haakon inspecting a seismic vault at NORSAR's premises at Kjeller during his visit on 15 June 2018, and to the right, he is listening to a presentation at one of the stands.*

***Fig. 11.5.2** The photo on the left shows in the middle the two leading actors in the movie "Skjelvet," Kristoffer Joner and Ane Dahl Torp, flanked by NORSAR's Conrad Lindholm, Arve E. Mjelva and Anne Lycke. To the right: NORSAR on public display in downtown Oslo.*

The Norwegian ambassador in Vienna also celebrated NORSAR's 50 years at a reception in her residence during the September 2018 WGB session. Many ambassadors, WGB delegates, and representatives of the PTS were in attendance. In late

September, the entire NORSAR staff marked the anniversary with a trip to Iceland, which included a full-day tour of the earthquake-prone Reykjanes peninsula, inspecting its volcanic systems, lava fields, geothermal craters, and mud pools (see Fig. 11.5.3).

***Fig. 11.5.3** The photo shows the NORSAR staff distributed across the Mid-Atlantic Ridge in southwestern Iceland, which separates the diverging North American and European plates.*

11.6 50th anniversary of the Nordic detection seismological cooperation in 2019

The Nordic cooperation in detection seismology has been important to NORSAR. In Section 2.3, we looked at the initiation of this cooperation and its development over the first few years. But what has come from the high ambitions formulated with considerable political support in the late 1960s?

The 50th Nordic Seismology Seminar (the word "Detection" in the title was dropped along the way to broaden the scope of the seminar) took place in Uppsala, Sweden, from 14 - 16 October 2019 (see Fig. 11.6.1, which shows the participants at the 50th seminar). This meant that the seminar had continued, after the two first meetings in late 1969 and early 1971, annually thereafter in an unbroken series, with seminar organizers loyally taking on their duties on a rotational basis. This commitment is an achievement in itself, given the increasing number of meetings and conferences competing for attention. The list of these 50 seminars with dates and venues is provided in Appendix 3. Iceland joined as a regular seminar organizer in 1981.

***Fig. 11.6.1** The photo shows the participants at the 50th Nordic Seismology Seminar in Uppsala in October 2019. Seated in the middle of the front row: Hilmar Bungum (formerly at NORSAR), Ola Dahlman, and Ragnar Slunga (both formerly at FOI, Sweden), who participated in the first seminar in Oslo in 1969.*

Beyond the annual seminars, what are the results of the Nordic cooperation? As we noted in Section 2.3, some of the ambitions were revised in 1973 because of the strong development of national detection seismology programs in Norway and Sweden in particular. We can make the following observations when we look back:

- The basic goal of the Nordic cooperation was to contribute to the international efforts to verify a future ban on underground nuclear tests. It is fair to say that joint Nordic efforts and efforts by individual countries have contributed significantly to this goal. As we have seen, Sweden and Norway assumed leading roles in the work of the GSE, leading up to the CTBT negotiations, and in the efforts by WGB of the CTBTO PrepCom to implement the CTBT. From 1976 to 2006, Sweden chaired the GSE and then the WGB; from 1976 to 1996, Norway had the Scientific Secretary of the GSE; from 1997 to the present, Norwegians held positions in WGB as Friend of the Chair and Task Leaders. Denmark and Finland have also participated actively in these bodies. In our assessment, the Nordic leadership enjoyed confidence from representatives of all regions of the world and was seen as highly credible, without specific national partialities. This facilitated the development of a culture of cooperation across the board, especially in the GSE.
- As we saw in Section 2.3, there was an ambition of a common Nordic research program in detection seismology. Such a program was formulated in 1973 but was not executed as a coordinated effort. On the other hand, the Nordic seminars have been a venue for reviewing research results in test

ban verification, inspiring further developments. A review of the programs of the seminars shows that research efforts in the Nordic countries have helped advance all technologies of the CTBT verification regime, with many contributions, especially in station design, development, and operation, as well as in IDC data processing.
- The Nordic cooperation has given birth to a number of bilateral projects. For NORSAR, the most significant projects have been with FOI, regarding the refurbishment and operation of the Hagfors array (auxiliary seismic station AS101 in the IMS), and with the Institute of Seismology of the University of Helsinki, regarding the development and installation of the original FINES array, which later became a primary seismic station in the IMS (PS 17).

After the anniversary meeting in 2019 and as of the writing of this book, two more Nordic meetings have been held, both in virtual format due to the Covid-19 pandemic. During the last 10 - 20 years, there was less emphasis in these meetings on CTBT verification matters than previously, and one may wonder why. One reason may be that WGB offers increasing opportunities to discuss technical issues and is seen as a more relevant venue. We think, however, that the past has shown that joint efforts by the Nordic countries have efficiently advanced CTBT verification. A revitalization by the younger generation might provide one means of again joining efforts at the Nordic level to benefit the further development of the CTBT verification regime.

11.7 NORSAR expands its network of seismic stations

The last decade has seen a significant expansion of NORSAR's network of seismic stations. Here we will focus on NORSAR's station in Antarctica and the array at Bjørnøya.

NORSAR's Johannes Schweitzer and Michael Roth installed a high-quality, broadband seismic station in February 2012 named TROLL, close to the Troll research station in Antarctica, with support from the Norwegian Polar Institute. The station, which provides data on a real-time basis, is installed on bedrock, some 230 km from the coast of Dronning Maud Land (see Fig. 11.7.1). This location makes TROLL one of the quietest stations in Antarctica. TROLL records a multitude of seismic signals, with only very minor data loss.

The seismic activity recorded at TROLL results from tectonic processes in the vicinity of the station and globally, as well as the dynamics of the Antarctic ice sheet. Recorded earthquakes at large distances complement NORSAR's monitoring of global seismicity, while, due to the favorable distance, TROLL seismic recordings can be used to enhance our knowledge of the focal depth of large earthquakes in the European Arctic. Records of earthquake activity in Antarctica are especially important since, until recently, the continent was considered largely aseismic. However, most of the seismic events recorded in the surroundings of TROLL are due to seismic emissions related to the movements (surging, crevassing, calving) of the ice sheet. Another type of signals recorded at TROLL originates from large icebergs drifting along the coastline of Dronning Maud Land, interacting with the ice shelf, the ocean floor, or each other.

Fig. 11.7.1 *The photo on the left shows the TROLL seismic station just before the installation was completed in February 2012. The Troll research station is seen in the background. Right: View from the station.*

The European Plate Observing System (EPOS) is a multidisciplinary, distributed research infrastructure that facilitates the integrated use of data, data products, and facilities from the solid Earth science community in Europe. Within the EPOS framework, the Research Council of Norway provided funds to six geoscience institutions in Norway, including NORSAR, to establish new geoscientific infrastructure in Norway during 2016-2020. One of the main goals of this project, EPOS-Norway, was to expand the network of seismic stations in the Arctic parts of Norway to improve the capability of monitoring earthquakes and other seismic events in this area. NORSAR's main share of EPOS-Norway is a seismic array at Bjørnøya, an island located midway between mainland Norway and Spitsbergen.

The temporary seismic array which was deployed on Bjørnøya during the summer of 2008 showed a significantly improved event detection capability in comparison with that of the permanent three-component station on the island. It was thus clear that a seismic array on Bjørnøya would have the potential to close a large gap in the monitoring of seismic events on the western Barents Sea shelf, Mohns Ridge and the Knipovich Ridge, as well as the main Barents Sea region to the east. This potential provided the impetus for NORSAR to propose an array at Bjørnøya as part of EPOS-Norway.

Fig. 11.7.2 *To the top left is Bjørnøya, approximately 20 km in length, north to south. The six-element seismic array is located within the area shown with red borders in both maps, close to the meteorological station on the island. Right: NORSAR's Kjell Arne Løken and Jon Magnus Christensen during the array installation campaign on the island in August 2019.*

NORSAR originally planned to build a nine-element, one-kilometer aperture array about four to five km inland to avoid the seismic noise created by sea waves hitting the shorelines. However, nearly all of Bjørnøya is a nature reserve with strict restrictions on installations and activities. Two full rounds of applications to the Governor of Svalbard for the necessary permissions to establish the station within the nature reserve were unsuccessful, and eventually, permission was granted for a six-element array of an aperture of about 400 meters within the less restricted area surrounding the meteorological station at Bjørnøya; see Fig. 11.7.2. The array station was established in August 2019. NORSAR personnel can only travel to the station with the help of the Coast Guard, their sailing plans permitting, so it is an asset to NORSAR that staff at the meteorological station are available to assist with operational issues as needed. Data are transmitted continuously and in real time to Kjeller, using capacity on the satellite link of the meteorological station. The station has operated stably, with a minimum loss of data, after some adjustments were made during the first year of operation. The array has contributed to the definition of additional seismic events in the Arctic, but a full evaluation of its capabilities is still pending.

In addition to the two stations described above, the following stations have been installed during approximately the last fifteen years and are currently in operation:

- In cooperation with the Institute of Geophysics of the Polish Academy of Sciences, NORSAR installed a three-component broadband seismic station at the Polish Research Base Hornsund in Spitsbergen in 2007. The Polish Academy of Sciences operates the station. There are concrete plans for extending this station to an array during 2022, using excess equipment from the EPOS-Norway project.
- In 2010/2011, NORSAR and the Kola Regional Seismological Centre installed two three-component broadband seismic stations in Barentsburg in Spitsbergen. These stations improve the monitoring capabilities of man-made events (e. g., mining blasts and rockbursts), seismic events related to moving glaciers, and earthquakes.
- To monitor unstable rock slopes in Norway, NORSAR operates two three-component broadband stations at Åknes (since 2009) and Nordnes (since 2014), in southern Norway and northern Norway, respectively.
- The IMS infrasound station IS37 at Bardufoss was augmented in 2015 with a seismic three-component broadband station at the central array site to measure seismic ground motion alongside infrasound.
- Seven short-period three-component stations were deployed in 2018 as a network around the Oslofjord in southern Norway to monitor local seismicity in this densely populated region.
- In 2020, a small-aperture, broadband nine-element seismic array was installed at Holsnøy on the west coast of southern Norway as part of a collaborative project between Equinor and NORSAR. The purpose of this array is to establish the level of background seismicity in the Horda platform area, which is a designated area for a future subsurface CO2 storage site.
- The original NORES array from 1984 was struck by lightning in 2002 and was totally damaged. The array was gradually restored over the years, using modern instruments compatible with those of NORSAR's other stations, and from 2010, the array comprises 16 elements (center, A-, B- and C-ring).

- Both NORES and ARCES incorporate small, experimental infrasound arrays.

A Norwegian national pool of 30 mobile broadband seismic stations was established in 2014. The instruments in this pool are available for temporary deployments. The pool is managed by a committee with representatives from all institutions in Norway that have an activity in seismology. NORSAR leads the committee and also hosts the instruments.

