Science & Global Security, 20:64–67, 2012
ISSN: 0892-9882 print / 1547-7800 online
DOI: 10.1080/08929882.2012.652559

Book Review

Detect and Deter: Can Countries Verify the Nuclear Test Ban by Ola Dahlman, Jenifer Mackby, Svein Mykkeltveit and Hein Haak, (Springer, 2011), 271 pages

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Monitoring the 1996 Comprehensive Nuclear-Test-Ban Treaty (CTBT) is both globally important and scientifically interesting. A dozen years after first signatures, the CTBTO Provisional Technical Secretariat (PTS) established the International Scientific Studies (ISS) project which called for technical papers in eight areas: seismology; infrasound; hydroacoustics; radionuclide monitoring; atmospheric transport modeling; system performance; on-site inspection; and data mining. The response for the June 2009 ISS Conference in Vienna was large, 600 scientists from 99 nations contributed 236 papers, with over 50 invited speakers and panelists. *Detect and Deter* summarizes the current and emerging technologies and capabilities for monitoring of underground, atmospheric, and underwater nuclear explosions, as well as on-site inspections, and the synergy with science and national perspectives as compared to international perspectives. *Detect and Deter* will serve as a valuable reference on CTBT monitoring for scientists, diplomats, and the public. The results are very encouraging and the science has progressed. Space limits this review to just the topic of seismic detection.

SEISMIC DETECTION

At the time of signature, it was generally assumed that the Primary Seismic Network of the International Monitoring System (IMS) would have a threshold magnitude m_b of four for a well-coupled yield of about 1 kiloton at three or more IMS primary stations with 90% probability of detection. Seismologists

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expected it would be better than that, but they did not over-promise, awaiting the results of construction and measurement. A half-dozen years after signature, the U.S. National Academy of Sciences concluded that the limit for detection was 3.5 m_b (about 0.1 kt) for Asia, Europe, North America, and North Africa, a factor of ten lower in yield than the 1-kiloton level of 1996.[1] This result was confirmed to good measure by the relative ease of detection for the two nuclear tests by the Democratic People's Republic of Korea. The 9 October 2006 test of 0.6–0.9 kt was detected with explosion-like characteristics at 22 IMS stations, as far away as South America, at a time when the IMS seismic network was only 60% completed. The 25 May 2009 test of 2.5–4.6 kiloton was detected at 61 IMS stations. The International Data Centre provided estimates for location and magnitude of the test within four hours, before DPRK announced the test. Chemical tests of 0.002 kt (1.9 m_b) have been detected and identified with explosive characteristics by Richards and Kim for the Korean Peninsula, using data from four 1998 underground chemical tests at a distance of 289 km.[2]

Detect and Deter gives evidence of further progress in monitoring the CTBT. A good place to start is the work of Kværna and Ringdal (p. 42–46) in which they use the individual characteristics of the IMS stations, which vary as much as Δm_b of 1.5 units, to determine network capabilities. Their results in Figure 2.12 give a threshold of 3.4 m_b for the Northern Hemisphere and 3.6 m_b for the Southern Hemisphere for 90% detection with 3 or more stations. But there are many thresholds to consider. If the probability of detection is dropped to 10% detection with 3 or more stations, the threshold is lowered 0.4 units to 3.0 m_b (0.03 kt) for the Northern Hemisphere and 3.2 m_b (0.06 kt) for the Southern Hemisphere. Ten percent detection may not seem good enough, but ten percent detection at one-third the threshold yield would give cheaters pause for concern. Ultimately 33 of the 50 Primary stations will be arrays of up to 25 seismographs per station, further reducing noise and improving location determinations. The P/S spectral ratios at frequencies above 6 Hz effectively discriminate between earthquakes and explosions in most relevant situations.

