Testing the nuclear test-ban treaty

A recent earthquake near a former Soviet nuclear test site has tested mechanisms for monitoring the test-ban treaty. Technical systems passed with flying colours, but relevant US agencies could have done better.

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Early on the morning of Saturday 16 August 1997, there was a small seismic event in the Kara Sea, about 100 kilometres from the nuclear test site on the far northern island of Novaya Zemlya now used by Russia for nuclear weapons research (Fig. 1). Within days, seismologists located the event in an area where it could only have been an earthquake.

Yet at the end of August, spokesmen for the US State and Defense Departments described the event as having “explosive characteristics”, and in late September officials of other US agencies were still characterizing it as “unresolved” (George Ullrich, Defense Special Weapons Agency) or “lending itself to alternative interpretations” (Bob Bell, National Security Council).

These statements suggest that the seismic signals might have been generated not by an earthquake but by a nuclear test. Underground nuclear explosions were carried out by the Soviet Union at the Novaya Zemlya test site from 1964 to 1990. But Russia and many other countries signed the Comprehensive Test Ban Treaty (CTBT) in September 1996, so making a commitment not to carry out nuclear explosive tests for any purpose.

To a seismologist, the evidence is straightforward: the event took place several tens of kilometres offshore to the southeast of Novaya Zemlya, in an area where water depths are around 400 metres. Nuclear explosive testing is not credible in such an ocean environment unless there is other evidence, such as signals from hydroacoustic or radionuclide detectors, or the presence of a vast and complicated drilling operation. The event must therefore have been an earthquake.

On 23 September, President Bill Clinton submitted the CTBT to the US Senate for advice and consent to ratification. The 16 August event and its aftermath will provide valuable input to the discussion surrounding the Senate’s deliberations, including the question of whether the treaty is verifiable. As we show here, analysis of this small earthquake indicates excellent capability to monitor the Russian nuclear test site.

But, paradoxically, the event is being used in some quarters to cast doubt on the verifiability of the CTBT[1]. The unfortunate lack of clarity in the handling of this ‘problem event’ — of which there will be many more in years to come — shows that the United States must develop the necessary government forums to evaluate relevant technical inputs and summarize them appropriately for policy-makers.

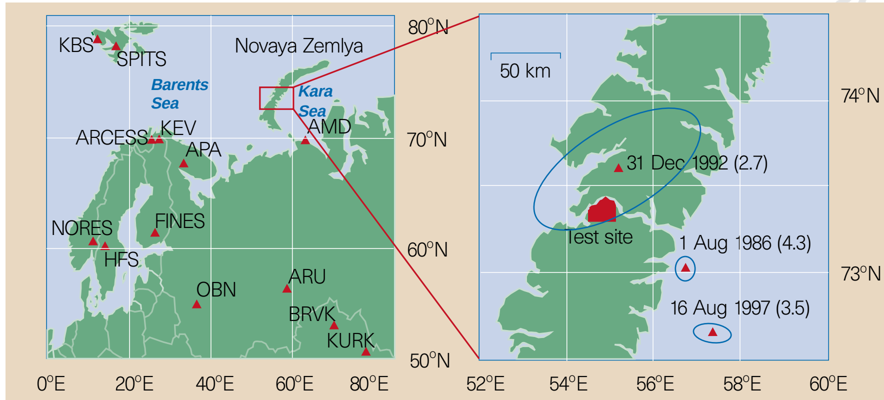

Figure 1 **Maps showing the Novaya Zemlya test site, locations and magnitudes of recent earthquakes, the 16 August event and some of the relevant seismographic stations. Earthquake locations and their uncertainty are characterized by error ellipses[2–4], which give 90 per cent confidence intervals.**

When the CTBT comes into force, an international data centre in Vienna will receive data from an international treaty monitoring system (IMS) and process them to provide basic information such as the locations of sources of various signals. A prototype international data centre (PIDC) in Arlington, Virginia, has begun the work of CTBT monitoring, receiving data from global networks of hydroacoustic, infrasound and radionuclide sensors (as yet incomplete) and seismic data from stations of the IMS (essentially complete for coverage of Novaya Zemlya).

It is not the responsibility of the PIDC to determine whether detected events are explosions or earthquakes, but rather to provide the data to national data centres of treaty signatories so they can make their own determinations. The 16 August event provides an opportunity to assess the performance of national and international data centres, and the contribution of stations outside any treaty-monitoring network.