It should also be mentioned that most of NORSAR's seismological data are made available through the Norwegian EIDA (European Integrated Data Archive) node, a joint undertaking between the University of Bergen and NORSAR.

A paper by Schweitzer and others (2021) provides a complete overview of the status of NORSAR's seismic network.

11.8 Special events observed at NORSAR's stations

Over the years, NORSAR's stations have recorded signals from various types of accidents, and also from a terrorist attack. Several of these events have resulted in tragic losses of lives. One such example is the accident in August 2000 with the Russian submarine Kursk, for which we described NORSAR's observations in Section 9.4. Although not directly relevant to CTBT monitoring, we will show NORSAR's data related to several such events to illustrate the potential of providing essential information to, e.g., investigating committees for their consideration. Tormod Kværna has been a key person in performing analysis for many such events over the years.

In August 1991, the concrete support structure of the Sleipner A oil platform sunk in Gandsfjorden, near Stavanger on the west coast of southern Norway, resulting from leakages during testing. The platform hit the sea bottom at a depth of 200 meters, and only rubble was left. Seismic records of the impact from seven sensors of the NOA array at distances of approximately 400 kilometers are shown in Fig. 11.8.1. The amplitudes of the signals at the NOA array corresponded to a magnitude 3 earthquake. From seismic energy considerations, NORSAR could estimate the sea bottom impact velocity.

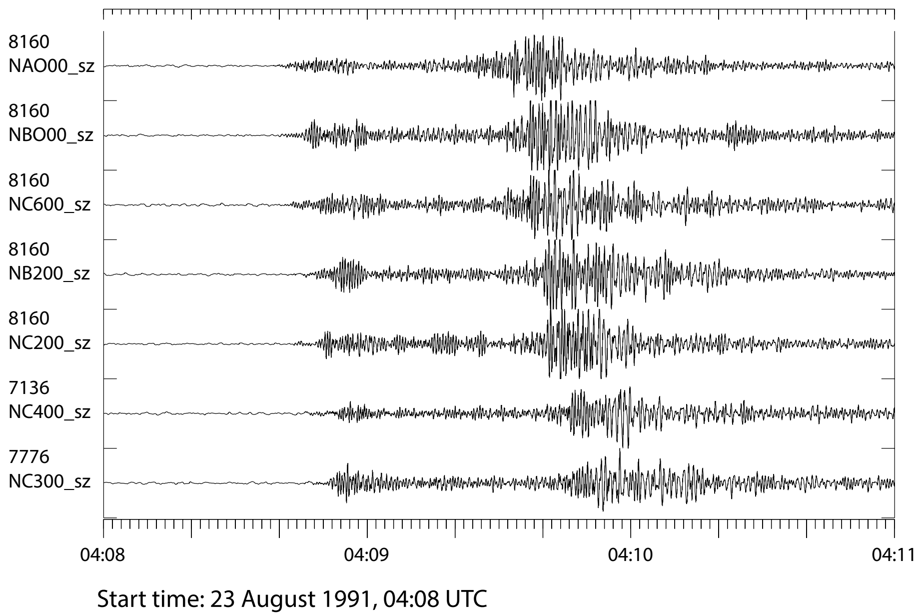


Fig. 11.8.1 *The impact from the Sleipner A platform hitting the sea bottom generated seismic P and S waves observed at the NOA array some 400 km away.*

In August 1996, a tragic accident happened in Spitsbergen when an aircraft hit Operafjellet on its approach to landing in Longyearbyen. There were 141 fatalities, including the crew and Russian and Ukrainian miners and their families, making this the largest aircraft accident in Norway. The seismic SPITS array is located only 6 km from the crash site. In Fig. 11.8.2, the seismic P and S waves from the impact can be seen on all nine elements of the SPITS array. Sound waves, traveling more slowly than the seismic waves, are also observed.

A tragic train accident occurred in January 2000 near Åsta in the eastern part of southern Norway. Two trains collided, and 19 people died. Subarray NB2 (earlier called 02B) of the NOA seismic array is located very close to the accident site, with the nearest sensors only a few kilometers away. Fig. 11.8.3 shows the recordings of the signals from the accident made at the six elements of this subarray. From these records, NORSAR could provide an estimate of the time of the collision to the investigating committee, with a precision of 0.3 s. According to the committee, this was the most precise estimate of the collision time available.

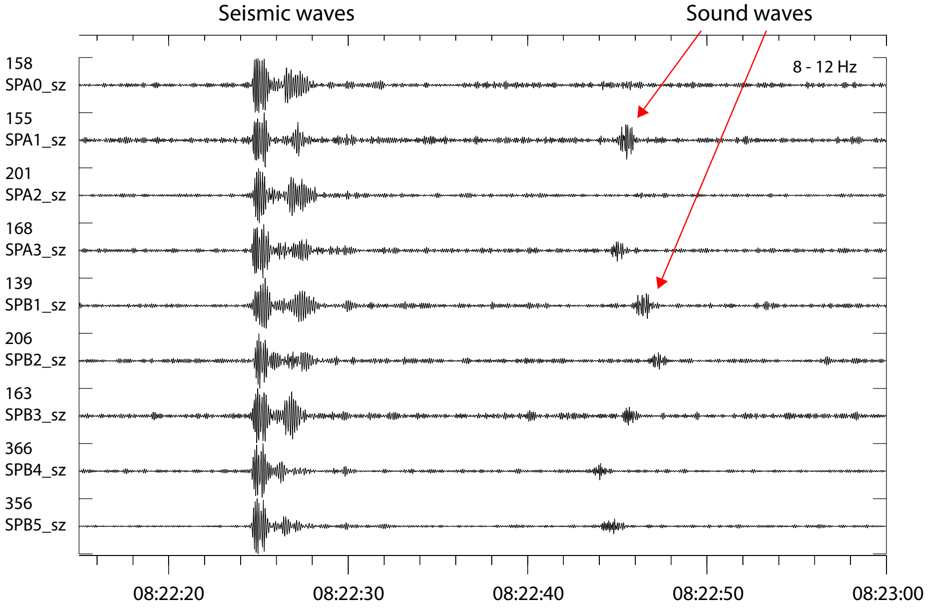


***Fig. 11.8.2** The aircraft accident at a distance of 6 km from the SPITS array on 29 August 1996 generated both seismic and sound waves that are clearly seen in these records from the station.*

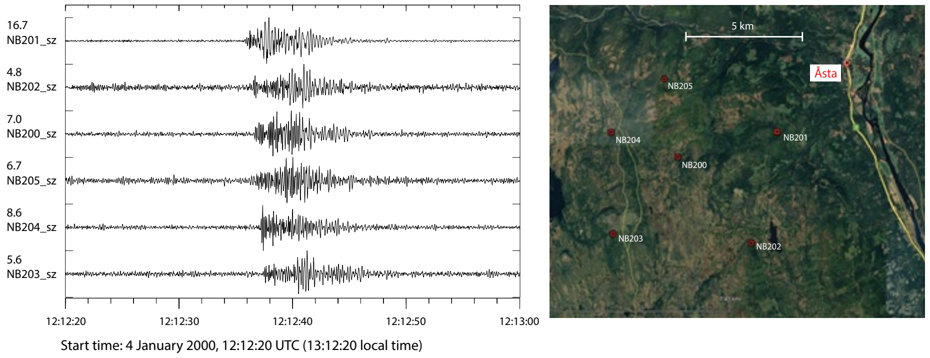


***Fig. 11.8.3** The train collision at Åsta in January 2000 occurred just a few km from the six sensors of NOA subarray NB2 (earlier called 02B). Signals from the accident were recorded on the sensors shown as red symbols on the map to the right. The railway line closely follows the leftmost yellow line, a road.*

Seismic signals from the terrorist attack on the government buildings in the center of Oslo on 22 July 2011, which tragically killed eight people, were observed at NORSAR's instruments at Hedmark and also at the Hagfors array in Sweden (see Fig 11.8.4), all at distances of more than 100 km from Oslo. The bomb consisted of 950 kg of ANFO explosives.

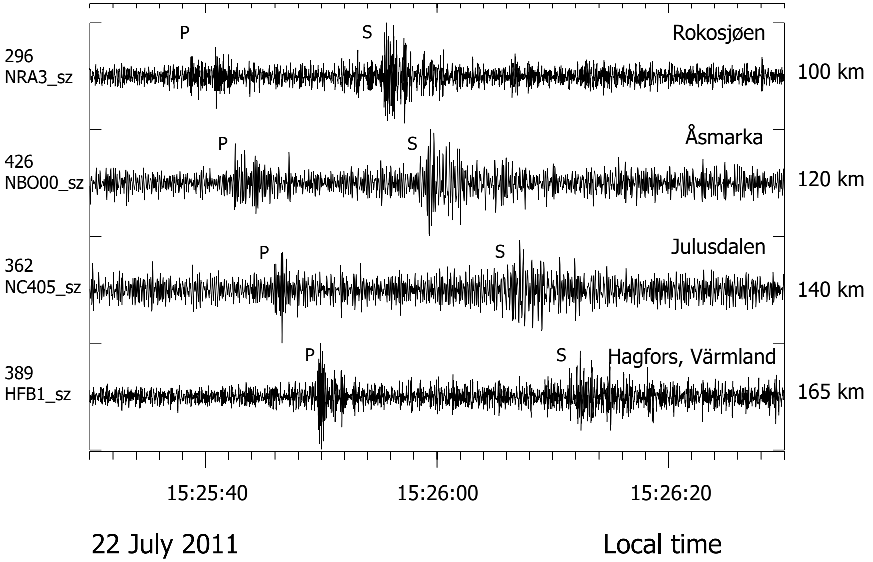


***Fig. 11.8.4** Seismic signals from the terrorist's bomb in Oslo on 22 July 2011 were observed at NORSAR's stations 100 km and more to the northeast, and in Sweden.*

Almost 15 tons of dynamite, loaded on a truck at Drevja in northern Norway, exploded in December 2013, resulting in damage to about 20 buildings, but fortunately, there were no casualties. Infrasound signals from this explosion (see Fig.11.8.5) were observed in Norway, Sweden, and Finland, and also at a station in Apatity on the Kola Peninsula in Russia, at a distance of close to 900 km.