THRESHOLD DETECTION

Seismic signals at a few hundred km distance are much stronger than those for similar events at 2000 km distance, and the knowledge of past regional events can aid interpretation (Figure 2.9). If a nation wishes to monitor a particular state, detection at lower magnitudes than those discussed above can be achieved with the concept of "threshold monitoring" that uses previous seismic waveforms and relies on fewer stations for identification. *Detect and Deter* concludes the following (p. 47–48):

> One might say that the requirement of detection at three stations or more is too conservative, or stringent, in the sense that its applications does not show the full potential of the network . . . . By subjecting the North Korean test site to threshold monitoring, Kværna et al. (2007) conclude that, using data from the IMS network available at the time of the test, this site can be monitored—in the threshold monitoring sense—at the 90 percent probability level down to a magnitude of between 2.3 and 2.5. This corresponds to explosive yields of only about 10 tons for explosions in hard rock. Not surprising, use of data from the IMS seismic array station in South Korea was essential in obtaining such low values . . . . The threshold monitoring technique can be said to provide a more complete picture of actual capabilities than the traditional approach based on detection at three stations, and in that sense this technique represents an optimal use of the available data . . . . Kværna et al. (2002) were able to continuously monitor Novaya Zemlya during November and December 1997 down to magnitude 2 most of the time, and were confident that no event exceeding magnitude 2.5 took place. Data from non–IMS stations can be included in the analysis and this will contribute to a further lowering of the detection threshold. These low thresholds will represent a considerable deterrence to clandestine nuclear testing under the CTBT.

AUXILIARY AND GLOBAL SEISMIC NETWORK

Analysis of seismic traces from the world's 16,000 reporting seismographs has enhanced the interpretation of the closer, regional waves. The U.S. Geological Survey receives seismic waveforms from about 1,000 seismographs in near real time. This data can be used in interpreting IMS data, but not directly used by the International Data Centre. Clearly, more quality seismographs improve CTBT data. The Auxiliary Network adds 120 stations to the 50 Primary stations, increasing station density by a factor of 170/50, or 3.4. A simple calculation shows that, on average, a network of 170 stations reduces the threshold sensitivity by 0.25 m_b for a further yield reduction of a factor of two. The Auxiliary Network data is now used by the IDC in selective cases in the Late Event Bulletin, further reducing threshold detection levels and improving location estimates. *Detect and Deter* doesn't allocate sufficient credit for the use of the Auxiliary Network. One can expect additional seismographs will lower thresholds further.

TESTING IN CAVITIES

Detect and Deter points out the following facts that make testing in a cavity risky. A decoupled cavity test will not produce a glass-sealed cavity that blocks leakage of radioxenon, thus the cavity can enhance detection of xenon. Six percent of fission fragments become ^{133}Xe at the rate of 10^{22}/kt. "A 1 percent release from an underground explosion is one to two orders of magnitude larger than the daily release from a large isotope production plant." (p. 67). The

40 IMS xenon stations can be supplemented by national xenon stations on the ground, as Sweden did next to the DPRK in 2006, or by nearby aircraft. In addition, the lowered thresholds for seismic detection, discussed above, force the violator to test at very low yields; a 1-kt test with a reduction of a factor of 70 (less at higher frequencies) could be a significant risk for a small explosion. In addition, a first-time testing nation would not know the yield of the device and would risk an excess yield that could be detected, knowledge that is available to nations that have tested underground.

PRECISION MONITORING

Detect and Deter concludes that a new integrated approach should be implemented to take full advantage of the information in seismic waveforms (p. 85):

> Confident discrimination between explosions and earthquakes, especially for smaller events, must be approached on a regional scale . . . . The fact that less than half of the events reported by PTS can be screened out as earthquakes illustrates that characterization using globally applicable procedures is unsuccessful. A regional approach is needed for event characterization, optimum detection, and localization . . . . The existing methods and procedures for seismological data analysis used by the PTS date back almost three decades, and the time has come to create a new paradigm for such analysis. Developments in data analysis and exploitation have created the tools needed to form a new and integrated approach to the detection, location, and characterization of seismic events using data from the rapidly expanding data resources available from regional and global networks.

CONCLUSION

Detect and Deter analyzes the evolving *Can Countries Verify the Nuclear Test Ban* science and gives direction to future improvements. It fulfilled its goal by reviewing the work of world-wide experts and presenting the results of the ISS project in a clearly understandable fashion. The results are impressive. Any serious reviewer of CTBT monitoring had best read *Detect and Deter* and the ISS papers.[3]

NOTE

1. National Academy of Sciences, *Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty* (Washington, DC: National Academy Press, 2002), <http://www.nap.edu/openbook.php?record_id=10471>.

2. P. Richards and W. Y. Kim, "Seismic Signature," *Nature Physics* 3 (2002): 4–6.

3. ISS09–International Scientific Studies: <http://www.ctbto.org/specials/the-international-scientific-studies-project-iss/≥, 2011: <http://www.ctbto.org/specials/ctbt-science-and-technology-20118-10-june-2≥.