How monitoring worked in practice

Although the nearest IMS station to the event, an array of sensors at ARCESS in northern Norway, was (unusually and unfortunately) not operating on 16 August, the PIDC nevertheless received adequate seismic data to detect and locate the event automatically that morning, about an hour after it happened. The event was studied by PIDC experts a few days later. Their best estimate of the location, published in their *Reviewed Event Bulletin* (*REB*)[2], is quite close to the automatically determined location. Automatic locations, not always reliable, are routinely available to national data centres and are important indicators of what data are available at the PIDC. Figure 1 shows the *REB* error ellipse as well as the location. Such error ellipses “must be taken as only tentative indicators of the actual epicentral location accuracy”[3], but a key point for the event of interest is that different error ellipses based on different choices of Earth structure all lie in the Kara Sea and do not overlap the land. The *REB* location (Fig. 1) is consistent with data from other stations that have subsequently become available, including some from as far away as Kazakhstan.

Of course, there will be some earthquakes on the land area of Novaya Zemlya, and, indeed, near other countries’ test sites — on 12 September a magnitude 4 earthquake took place directly under the US nuclear test site in Nevada. For such events, a way other than location is needed to discriminate between earthquakes and explosions.

For small seismic events at Novaya Zemlya, a systematic difference between earthquakes and explosions can be seen, if signal-to-noise ratios are adequate, in the high-frequency seismic waveforms for compressional waves (P waves) and shear waves (S waves). Previous experience with the IMS station at ARCESS has indicated that this station records waveforms extending well above 10 Hz for earthquakes and explosions at Novaya Zemlya, and that the strength of such high-frequency signals is indeed systematically different for the two types of seismic source, the P/S spectral ratio being weaker for earthquakes than for explosions.

Stations more distant than ARCESS may receive good signals, but not at frequencies high enough for waveform-based discrimination of small events. With no ARCESS data for the 16 August event, and with no other IMS station both near enough to record high-frequency signals and having an

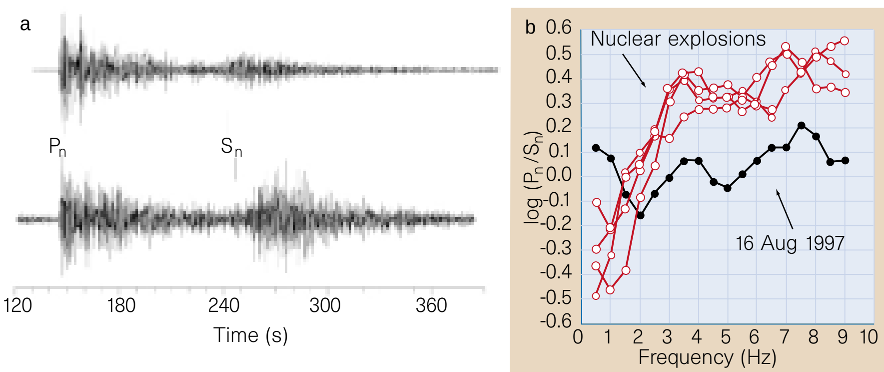

Figure 2 a**, Waveforms for a Soviet-era nuclear explosion at the Novaya Zemlya test site (top, 24 October 1990, 1,048 km) and for the 16 August event (bottom, 1,127 km), recorded at the same station, KEV, in northern Finland.** b**, Spectral ratios for a few nuclear explosions, and for the 16 August event, at KEV. Although no earthquake records from KEV were available for reproduction here, the weaker P/S ratio of the 16 August event is a well documented characteristic of earthquakes[3,5]. KEV is a station in the global network operated jointly by the USGS and the IRIS consortium of US academic institutions.**

archive of previous Novaya Zemlya nuclear explosions for comparison, many seismologists have been working to find non-IMS stations with data suitable for discrimination based on the P/S ratio. One such station is KEV in northern Finland, not far from ARCESS (Fig. 1).

Figure 2 shows a comparison of the KEV seismograms for the 16 August earthquake and for a nuclear explosion, together with the P/S spectral ratios for explosions and for the event of interest. These data show the distinctive feature of a weak (earthquake-like) P/S ratio for the 16 August event. Incidentally, that the delay between P- and S-wave arrivals is longer (by about eight seconds) for the 16 August event than for the nuclear explosion is in itself clear evidence that the event could not have happened at the nuclear test site.