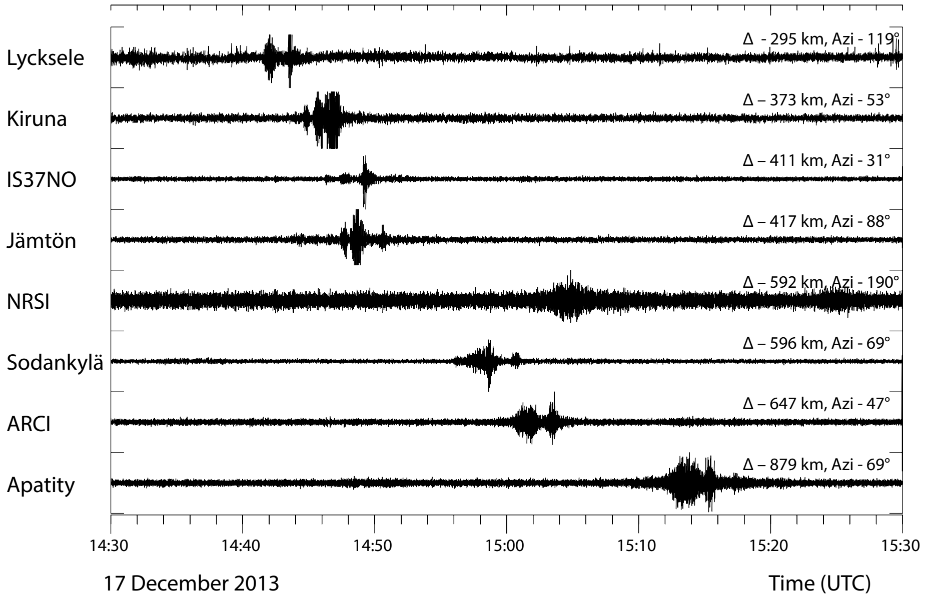


Fig. 11.8.5 *Infrasound signals from the dynamite explosion at Drevja in December 2013, observed at eight stations in Norway, Sweden, Finland, and Russia.*

In October 2017, a Russian helicopter disastrously crashed into the sea at Barentsburg, Spitsbergen, a few km north of its intended landing site, and eight people lost their lives. Data from the seismic three-component station BRBB and a co-located three-element infrasound array could be used in a detailed and careful analysis to estimate the geographical coordinates of the crash site in the water and to reconstruct aspects of the flight of the helicopter prior to the crash. This analysis is illustrated in Fig. 11.8.6. Results were provided to the Governor of Svalbard, and the helicopter was later found on the sea bottom, right below the crash location estimated by NORSAR.

NORSAR receives telephone calls and emails around the clock from the public and news media about earthquakes and sometimes various kinds of explosions that people have felt. NORSAR has considered it a part of its mission to make its best effort to respond to such inquiries in a timely manner. NORSAR's chief analyst Berit O. Paulsen is key in these efforts.

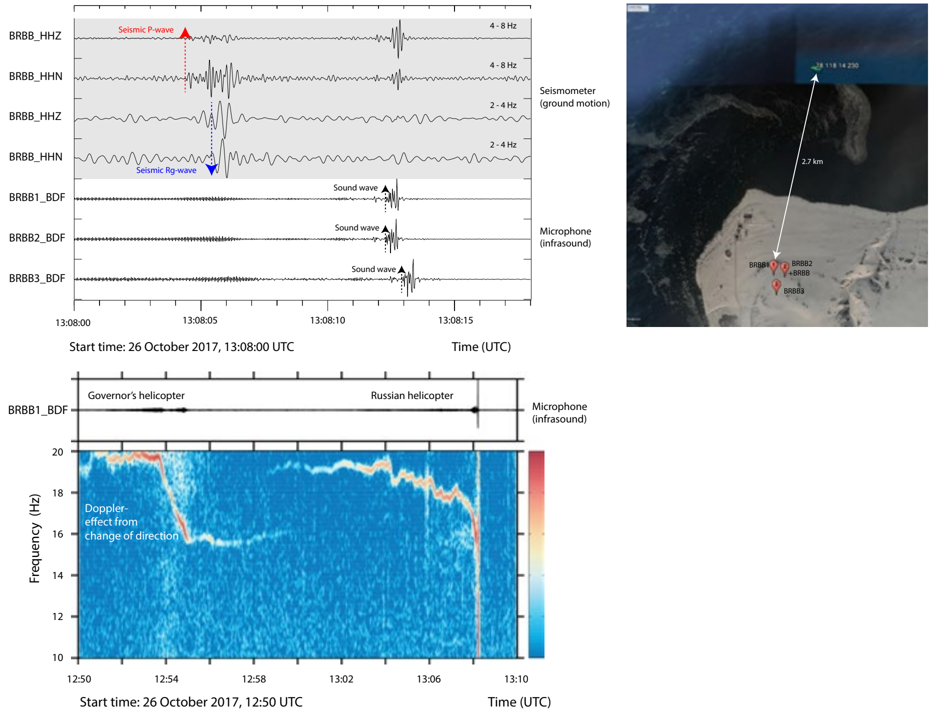


Fig. 11.8.6 *This figure shows aspects of NORSAR's analysis of seismic and infrasound data performed to shed light on the helicopter accident near Barentsburg, Spitsbergen, on 26 October 2017. Upper left: Seismic and infrasound recordings of the crash. Lower left: Variation in the Russian helicopter's main rotor frequency to the right (the curve to the left is for another helicopter in the area some minutes earlier, unrelated to the accident). Upper right: The estimated crash site in the sea, based on a distance estimate from the seismic and infrasound data in combination, and an estimate of the direction from the infrasound array data alone.*

Chapter 12

The way forward

12.1 A summary of NORSAR's main contributions

At this stage, we summarize what we consider NORSAR's main contributions to test ban monitoring in general and the external and internal conditions that made these contributions possible. We will also address some of the disappointments we encountered and how they changed the focus of NORSAR's efforts.

A quick guide to the developments towards the CTBT, internationally and from Norway's and NORSAR's perspectives, is found in Appendix 4.

Achievements until the 1996 CTBT

When the United Nations adopted the CTBT in 1996, the NORSAR organization could rightly be proud of its role as an important participant in an international effort to achieve this longstanding goal.

The basis for establishing NORSAR was the United States-Norway Government-to-Government agreement of 1968. Thus, the background for NORSAR was political. The United States financed the construction of all the NOA facilities, including the field development of the array sites, cables, telephone connections, and the NORSAR data center.

The NOA array and the associated data processing software were modeled after the large LASA array in Montana and was initially thought to be one of a few gigantic seismic observatories to monitor a future comprehensive test ban treaty. After a few years, the United States changed its emphasis on large arrays, which resulted in a significant reduction in the size of the NOA array. Initially, this reduction was a disappointment for NORSAR, but on the other hand, this reduction became the starting point of the regional array program, which became a formidable success.

The initiative by Sweden in 1976 to establish the GSE, under the auspices of the Conference of the Committee on Disarmament in Geneva, turned out to be key to advancing and broadening the scientific work associated with monitoring a CTBT (Dahlman et al., 2020). This initiative created a forum that established a unique synergy between the political and scientific communities.

Many diplomats, including the Chairman of the CTBT negotiating committee, have characterized the GSE as the "success story of the Conference on Disarmament."

NORSAR's participation in the GSE resulted, for the first time, in financial support to NORSAR by the Norwegian Ministry of Foreign Affairs. As described in previous chapters, Norway, through NORSAR, obtained key roles in the GSE throughout its 20-year lifetime in Geneva until the United Nations adopted the CTBT in 1996.

From 1979, NORSAR began developing a prototype small regional seismic array in cooperation with experts from ARPA and the Sandia and Livermore laboratories of the United States Department of Energy. These joint efforts reached a pinnacle when United States President Ronald Reagan sent a congratulatory message in 1985 on the NORESS construction, followed by the Conference on Disarmament (CD) workshop in Oslo with the participation of 84 diplomats from 41 countries and the Secretariat of the CD.

It is no exaggeration to state that Norway, although not a member state of the CD until just before the conclusion of the CTBT negotiations, carried more weight in test ban issues than most of the member countries. In addition to Frode Ringdal's efforts in drafting all of the GSE progress reports and all of the comprehensive GSE reports to the CD, the Norwegian participants in the GSE submitted more than 100 detailed scientific and technical working papers that were presented and discussed at the GSE sessions.

Moreover, Norwegian diplomats, particularly Sten Lundbo, kept the CD informed for several years on the progress of Norway's seismic array research, as shown in Box 4.4.2.

More than 1000 scientific papers were published by NORSAR scientists and visiting experts during these years, many of them in international peer-reviewed journals. Groundbreaking advances that NORSAR achieved or contributed to within seismology and seismic monitoring included:

- Operation and processing of data from some of the world's largest and most advanced seismic observatories
- Development and application of maximum likelihood estimation of seismic magnitude
- Small-aperture array detection and location processing algorithms
- Explosion yield estimation
- Development and evaluation of expert system analysis procedures
- Generalized beamforming for advanced processing of regional and global seismic networks
- Seismic threshold monitoring and global capability studies.

Achievements after the 1996 CTBT

The United Nations adopted the CTBT in September 1996, and the CTBTO PrepCom was established in November 1996 by the countries that had signed the CTBT by then. Following considerable political effort by many countries (described in detail in Chapter 8) the PrepCom opened its doors in March 1997 in Vienna, Austria.

NORSAR experts assumed key roles in contributing to developing the global monitoring networks and establishing the Provisional Technical Secretariat (PTS) in Vienna.

NORSAR recorded the Indian and Pakistani nuclear tests in 1998 and could confidently state to the Norwegian Ministry of Foreign Affairs that those countries' reported yields were exaggerated. Nevertheless, it was clear that the two countries had documented beyond any doubt that they possessed nuclear weapons.

In 1999, Norway ratified the CTBT and allocated 15.3 million NOK to NORSAR. However, for the year 2000, the funding was cut back to 13.3 million NOK, and there were further cuts over the years so that the annual funding after 15 years was only about 50 percent of the amount for 1999 in real terms, despite the efforts by NORSAR to reverse this trend.

The United States continued to engage NORSAR in scientific projects, notably the five-year calibration workshops (Section 9.6) and various infrasound studies (Section 10.5). The Spitsbergen array refurbishment (AS72) was supported financially by the U.S. NORSAR continued its longstanding cooperation with AFTAC, including annual meetings on technical matters. Nevertheless, NORSAR's financial situation became increasingly strained.

On 9 October 2006, North Korea (DRPK) announced that it had conducted a nuclear weapon explosion at its test site. This event presented a real-life test case for the CTBT verification system. Although completed only partially and operating in test mode, the CTBT verification regime proved capable of meeting the expectations set for it.

As is now well known, the DPRK has carried out an additional five nuclear tests, the last one (as of this writing) in 2017. The DPRK claimed that the 2017 test was a thermonuclear explosion. It had a much higher yield than the previous ones. NORSAR estimated the power of the 2017 test to be about 250 kilotons. Radionuclide xenon gases that might be attributed to releases from nuclear tests in DPRK were detected following the explosions in 2006, 2013, and 2017.

Anne Strømmen Lycke took over as CEO of NORSAR on 1 January 2014. She brought new energy to the efforts to increase the Ministry of Foreign Affairs' budget for NORSAR's CTBT-related activities through persistent and systematic work to document the funding shortfall. A revised program of work was defined that responded to the needs of the authorities, keeping in mind the will expressed by the parliament when Norway ratified the CTBT in 1999.

As a result of these initiatives, the funding of the CTBT mission for the Ministry of Foreign Affairs has increased and is now comparable to the 1999 funding level in real terms, i.e., with inflation and salary increases taken into account. However, the scope of the mission has changed over these years to include additional elements.

In early 2007, NORSAR took the first step in expanding its scope of work to the broader nuclear disarmament issues beyond CTBT verification. Three Norwegian institutions had formed a network, "NorNed," to address technical issues related to nuclear disarmament and invited NORSAR to join. As its first substantial activity and with support from the Ministry of Foreign Affairs, NorNed embarked on bilateral, technical cooperation with the UK.

In 2015, Sweden and the United States joined Norway and the United Kingdom in pursuit of further advances in nuclear disarmament verification called the Quad Nuclear Verification Partnership. NORSAR also participates in the work of the International Partnership for Nuclear Disarmament Verification, which was formed in 2014 by the United States and the Nuclear Threat Initiative and includes 25 member countries. This initiative has explored the physical dismantlement of a nuclear weapon, verification of declarations and reduction of weapon arsenals, and various technologies for verification.

NORSAR's success during these years has definitely been due to hard-working and dedicated staff, many of whom actually spent most, if not all of their careers in support of NORSAR. Furthermore, NORSAR enjoyed consistent support from its Board of Directors, the Norwegian Research Council (originally NTNF), and the Norwegian Ministry of Foreign Affairs.

NORSAR's cooperation with the Norwegian permanent mission in Vienna has always been excellent. The diplomats there have taken a keen interest in the PrepCom and its activities, and they have, to a large extent, attended the WGB plenary sessions along with NORSAR's representatives. A highlight in their engagement occurred in 2013 when Ambassador Jan Petersen served as the chair of the PrepCom.

12.2 The future of the CTBT

The future of the CTBT will impact NORSAR's test ban-related activities in the coming years, whether the Treaty enters into force or not in the foreseeable future. On the political level, there are no concrete signs that any of the eight hold-out states (China, Egypt, India, Iran, Israel, North Korea, Pakistan, and the United States) are moving toward ratification, to permit the Treaty to enter into force. On the other hand, the CTBTO PrepCom, with its secretariat and governing bodies, is in good shape. Through constructive cooperation and stable processes among the organization's 185 member states (as of 2021), about 90 percent of the Treaty's verification system has been implemented thus far, and the efforts towards completing the system continue. In broad terms, the organization's financial situation is good and stable, as most member states pay their annual dues in full and on time, even in times of global financial austerity. There is, thus, every reason to continue supporting this organization's efforts, despite the current poor prospects for entry into force of the Treaty.

So, what can NORSAR do to promote the future of the CTBT? Obviously, NOR-

SAR will continue to support Norwegian authorities in all aspects of the implementation of the Treaty, both nationally and internationally. In this regard, continued active participation in the processes in the PrepCom in Vienna, especially in WGB, is of key importance. NORSAR's participants have communicated well with all regional and political groups in WGB and enjoy high respect for their technical skills and integrity. This starting point is excellent for a delegation that wants to build bridges between opposing views and contribute to obtaining consensus. One aspect of this is to develop the verification mechanisms to a level that makes it very difficult for any country to use the argument that the verification is not good enough as a reason not to ratify the Treaty.

For the credibility and integrity of CTBT verification, securing the widest possible participation by countries around the world is essential. Many member states, especially developing countries, do not have the specific competence or infrastructure needed for such participation, but almost all countries have a basis for developing what is needed. With support from the Ministry of Foreign Affairs, NORSAR has, over the years, engaged in capacity building for CTBT verification, most notably in Central Asia, as we described in Section 10.4, and NORSAR is in a good position to extend such activities to yet other regions.

12.3 The way forward for NORSAR

With past achievements, as summarized in Section 12.1, NORSAR is in an excellent position to continue its good work in the test ban area. Moreover, the recent increase in funding from the Ministry of Foreign Affairs enables NORSAR to plan the activities of its CTBT mission in a way that responds to today's needs and requirements. In this regard, the following assets are available to NORSAR:

- Competence and skills developed over the years that have largely been transferred to a new generation
- Several new employees mastering modern tools that can be applied to solve longstanding issues and problems in CTBT verification
- An environment comprised of both advanced research and operations. Having direct access to both a wealth of archive data going 50 years back in time and online data from many stations is a great asset to a research group for the testing and evaluation of new methods and algorithms in event detection and characterization

- A network of contacts working at institutions around the world that are involved in the test ban area. For NORSAR to maintain and further develop its position in CTBT verification, keeping up close ties with key institutions in the United States will be particularly important.

This narrative started in 1967 by describing plans, hopes, and prospects for future Norwegian contributions to the nuclear test ban efforts. It is fair to say that NORSAR has met or exceeded these expectations and can look forward confidently to the future.

Abbreviations and acronyms

AFTAC	Air Force Technical Applications Center (USA)
ALPA	Alaskan Long Period Array
ARCESS	Arctic Experimental Seismic System. Also called ARCES. Certified as PS28 in IMS
ARISE	Atmospheric Research Infrastructure in Europe
ARPA	Advanced Research Projects Agency (USA)
ARPANET	The initial American computer network that later became the Internet
AWE	Atomic Weapons Establishment (UK)
CCD	Conference of the Committee on Disarmament
CD	Conference on Disarmament
CEA	The French Alternative Energies and Atomic Energy Commission
CORRTEX	An American method to measure the size of a nuclear explosion
CTBT	Comprehensive Nuclear-Test-Ban Treaty
CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
CWC	Chemical Weapons Convention
DPRK	Democratic People’s Republic of Korea (North Korea)
DSA	Norwegian Radiation and Nuclear Safety Authority
EIDA	European Integrated Data Archive
EPOS	European Plate Observing System
EU	European Union
FFI	Norwegian Defence Research Establishment
FINESA	Seismic monitoring array in Finland. Also called FINESS and FINES. Certified as PS17 in IMS
FOA	National Defence Research Institute (Sweden)
FOI	Swedish Defence Research Agency (formerly called FOA)
GA	Global Association
GBF	Generalized BeamForming
GERESS	Seismic monitoring array in Germany. Also called GERES. Certified as PS19 in IMS
GSE	Group of Scientific Experts
GSETT-1	Group of Scientific Experts Technical Test No. 1
GSETT-2	Group of Scientific Experts Technical Test No. 2
GSETT-3	Group of Scientific Experts Technical Test No. 3

IAEA	International Atomic Energy Agency
IBM	International Business Machines
IDC	International Data Center (Vienna)
IFE	Institute for Energy Technology, Norway
IGR	Institute of Geophysical Research, Kazakhstan
IMP	Interface Message Processor (for ARPANET)
IMS	International Monitoring System
INGE	International Noble Gas Experiment
INTELSAT IV	Geostationary communication satellite
IRF	Swedish Institute of Space Physics
IRIS	Incorporated Research Institutions for Seismology
IS	Institute of Seismology, Bishkek, Kyrgyzstan
IS37	Certified IMS infrasound station in Bardufoss, Norway
ISC	International Seismological Centre, United Kingdom
JMIC	Auxiliary seismic station at Jan Mayen, Norway. Certified as AS73 in IMS
KRSC	Kola Regional Seismological Centre
KSAT	Kongsberg Satellite Services
kt	kiloton TNT (used to indicate yield of nuclear explosions)
LASA	Large Aperture Seismic Array (Montana, USA)
MFA	Ministry of Foreign Affairs (Norway)
NATO	North Atlantic Treaty Organization
NDC	National Data Center
NEIC	National Earthquake Information Center (USA)
NFR	The Research Council of Norway
NIL	Seismic station in Pakistan
NNWS	Non-Nuclear Weapon State
NOA	Norwegian large aperture seismic array. Certified as PS27 in IMS
NOK	Norwegian krone
NORESS	Originally short for Norwegian Experimental Small Subarray. Later the name of a permanent regional array. Also called NORES
NorNed	Network to address technical issues related to nuclear disamament, Norway
NORSAR	In this book used as the name of a research institute (see Section 1.4)
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
NRC	National Research Council of the National Academies of the United States

NTNF	Royal Norwegian Council for Scientific and Industrial Research
NWS	Nuclear Weapon State
OPEC	Organization of the Petroleum Exporting Countries
OSI	On-Site Inspection
PCA	Post-Certification Activities
PDE	Preliminary Determination of Epicenters
PIDC	Prototype International Data Center
PNE	Peaceful Nuclear Explosion (i.e., carried out for non-military purpose)
PNET	Peaceful Nuclear Explosions Treaty
PrepCom	Preparatory Commission for the CTBTO
PRIO	Peace Research Institute Oslo
PTS	Provisional Technical Secretariat (Vienna)
REB	Reviewed Event Bulletin
RN49	Certified IMS radionuclide station on Spitsbergen, Norway
SAIC	Science Applications International Corporation
SDAC	Seismic Data Analysis Center (USA)
SnT	Biennial Science and Technology conference (in Vienna)
SPITS	Spitsbergen auxiliary seismic array. Certified as AS72 in IMS
SSTM	Site-Specific Threshold Monitoring
TIP	Terminal Interface Processor (for ARPANET)
TM	Threshold Monitioring
TROLL	Seismic station in Antarctica, established by NORSAR
TTBT	Threshold Test Ban Treaty
UKNI	United Kingdom-Norway Initiative
UN	United Nations
USD	United States dollar
USGS	United States Geological Survey
USSR	Union of Soviet Socialist Republics
vDEC	Virtual Data Exploitation Centre
WGA	Working Group A of the Preparatory Commission of the CTBTO
WGB	Working Group B of the Preparatory Commission of the CTBTO
WMO/GTS	Global Telecommunication System of the World Meteorological Organization
WWSSN	World-Wide Standardized Seismograph Network
YPN	Young Professionals Network

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Appendix 1

The agreement with the United States

The following pages contain the proposition from the Government of Norway, submitted to the parliament in May 1968, for its consent to enter into a bilateral agreement with the United States on cooperation within detection seismology. The text of the agreement on such cooperation is included in the proposition in the Norwegian and English languages. The parliament unanimously agreed to the proposition, with no changes to the text proposed for the government-to-government agreement, which was signed on 15 June 1968.

Utenriksdepartementet.