Several other lines of evidence support identification as an earthquake. For example, there was an aftershock nearby about four hours after the main event. Aftershocks are common for earthquakes, but would not be detectable after small nuclear explosions at Novaya Zemlya. Comparison of the mainshock waveforms with those from an earthquake on 1 August 1986 also shows that the 16 August event was an earthquake. Further studies are under way to estimate its depth, which can provide yet another discriminant.

Implications

The ease of location and identification of the 16 August event, with a magnitude of about 3.5, demonstrates that the CTBT can be monitored near the Russian test site down to magnitude 3, and maybe even lower. Magnitude 3 translates to about a twentieth of a kilotonne for a nuclear explosion that is well coupled to the ground, and a few kilotonnes for a fully decoupled test. (To decouple the explosion from the surrounding rock requires construction of an underground cavity of more than 100,000 m^3 and even then the explosion would generate signals that could provide the basis for an on-site inspection request.) So the 16 August event indicates excellent capability to monitor the CTBT.

But this straightforward implication for the treaty is being obscured by the fact that the 16 August event is still “unresolved” by US officials, who are now in the unenviable position of having to accept the earthquake interpretation (critics will ask why it took so long) or of continuing to argue for alternative interpretations (critics will ask for evidence, and for reasons why the obvious interpretation should not be accepted). It may be difficult for these officials to accept that data from non-IMS stations and data analysis by independent groups of seismologists have had such prominence. But there are more than 10,000 seismographic stations around the world for the general purpose of research into earthquake hazard and the structure of the Earth’s interior, so supplementary data will often be available.

Unfortunately, permission was withdrawn (having earlier been granted by the Pentagon) for the PIDC director to present the basic IMS data and data analysis on 25 September to the annual CTBT research and development (R&D) symposium, this year organized by the Defense Special Weapons Agency. The meeting attracts about 200 people from US agencies and national laboratories, and from universities and other research contractors, as well as several participants from outside the United States. A presentation of the PIDC’s material would have widened appreciation that the international data centre is performing well.

A vigorous R&D programme in support of CTBT monitoring is essential to future improvements; and US researchers, who have recently seen the destruction of two air force programmes that long supported academics and private contractors to improve CTBT monitoring, are apprehensive about Department of Defense plans for reorganization in this area. An R&D programme that subordinates problem-solving to bureaucratic concerns — which probably lay behind the withdrawal of permission for the PIDC director to speak at the recent symposium — will drive leading researchers from the field.

When the research community can demonstrate a good new method of discrimination, or the need for good communication to non-IMS stations with openly available data, the development must be assessed and operational procedures perhaps revised. Regrettably, there can be great resistance to such revisions — in the United States, after research results in the 1970s pointed to a seismic magnitude bias between Soviet and US test sites, it took more than 10 years of wrangling to change government procedures for estimating the yield of Soviet explosions.

Practical issues of national data centre operation, and how to evaluate suspicious events, are likely to arise soon in debates on organization of the US National Authority for the CTBT — which will have to be established by new domestic legislation to do the real work of advising US policy-makers on technical issues of CTBT verification.

Encouragingly, an agreement has recently been reached between the Department of Defense and the US Geological Survey (USGS) on the role of the USGS in generating and circulating IMS data. The USGS is to have “timely access to all CTBT IMS data... relevant to USGS programs and missions” — which may be the way these data are made accessible to researchers in nongovernmental organizations working to improve methods of discrimination. These researchers have been handicapped in studying the 16 August event and its aftershock because many have been unable to obtain relevant IMS data. The USGS of course has expertise in studying earthquakes, and has a long tradition of working to make data openly available. It remains to be seen if limits are somehow still put on distribution of IMS data.

It is truly a difficult management problem to handle treaty monitoring where key technical skills often lie outside government agencies, and where rapid decisions may be needed on problem events but the best data may come in days or weeks later. The event of 16 August has provided an opportunity to show what can go wrong, and what can go right. □

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1. Macilwain, C. *Nature* **389,** 425 (1997).
2. *Reviewed Event Bulletin* of the PIDC (http://www.cdidc.org/).
3. NORSAR semi-annual technical report, November 1996.
4. Marshall, P. D., Stewart, R. C. & Lilwall, R. C. *Geophys. J. Int.* **98,** 565–573 (1989).
5. Kim, W.-Y., Aharonian, V., Lerner-Lam, A. L. & Richards, P. G. *Bull. Seism. Soc. Am.* **87**, 569–588 (1997).