St. prp. nr. 128.
(1967—68)

Om samtykke til foretakelse av noteveksling om inngåelse av en avtale mellom Norge og Amerikas Forente Stater om deteksjonsseismologisk samarbeid. Tilleggsbevilgning i 1968 under nytt kap. 108.

Tilråding fra Utenriksdepartementet av 10. mai 1968,
godkjent ved Kronprinsregentens resolusjon samme dag.

(Foredratt av utenriksminister John Lyng.)

Nye vitenskapsgrener har i de senere år kommet til anvendelse i det internasjonale arbeidet for å nå frem til atvaler om tiltak for rustningsbegrensning.

Helt siden 1958 da arbeidet for en avtale om forbud mot kjernefysiske prøveeksplosjoner tok til har identifikasjons- og deteksjonsseismologisk forskning stått sentralt i arbeidet for en fullstendig avtale om forbud mot kjernefysiske prøveeksplosjoner. Den avtale om forbud mot prøver med kjernefysiske våpen i atmosfæren, i det ytre verdensrom og under vannet som ble inngått i 1963, omfatter ikke underjordiske prøveeksplosjoner. En fullstendiggjøring av avtalen til også å omfatte slike eksplosjoner har imidlertid stadig vært et mål som i den senere tid har fått aktualitet etter at arbeidet med å få i stand en avtale som skal hindre spredning av kjernefysiske våpen er gått fremover. I innledningen til det foreliggende utkast til en ikke-spredningsavtale henvises således uttrykkelig til den endelige målsetting for prøvestansavtalen av 1963.

Spørsmålet om nødvendigheten av stedlig inspeksjon som ledd i en kontrollordning har hittil vært den fremste politiske hindring i arbeidet for en fullstendig prøvestansavtale omfattende også underjordiske eksplosjoner. På avstand kan slike prøve-eksplosjoner bare registreres ved hjelp av seismiske signaler. Det har derfor i de senere år i en rekke land vært arbeidet iherdig for å utvikle vitenskapelige metoder som bedre kan skille mellom signaler fra underjordiske prøver og fra jordskjelv.

Norge har gjennom Jordskjelvstasjonen, Universitetet i Bergen, tatt aktiv del i det internasjonale vitenskapelige samarbeid på dette felt. I årene etter 1958 arbeidet man særlig etter amerikansk initiativ med å etablere et verdensomspennende nett av vanlige seismografer. To slike seismologiske stasjoner er opprettet i Norge (Kongsberg og Kirkenes). Dette nett av mindre stasjoner har imidlertid hatt relativt liten betydning i rustningskontrollarbeidet.

I begynnelsen av 1960-årene utviklet man nye seismiske målemetoder gjennom etablering av såkalte «array»-systemer, bestående av et antall seismometre plassert i et bestemt geometrisk mønster hvor signalene fra enkeltinstrumentene underkastes en kombinasjonsprosess ved hjelp av databehandlingsteknikk. I årene 1962—63 ble det opprettet en rekke mindre slike anlegg, hvorav ett ved Lillehammer, som fra 1963 til mars 1965 ble drevet av amerikanerne og deretter overlatt som gave til Jordskjelvstasjonen ved Universitetet i Bergen.

Som et resultat av erfaringene av driften av disse anlegg opprettet amerikanerne høsten 1965 en stor deteksjonsseismologisk stasjon i Montana, LASA (Large Aperture Seismic Array). Det har vist seg at driften av denne stasjon har økt mulighetene for å oppdage og identifisere rystelser som jordskjelv eller atomeksplosjoner betraktelig.

De amerikanske myndigheter fremsatte i mai 1967 forslag om et norsk-amerikansk deteksjonsseismologisk samarbeid. Som et resultat av LASA-stasjonen i Montana var

man på amerikansk side kommet til at det ville være ønskelig å vinne ytterligere vitenskapelige erfaringer ved bygging av et nytt anlegg av LASA-typen. Man ønsket å vinne erfaring med hensyn til hvilke resultater som kunne oppnås ved et samspill mellom to slike anlegg i retning av deteksjon, identifikasjon og lokalisering av underjordiske rystelser. Etter å ha vurdert forskjellige muligheter var man på amerikansk hold kommet til at Norge vil være et av de best egnede steder for et slikt anlegg, bl. a. fordi det i Syd-Norge lar seg gjøre å finne et passende anleggsområde med solid fjellgrunn, med den nødvendige diameter på ca. 100 km.

Det amerikanske forslag som forutsatte en utbygging i to trinn, ble nærmere overveiet fra norsk side av vedkommende fagmyndigheter. Saken ble forelagt Kirke- og Undervisningsdepartementet, Forsvarsdepartementet, Forsvarets Forskningsinstitutt, Norges Teknisk-Naturvitenskapelige Forskningsråd, samt Jordskjelvstasjonen, Universitetet i Bergen. I første omgang ble tatt stilling til forslagets første trinn. Dette skulle søkes gjennomført i løpet av 1967—68 og innebære undersøkelser av den såkalte seismiske bakgrunnsstøy i Norge ved reisning av en eksperimentell stasjon (subarray) bestående av ca. 20 kortperiodiske seismometre i borehull fordelt over et område på ca. 18—25 km i diameter, samt et lite antall mindre kortperiodiske og langperiodiske måleinstrumenter. Det var en forutsetning at en slik eksperimentell stasjon senere skulle kunne inngå som ledd i et større anlegg av LASA-typen. Samtidig var det på det rene at en slik stasjon ville ha en vitenskapelig egenverdi, selv om det ikke skulle bli noe av det større anlegg som var tenkt etablert i henhold til forslagets annet trinn. Dette trinn skulle innebære etableringen av et LASA-anlegg, omtrent halvparten så stort som Montana-anlegget, omfattende opp til 10 understasjoner (subarrays) spredt over et sirkelformet område med en diameter på 100—200 km.

De ovenfor nevnte instanser som saken hadde vært forelagt stilte seg positivt til forslaget om utbygging såvel av en prøvestasjon som av det større anlegg.

Regjeringen besluttet på dette grunnlag å innlede forhandlinger med de amerikanske myndigheter. Man tok sikte på inngåelse av en rammeavtale i form av en noteveksling mellom de to regjeringer, samt en administrativ tilleggsavtale mellom vedkommende amerikanske institusjon, Advanced Research Projects Agency (ARPA) under det amerikanske forsvarsdepartement, og på norsk side Forsvarets Forskningsinstitutt og Norges Teknisk-Naturvitenskapelige Forskningsråd. I henhold til de avtaleutkast det er oppnådd enighet om, skal Forsvarets Forskningsinstitutt være ansvarlig for planlegging, utbygging og prøvedrift av anlegget, mens Norges Teknisk-Naturvitenskapelige Forskningsråd — eller en annen egnet institusjon — skal forestå driften når anlegget er ferdigbygget. Jordskjelvstasjonen ved Universitetet i Bergen fungerer som rådgiver og som uavhengig bruker av data fra stasjonen for egen vitenskapelig forskning. Utkastet til hovedavtale følger som trykt vedlegg til denne proposisjon i engelsk tekst med oversettelse til norsk. Utkastet til tilleggsavtale følger som utrykt vedlegg, i engelsk tekst og oversettelse til norsk. De enkelte bestemmelser i avtalene vil bli nærmere omtalt nedenfor.

Samtidig med forhandlingene om avtaletekstene har det pågått drøftelser mellom norske og amerikanske eksperter om den teknisk mest hensiktsmessige utforming og plassering av det samlede anlegg. Dette var som foran nevnt opprinnelig planlagt utbygget med opp til 10 understasjoner, med ca. 20 måleinstrumenter på hver stasjon. Ekspertene er imidlertid kommet til at det vil være mer formålstjenlig å anvende flere understasjoner, men med færre instrumenter på hver stasjon, og man er blitt stående ved at det samlede anlegg bør utbygges med i alt 22 understasjoner, hver med 7 måleinstrumenter. Prøvestasjonen inngår som én av det samlede anleggs 22 stasjoner. Stasjonene grupperes i en syv-kant innenfor et område begrenset av Øyer i nord, Elverum i øst, Minnesund i syd og Dokka i vest. En viktig del av anlegget utgjøres av et databehandlingssenter som vil bli opprettet på Kjeller og som skal ta imot og bearbeide de signaler som kommer inn fra understasjonenes måleinstrumenter. Dataene blir overført fra understasjonene ved hjelp av kabler som tilknyttes Telegrafverkets nett. Anlegget blir lite synlig i terrenget, idet toppen av instrumentkjelleren bare rekker 10—12 cm opp over bakken. Stasjonene vil ikke bli inngjerdet. Under forutsetning av at arbeidet kan påbegynnes i år, vil anlegget kunne være ferdig i 1969.

Hva finansieringen angår, bemerkes at De Forente Stater betaler alle utgifter, inklusive ulempe-erstatninger, ved planlegging, bygging, drift og vedlikehold av anlegget. Fra norsk side betales leie (eventuelt kjøp) av nødvendig grunn for understasjonene. Leieutgiftene er beregnet til kr. 120 000 pr. år for det samlede prosjekt. Disse utgifter vil måtte dekkes ved bevilgning over statsbudsjettet, nytt kap. 108, Norsk-amerikansk deteksjonsseismologisk samarbeid, post 70. Anleggsomkostningene er eksklusive instrumentutstyr beregnet til ca. 44 mill. kroner, som i det vesentlige vil medgå til kjøp av varer og tjenester i Norge. Det regnes videre med årlige innkjøp innenlands av varer og tjenester under driften av anlegget for ca. 6 millioner kroner.

Om de enkelte bestemmelser i avtaleutkastene skal departementet bemerke følgende:

1. Hovedavtalen fastslår i punkt 1 at formålet med anlegget er seismologisk forskning og eksperimentering. Dets hovedfunksjon er å tilveiebringe data som kan bidra til deteksjon og identifikasjon av underjordiske rystelser. I henhold til punkt 2 kan Norge bruke stasjonen til egen vitenskapelig forskning. Norge kan videre la andre land delta i stasjonens virksomhet og kan la disse få adgang til de data som stasjonen registrerer. De Forente Stater underrettes om andre lands deltakelse i virksomheten (pkt. 3). Leie av grunn og adkomstrettigheter skal dekkes av Norge, mens alle andre utgifter, inklusive ulempeerstatninger, dekkes av De Forente Stater (pkt. 4). I pkt. 5 konstateres at gjennomføring av avtalen er betinget av at henholdsvis Norges Storting og De Forente Staters Kongress bevilger de nødvendige midler. Pkt. 6 og 7 omhandler skatte-, toll-, og avgiftsspørsmål, under henvisning til dobbelt-beskatningsavtalen av 13. juni 1949, samt til prinsippene i toll- og avgiftsavtalen av 27. juni 1952, mellom Norge og De Forente Stater. Pkt. 8 omhandler de samarbeidende institusjoner på norsk og amerikansk side. Disse er som foran nevnt det amerikanske Advanced Research Projects Agency (ARPA) og på norsk side Forsvarets Forskningsinstitutt samt Norges Teknisk-Naturvitenskapelige Forskningsråd — eller eventuelt en annen egnet institusjon. Avtalen kan oppsies av en av partene med 1 års varsel. Oppsigelse kan tidligst finne sted 30. juni 1971, til opphør 30. juni 1972.

2. Den administrative tilleggsavtale beskriver anleggets art, finansieringsordningen, samt de samarbeidende institusjoner, i samsvar med de tilsvarende bestemmelser i hovedavtalen. Avtalen bestemmer videre at det på alle stadier i utbyggingen av anlegget, og likeledes under driften av dette, skal gjøres bruk av norsk personell og materiell så langt det er mulig. Amerikanske firmaer skal dog ha rett til å inngi anbud på arbeidene med mindre dette frafalles fra amerikansk side. Den amerikanske regjering beholder eiendomsretten til rørlig eiendom som bringer inn i Norge i forbindelse med anlegget, eller som anskaffes her. Ved eventuelt salg av slik eiendom har den norske regjering forkjøpsrett. Avtalen fastslår at Norge bemanner stasjonen med eget personell. Det amerikanske forskningsinstitutt, ARPA, kan avgi personell til anlegget dersom det ønsker det, etter samråd med vedkommende norske myndigheter.

Tilleggsavtalen gjelder for samme tidsrom som hovedavtalen, jfr. pkt. 1 foran.

Utenriksdepartementet legger vekt på at bygging og drift av et stort deteksjonsseismologisk anlegg som foran skissert vil kunne bidra i vesentlig grad til å øke mulighetene for deteksjon, identifikasjon og lokalisering av underjordiske rystelser. Anlegget vil derved kunne bety en effektivisering av kontrollen med underjordiske kjernefysiske eksplosjoner, og det vil således kunne bidra til å legge forholdene til rette for en utvidelse av prøvestansavtalen av 1963. Spørsmålet om inngåelse av en fullstendig prøvestansavtale antas å bli hovedtemaet når 18-maktskonferansen for nedrustning gjenopptar sine forhandlinger i Genève i 1968. Anlegget vil samtidig gi muligheter for videregående norsk seismologisk forskning og for avansert signalbehandlingsteknikk.

Utenriksdepartementet

tilrår:

At Deres Majestet godkjenner og skriver under et fremlagt utkast til proposisjon til Stortinget om:

1. Samtykke til foretakelse av noteveksling om inngåelse av en avtale mellom Norge og Amerikas Forente Stater om deteksjonsseismologisk samarbeid.

2. Bevilgning på statsbudsjettet for 1968 under nytt kap. 108, Norsk-amerikansk deteksjonsseismologisk samarbeid.

Vi OLAV, Norges Konge,

gjør vitterlig:

Stortinget blir innbudt til å gjøre følgende vedtak:

I

Stortinget samtykker i foretakelse av noteveksling om inngåelse av en avtale mellom Norge og Amerikas Forente Stater om deteksjonsseismologisk samarbeid, i samsvar med et fremlagt utkast.

II

På statsbudsjettet for 1968 foretas følgende endringer:

Kap. 108 (nytt), Norsk-amerikansk deteksjonsseismologisk samarbeid, post 70, Tilskott, bevilges med kr. 120 000.

Tilråding ligger ved i avtrykk.

Gitt på Oslo slott, 10. mai 1968.

Under rikets segl

Under Hans Majestet Kongens fravær

HARALD
(L. S.)

Per Borten

Dag Berggrav
kst.

Vedlegg

Utkast til noteveksling mellom Norge og Amerikas Forente Stater om norsk-amerikansk deteksjonsseismologisk samarbeid.

His Excellency
John Lyng,
Minister for Foreign Affairs,
Oslo.

Excellency:

I have the honor to refer to recent discussions between representatives of the Government of the United States of America and the Government of Norway concerning seismic array research by our two Governments and plans for utilizing a large seismic array facility which would be installed and operated in Norway. This project, serving the mutual interest of our countries, would be a significant contribution to seismological research, particulary in the field of detection and identification of underground events.

The proposed Large Seismic Array facility would comprise the following four phases:

Phase I — Survey using one subarray, several long-period sensors, test boreholes, and extended Lillehammer array.

Phase II — Installation of remainder of seismic array.

Phase III — Management of seismic array (in part concurrent with Phase II).

Phase IV — Termination of operating and disposition of equipment.

I understand that the Government of Norway would be willing to participate in the installation, operation and management of the seismic array facility in accordance with the provisions below.

1. The purpose of the installation is seismological research and experimentation. The system is primarily designed to produce data valuable as a means of detecting and distinguishing between signals orginating from underground explosions and from other sources, especially earthquakes.

(Oversettelse.)

Utkast til noteveksling mellom Norge og Amerikas Forente Stater om norsk-amerikansk deteksjonsseismologisk samarbeid.

Hans Eksellense
John Lyng,
Utenriksminister,
Oslo.

Eksellense,

Jeg har den ære å vise til de nylige drøftinger mellom representanter for De Forente Staters regjering og Norges regjering angående våre to regjeringers forskning ved hjelp av seismiske anlegg og planer for anvendelsen av et stort seismisk anlegg som eventuelt vil bli installert og satt i drift i Norge. Dette prosjektet, som tjener våre to lands gjensidige interesser, ville utgjøre et betydelig bidrag til seismologisk forskning, særlig når det gjelder deteksjon og identifikasjon av underjordiske rystelser.

Det foreslåtte store seismiske anlegg ville omfatte følgende fire trinn:

Trinn I — Undersøkelse ved hjelp av én seismisk understasjon, flere langperiodiske seismometre, prøveborehull, samt en utvidelse av det seismiske anlegg ved Lillehammer.

Trinn II — Installasjon av den resterende del av det seismiske anlegg.

Trinn III — Drift av det seismiske anlegg (delvis samtidig med trinn II).

Trinn IV — Avvikling av driften og avhending av utstyret.

Jeg forstår at Norges regjering vil være enig i å delta i installasjonen, driften og ledelsen av det seismiske anlegg i samsvar med følgende retningslinjer:

1. Formålet med anlegget er seismologisk forskning og eksperimentering. Systemet er i hovedsak beregnet på å fremskaffe data av verdi når det gjelder å oppdage og skille mellom signaler fra underjordiske eksplosjoner og fra andre kilder, særlig jordskjelv.

2. The facility may be used for independent research at the discretion of the Norwegian Government, it being understood that such activities shall be conducted so as not to conflict with the agreed schedule of operation and that any additional operating costs resulting from such independent activity will be borne by the appropriate Norwegian authorities, or as agreed by the Advanced Research Projects Agency (ARPA).

3. The Government of Norway may permit participation by other governments in the activities of the facility under appropriate arrangements for the sharing of costs and exhange of data. As soon as data of interest can be accumulated, the Government of Norway shall have the right to disseminate and transmit such data to foreign countries after notification to the United States Government.

4. Necessary land leases and access rights to individual seismometer sites, sensor and central terminal vault locations shall be acquired by the Government of Norway and made available for this project at no cost to the United States Government. The United States Government shall be responsible for all other costs involving the installation of cables and equipment, as well as any claims for damage arising from the installation, operating and maintenance of the facility.

5. To the extent that United States participation in the activities of the facility shall be dependent upon funds to be appropriated by the Congress of the United States, it shall be subject to the availability of such funds. Likewise, to the extent that Norway's participation in the activities of the facility shall be dependent upon funds to be appropriated by the Norwegian Storting, it shall be subject to the availability of such funds.

6. Taxation of salaries and emoluments of the nationals of the United States connected with this project will be subject to the Double Income Taxation Treaty of June 13, 1949, as amended. No customs duties, taxes or other charges shall be levied on the personal belongings, household effects, and automobile of a national of the United States in connection with his arrival in Norway for the purposes of this agreement, provided such effects are in the owner's possession prior to arrival in Norway, and are imported within a reasonable period after his arrival.

2. Anlegget vil kunne brukes til uavhengig forskning etter den norske regjerings forgodtbefinnende forutsatt at slik bruk ikke kommer i konflikt med den vedtatte driftsplan og at mulige ekstra driftsutgifter som måtte følge av slik uavhengig virksomhet vil bli dekket av vedkommende norske myndigheter eller på en annen måte som Advanced Research Projects Agency (ARPA) er enig i.

3. Norges regjering vil kunne tillate deltakelse av andre regjeringer i virksomheten ved anlegget forutsatt at det treffes en passende ordning for deling av kostnader og utveksling av data. Så snart data av interesse foreligger, vil Norges regjering ha rett til å gjøre tilgjengelig og overføre slike data til andre land etter å ha underrettet De Forente Staters regjering.

4. Nødvendig feste av grunn og adgangsrettigheter til de enkelte seismometeranlegg, til seismometer- og terminalhvelv skal erverves av Norges regjering og gjøres tilgjengelig for dette prosjektet uten kostnader for De Forente Staters regjering. De Forente Staters regjering skal være ansvarlig for alle andre utgifter som omfatter installering av kabler og utstyr såvel som alle krav om skadeserstatninger som har sin årsak i installasjon, drift eller vedlikehold av anlegget.

5. I den utstrekning De Forente Staters deltakelse i virksomheten ved anlegget er avhengig av midler bevilget av De Forente Staters Kongress, skal deltakelsen gjøres betinget av tilgangen på slike midler. Likeledes skal Norges deltakelse i den utstrekning den er avhengig av midler bevilget av det norske Storting, gjøres betinget av tilgangen på slike midler.

6. Skattlegging av lønninger og annen godtgjørelse til amerikanske statsborgere ved prosjektet skal skje i henhold til dobbeltbeskatningsavtalen av 13. juni 1949 med senere endringer. Ingen toll, skatt eller andre avgifter skal erlegges av personlige eiendeler, flyttegods og bil tilhørende en amerikansk statsborger i forbindelse med ankomsten til Norge som ledd i gjennomføringen av denne avtale, forutsatt at disse effekter er i eierens besiddelse før ankomsten til Norge og at de innføres innen en rimelig tid etter ankomsten.

7. In conjunction with United States expenditures which may be involved in this project, relief from Norwegian taxes will be granted in accordance with the principles of the taxation relief agreement effected by the exchange of notes by and between the Governments of the United States and Norway of June 27, 1952, and with the related exchange of notes of the same date. The taxation relief will usually be granted by refunding the applicable amount of customs duties and taxes, except that if it is more practical, relief may be granted directly when the import takes place.

8. The cooperating agencies of the two Governments are authorized to conclude administrative agreements to carry out the details of the project. The cooperating agency for the Government of the United States shall be the Advanced Research Projects Agency (ARPA) of the Department of Defense of the Government of the United States of America. The cooperating agencies for the Government of Norway shall be (a) the Norwegian Defense Research Establishment (NDRE) of the Ministry of Defense of the Government of Norway, for the planning, procurement, installation and testing; and (b) the Royal Norwegian Council for Scientific and Industrial Research (RNCIR) or other appropriate agency to be agreed upon for the management of the facility. The Institute of Seismology of the University of Bergen will serve as an advisory body and will be an independent user for its own research of the data supplied by the facility.

9. This agreement shall remain in force until terminated by either Government after giving one year's written notice to the other Government of its intention to terminate the agreement. Such notice may be given at any time on or after June 30, 1971.

The foregoing provisions are acceptable to the Government of the United States. I now have the honor to propose that this note and your reply confirming the agreement of the Government of Norway shall constitute an agreement between our two Governments regarding this matter, which shall enter into force on the date of your reply.

Accept, Excellency, the renewed assurances of my highest consideration.

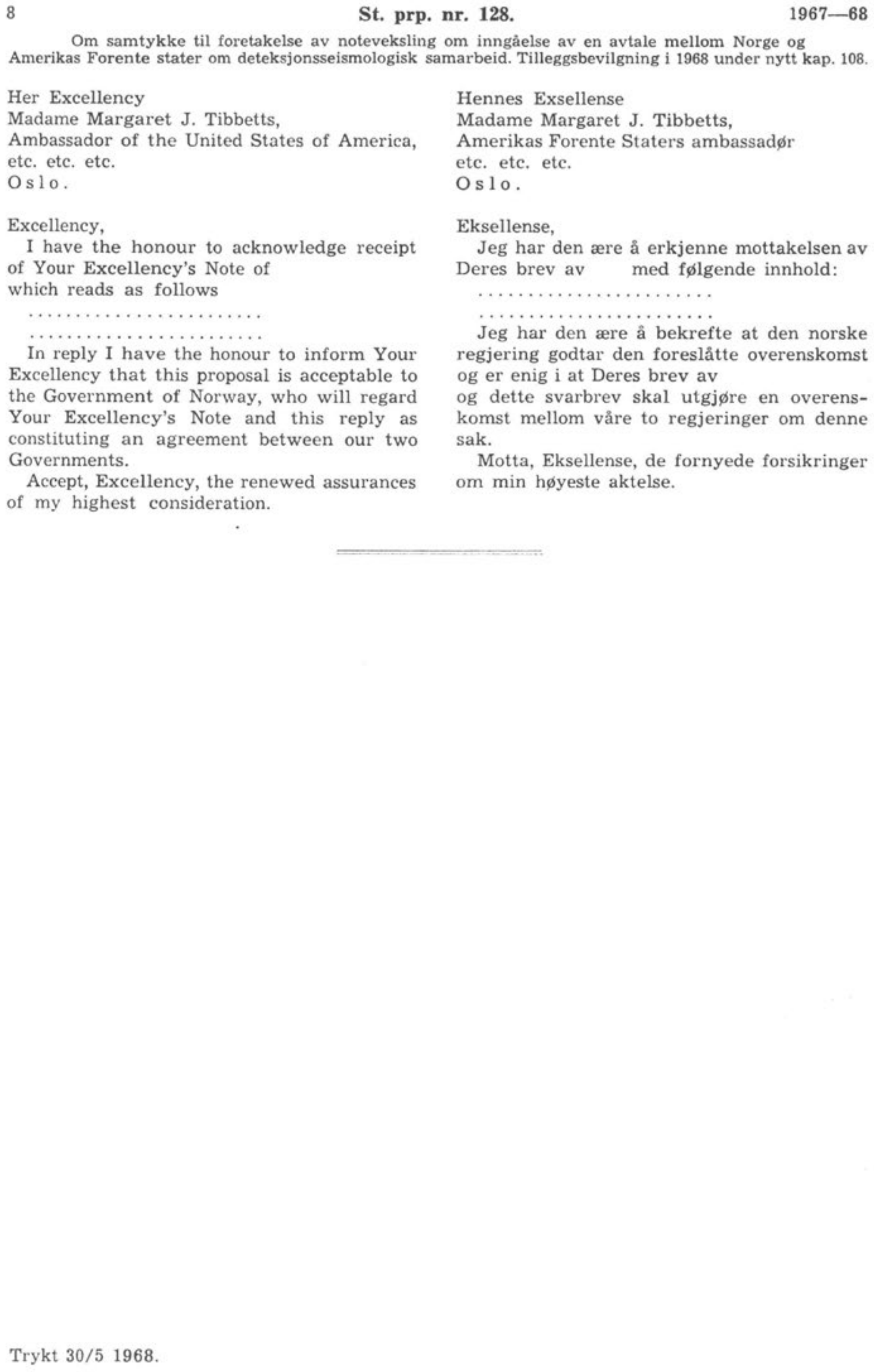
7. Når det gjelder De Forente Staters utgifter i forbindelse med dette prosjektet, vil det bli gitt skattelettelser i henhold til prinsippene i avtalen om skattelettelser inngått ved noteveksling mellom regjeringene i De Forente Stater og Norge datert 27. juni 1952 og i henhold til notevekslingen av samme dato med tilknytning til denne. Skattelettelsen vil som regel finne sted ved tilbakebetaling av det beløp som måtte være blitt betalt i skatt, toll osv., eller det vil, om dette viser seg mer praktisk, bli gitt fritakelse når importen finner sted.

8. De to regjeringers samarbeidende institusjoner er bemyndiget til å inngå administrative avtaler om gjennomføring av detaljene i prosjektet. Samarbeidsinstitusjonen for De Forente Staters regjering skal være The Advanced Research Projects Agency (ARPA) i De Forente Staters forsvarsdepartement. Samarbeidsinstitusjonene for den norske regjering skal være (a) Forsvarets Forskningsinstitutt (FFI) i det norske Forsvarsdepartement når det gjelder planlegging, materiellkjøp, installering og prøving, og (b) Norges Teknisk-Naturvitenskapelige Forskningsråd (NTNF) eller en annen egnet institusjon som man blir enige om når det gjelder driften av anlegget. Jordskjelvinstituttet ved Universitetet i Bergen vil tjene som rådgivende instans og vil være en uavhengig bruker for sine egne forskningsformål av de data som tilveiebringes av anlegget.

9. Denne avtale skal stå ved makt inntil den blir oppsagt av en av regjeringene etter at den har gitt ett års skriftlig varsel til den annen regjering om sin hensikt å oppsi avtalen. Slikt varsel vil kunne gis når som helst fra og med den 30. juni 1971.

Ovenstående vilkår kan aksepteres av De Forente Staters regjering. Jeg har nå den ære å foreslå at denne note og Deres svar med bekreftelse på Norges regjerings enighet skal utgjøre en avtale mellom våre to regjeringer i denne sak og at den skal tre i kraft på datoen for Deres svar.

Motta, Eksellense, de fornyede forsikringer om min høyeste aktelse.



Her Excellency
Madame Margaret J. Tibbetts,
Ambassador of the United States of America,
etc. etc. etc.
Oslo.

Excellency,

I have the honour to acknowledge receipt of Your Excellency's Note of which reads as follows

....

....

In reply I have the honour to inform Your Excellency that this proposal is acceptable to the Government of Norway, who will regard Your Excellency's Note and this reply as constituting an agreement between our two Governments.

Accept, Excellency, the renewed assurances of my highest consideration.

Hennes Exsellense
Madame Margaret J. Tibbetts,
Amerikas Forente Staters ambassadør
etc. etc. etc.
Oslo.

Eksellense,

Jeg har den ære å erkjenne mottakelsen av Deres brev av med følgende innhold:

....

....

Jeg har den ære å bekrefte at den norske regjering godtar den foreslåtte overenskomst og er enig i at Deres brev av og dette svarbrev skal utgjøre en overenskomst mellom våre to regjeringer om denne sak.

Motta, Eksellense, de fornyede forsikringer om min høyeste aktelse.

Trykt 30/5 1968.

Appendix 2

NORSAR's status and parent organizations over the years

Period	Status	Parent organization
1968 - 30 June 1970	Project	FFI
1 July 1970 - 31 December 1979	Project	NTNF
1 January 1980 - 31 December 1992	Department	NTNF
1 January 1993 - 30 June 1999	Department	NFR
30 June 1999 -	Independent research foundation	None

NORSAR's leaders over the years

Period	Name
1 July 1970 - 15 January 1971	Eivind Sætre
16 January 1971 –-31 March 1972	Per Tveitane (acting leader)
1 April 1972 - 30 June 1978	Nils Marås
1 July 1978 - 31 May 1997	Frode Ringdal
1 June 1997 - 31 December 2013	Anders Dahle
1 January 2014 -	Anne S. Lycke

Chairs of NORSAR's board over the years

Period	Name
1970 -1977	Markvard A. Sellevoll
1977 - 1994	Kaare Høeg
1994 - 1996	Roy Gabrielsen
1996 - 1999	Rolf Skår
1999 - 2005	Olav Eldholm
2005 - 2007	Hege M. Nordgård Bolås
2007 - 2011	Annik M. Myhre
2011 - 2014	Jarle Skjørestad
2014 - 2020	Sverre Strandenes
2020 -	Kim Traavik

Appendix 3

Nordic Seismology Seminars 1969 - 2019

No.	Year	Venue	Dates
1	1969	Oslo, Norway	20 - 21 November
2	1971	Hagfors, Sweden	1 - 4 March
3	1972	Roskilde, Denmark	8 - 10 May
4	1973	Helsinki, Finland	12 - 14 June
5	1974	Bergen, Norway	20 - 22 May
6	1975	Stockholm, Sweden	2 - 4 June
7	1976	Copenhagen, Denmark	24 - 26 May
8	1977	Helsinki, Finland	1 - 3 June
9	1978	Oslo, Norway	29 - 31 May
10	1979	Stockholm, Sweden	21 - 23 May
11	1980	Copenhagen, Denmark	19 - 21 May
12	1981	Reykjavik, Iceland	11 - 14 June
13	1982	Espoo, Finland	3 - 5 May
14	1983	Kristiansand, Norway	25 -27 May
15	1984	Tällberg, Sweden	21 - 23 March
16	1985	Copenhagen, Denmark	6 - 8 May
17	1986	Laugarvatn, Iceland	18 - 20 June
18	1987	Helsinki, Finland	1 - 3 October
19	1988	Oslo, Norway	4 - 6 October
20	1989	Sunne, Sweden	26 - 28 September
21	1990	Lyngby, Denmark	1 - 3 October
22	1991	Hveragerdi, Iceland	9 - 11 June
23	1992	Espoo, Finland	2 - 4 September
24	1993	Bergen, Norway	16 - 18 June
25	1994	Stockholm, Sweden	23 - 25 August
26	1995	Copenhagen, Denmark	20 - 22 November
27	1996	Reykjavik, Iceland	11 September
28	1997	Helsinki, Finland	16 -17 June
29	1998	Karasjok, Norway	19 - 21 August
30	1999	Gothenburg, Sweden	13 - 15 October

No.	Year	Venue	Dates
31	2000	Korsør, Denmark	27 - 29 September
32	2001	Husavik, Iceland	6 -7 June
33	2002	Lahti, Finland	25 - 27 September
34	2003	Flåm, Norway	4 - 6 June
35	2004	Åkersberga, Sweden	29 September - 1 October
36	2005	Copenhagen, Denmark	8 –-10 June
37	2006	Nesjavellir, Iceland	21 - 23 August
38	2007	Helsinki, Finland	13 - 15 June
39	2008	Oslo (Asker), Norway	4 - 6 June
40	2009	Stockholm, Sweden	14 - 16 October
41	2010	Århus, Denmark	6 - 8 October
42	2011	Reykjavik, Iceland	5 - 7 October
43	2012	Tallinn, Estonia	24 - 26 October
44	2013	Bergen (Sotra), Norway	16 - 18 September
45	2014	Visby, Sweden	8 - 10 October
46	2015	Bornholm, Denmark	30 September - 2 October
47	2016	Reykjavik, Iceland	11 -13 October
48	2017	Helsinki, Finland	12 - 13 June
49	2018	Kjeller, Norway	24 - 26 September
50	2019	Uppsala, Sweden	14 - 16 October

Appendix 4

A quick guide to developments towards the CTBT, internationally and from Norway's and NORSAR's perspectives

Early years

International developments

- First US test, July 1945, "Trinity"
- 1949-1964: First tests by USSR, UK, France, China
- Initiatives to limit/stop testing (Nehru 1954)
- First international meeting on nuclear test ban verification, Geneva 1958
- Periods of moratoria on testing, interrupted by periods of intense testing activity
- 1963: The Partial Test Ban Treaty (PTBT) signed. It bans nuclear explosions in space, in the atmosphere and under water

Developments in Norway

- 1950s: Public concern over nuclear weapons and nuclear testing
- Substantial fallout from Soviet atmospheric testing at Novaya Zemlya; weapons of up to 58 megatons tested
- Political attitude: "No nuclear weapons on Norwegian soil"
- Norway active internationally in promoting a test ban at the diplomatic level

Strong focus on seismology in the 1960s and onwards

International developments

- The PTBT did not cover underground explosions, because verification was not considered good enough at the time
- Hence, large seismology programs initiated, especially in the USA
- The World Wide Standard Station Network (WWSSN) was great for seismology, but not sufficient for verification purposes
- Proposed solution: Seismic arrays. Several arrays installed in the USA, and UK-type arrays built in several countries
- The largest of these was the LASA array in Montana, USA

Developments in Norway

- Discussions between Norwegian military intelligence services and the US about seismic stations in Norway, but none were built
- Two WWSSN stations installed in Norway (Kongsberg and Ny-Ålesund)
- The Seismological Observatory at the University in Bergen had a contract with US authorities to install a small seismic array at Lillehammer in 1963
- Norway - USA government-to-government agreement 15 June 1968
- NORSAR is the result of this agreement; NORSAR was established as an open institution on 1 July 1970
- The NOA array, now PS27 in IMS, was established during 1968-1970
- Research activities at NORSAR; came up to speed very quickly
- Extensive international network; visiting scientists at NORSAR

Group of Scientific Experts (GSE) 1976-1996

International efforts

- Met in Geneva in two-week sessions, with a mandate from the Conference on Disarmament (CD) to consider measures to detect and identify seismic events.
- GSE designed, installed and tested a global seismic verification system
- GSE was a large educational effort, as it engaged station operators and data center personnel around the world

NORSAR's contributions to GSE

- Strongly involved, scientific secretary (Frode Ringdal), working group convenors, and other delegates from NORSAR
- NORSAR's research was presented in GSE and used in GSE's work. This work was based on research contracts with the US government
- Areas for NORSAR's contributions, Seismic array design, station network configuration, data processing
- NORES, small array design, prototype for IMS stations, note USSR comment about its capabilities

CTBT negotiations 1994-1996

International efforts

- Took place in Geneva, under CD
- Treaty text adopted by the UN in September 1996
- The Treaty includes an extensive verification regime, with a global monitoring network (IMS, the International Monitoring System), an International Data Center, and provisions for on-site inspections
- Designs from GSE could be used by the negotiators as blueprints for the Treaty

NORSAR's contributions to the CTBT negotiations

- Configuration of the seismic network
- Participated also in discussions on infrasound, hydroacoustic, and radionuclide monitoring technologies
- Promoted Norwegian stations in the IMS

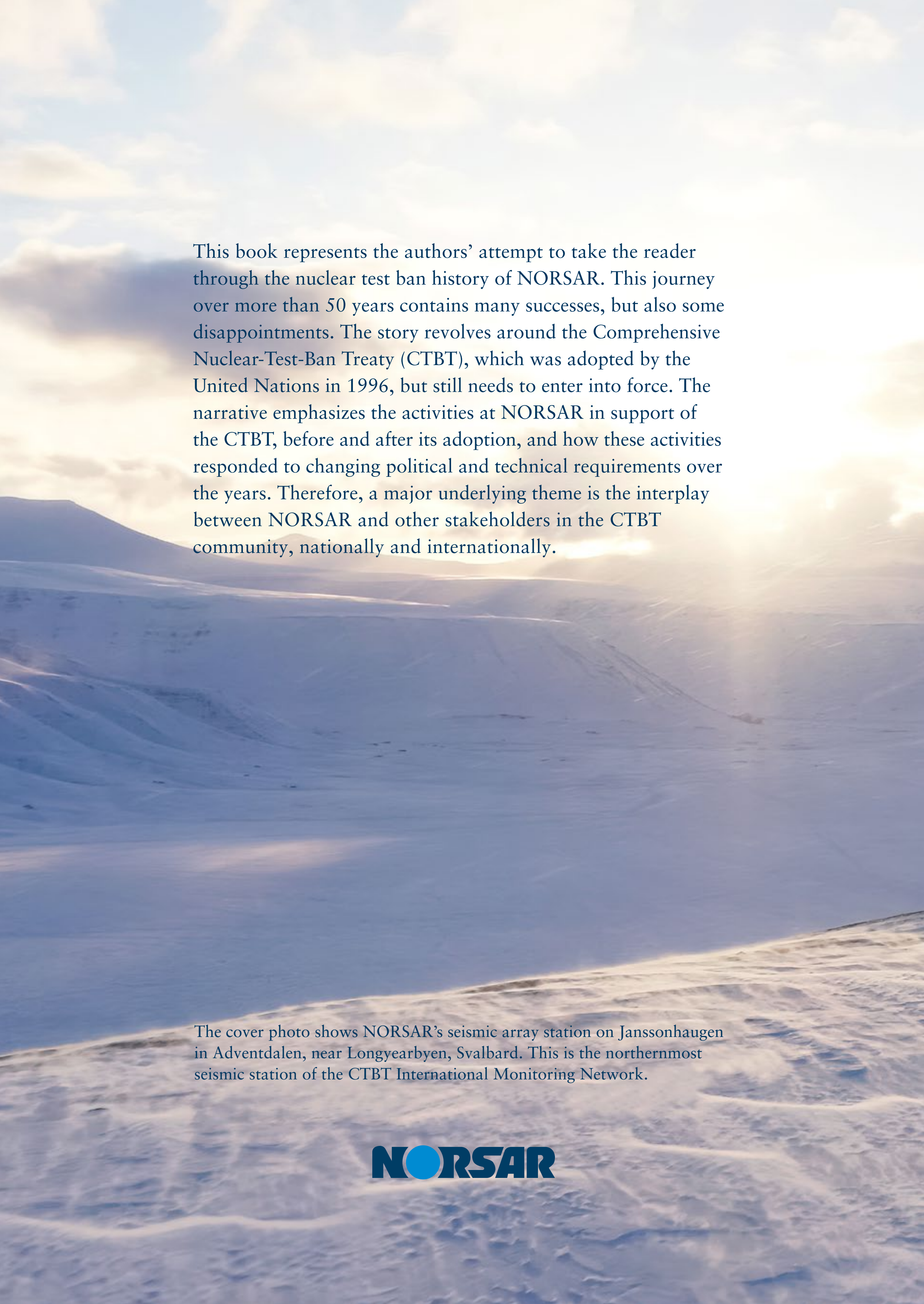
CTBTO Preparatory Commission (PrepCom) 1996-?

International efforts

- Established in Vienna, it comprises policy-making organs for the Treaty member states (185 states as of 2021, out of which 170 have ratified the Treaty) and a secretariat (PTS, with approximately 260 employees)
- The task of the PrepCom is to implement the verification regime of the CTBT in order to prepare for entry-into-force of the Treaty
- Annual budget approx. 130 million USD
- Working Group B (WGB) deals with all aspects of verification on behalf of all member states
- The Treaty enters into force when eight more states have ratified it: China, Egypt, India, Iran, Israel, North Korea, Pakistan, USA

NORSAR's contributions to and involvement in the CTBTO Preparatory Commission

- NORSAR was designated in 1999 by the parliament as the National Data Center for Norway for CTBT verification
- NORSAR has established and operates six IMS stations on Norwegian territory
- PTS certifies stations in the IMS; the NOA array (PS27 in IMS) was the first station in IMS to be certified
- NORSAR participates actively in WGB and has assisted the chairs of WGB from the beginning (Task Leaders)
- Maintain and develop competence: It will be up to PrepCom's member states to raise issues of possible non-compliance with the Treaty when it has entered into force. NORSAR's role will be to advise Norwegian authorities in this regard



This book represents the authors' attempt to take the reader through the nuclear test ban history of NORSAR. This journey over more than 50 years contains many successes, but also some disappointments. The story revolves around the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which was adopted by the United Nations in 1996, but still needs to enter into force. The narrative emphasizes the activities at NORSAR in support of the CTBT, before and after its adoption, and how these activities responded to changing political and technical requirements over the years. Therefore, a major underlying theme is the interplay between NORSAR and other stakeholders in the CTBT community, nationally and internationally.

The cover photo shows NORSAR's seismic array station on Janssonhaugen in Adventdalen, near Longyearbyen, Svalbard. This is the northernmost seismic station of the CTBT International Monitoring Network.

NORSAR