

## CTBT Monitoring: A Vital Activity for Our Profession

Late in 2007, the Seismological Society of America (SSA) and the American Geophysical Union (AGU) agreed on a joint position statement titled “Capability to Monitor the Comprehensive Nuclear-Test-Ban Treaty (CTBT).” It reaffirmed a similar joint statement issued eight years earlier, saying in essence that these two professional societies are confident that a combination of worldwide monitoring resources will meet the verification goals of the CTBT. The full statement can be found at [http://www.seismosoc.org/government/position\\_statement.html](http://www.seismosoc.org/government/position_statement.html) and in the March/April 2008 issue of *Seismological Research Letters* (*SRL* 79, 158–159). I appreciate the *SRL* editor’s invitation to expand here on some of the issues related to this joint statement.

The CTBT is intended to impede nuclear weapons development and as such is a major initiative in nuclear arms control, strongly supporting the endangered Non-Proliferation Treaty (NPT). It is of specialized importance to seismologists for a variety of reasons—first, because the development of seismology has been stimulated for decades by funding to improve the ability to monitor nuclear test explosions;<sup>1</sup> and second because policymakers sometimes interact intensively with seismologists who bring their specialized skills to bear on the analysis of a particular seismic event by detecting, locating, and identifying it and estimating its yield if the event appears to have been an explosion.<sup>2</sup> Given that seismology is recognized as the most important technology for monitoring nuclear explosions, a third reason for seismologists to pay attention to the CTBT is that ongoing professional assessments of monitoring capability are needed for serious discussion and decisions on whether this treaty is adequately verifiable.

1. Global and regional seismometer deployments costing on the order of \$1 billion have been made primarily for detection of nuclear explosions, and research and development programs to improve analysis of nuclear explosion seismic signals have been in place in the United States since 1960.
2. Examples include the nuclear explosions of India and Pakistan in May 1998 and North Korea in October 2006. Seismic events that were not nuclear in origin have also received special attention because of interesting characteristics that made interpretation of their signals a challenge—leading in some cases to improved methods of event identification.

**...the development of seismology has been stimulated for decades by funding to improve the ability to monitor nuclear test explosions...**

This latter reason may be particularly salient during the next few years, as the pros and cons of the treaty are likely to be re-examined in a number of different forums.

The general goals of the CTBT are strongly supported by the general public (Simons Foundation 2007) and also by the great majority of nations, as expressed by numerous lopsided votes in the United Nations.<sup>3</sup> But the treaty has not yet gone into effect, because although it has been signed by 178 nations (as of March 2008) since it was opened for signature in 1996, it has so far acquired only 35 of the signatures and ratifications of the 44 specific nations listed in a treaty annex as necessary for the treaty to enter into force.<sup>4</sup> Of the recognized nuclear weapons countries, the United Kingdom, France, and Russia have signed and ratified the treaty, but China and the United

States, both of which signed on to the treaty in 1996, have not ratified it. Ratification in the United States requires the advice and consent of the U.S. Senate, which debated the treaty on short notice in 1999 and voted against ratification. At the same time, there has been strong political opposition to a resumed nuclear test program in the United States. Because of this history, at present there is effectively a moratorium on nuclear testing (observed by the United States since 1992) rather than a formal treaty that has entered into force—which, for example, would have an onsite inspection program to gather information on the nature of events that treaty signatories deem sufficiently problematic.

After several years with little public attention, new interest in the CTBT has been sparked by a bipartisan group of policymakers led by George Shultz, Secretary of State under President

3. In December 2007, the United Nations General Assembly adopted a resolution stressing the vital importance and urgency of signature and ratification, without delay and without conditions, to achieve the earliest entry into force of the Comprehensive Nuclear-Test-Ban Treaty. The vote was 176 in favor to one against (United States), with four abstentions (Colombia, India, Mauritius, and Syria). Essentially the same result, with the United States casting the sole opposing vote, was recorded in 2003 and 2005. Two countries voted against the treaty in 2004 (U.S.A. and Palau) and 2006 (U.S.A. and North Korea), and more than 170 voted in favor.
4. See <http://www.ctbto.org> for the latest information on treaty signatures and ratifications. The 44 nations whose signatures and ratifications are necessary for entry into force are those deemed in 1996 to have potential as nuclear weapons states on grounds that they had some capability to operate nuclear power reactors.

Reagan, and more generally by consideration of the changes in U.S. policy that may accompany the next administration, recognizing that a CTBT has been a declared objective of the five Republican and four Democratic presidents from Dwight Eisenhower to Bill Clinton. In two articles in the *Wall Street Journal* and a forthcoming book, Shultz's group<sup>5</sup> recommends that, as an important step toward a world free of nuclear weapons, the United States and Russia, which together possess close to 95% of the world's nuclear warheads, should:

*Adopt a process for bringing the Comprehensive Test Ban Treaty (CTBT) into effect, which would strengthen the NPT and aid international monitoring of nuclear activities.* This calls for a bipartisan review, first, to examine improvements over the past decade of the international monitoring system to identify and locate explosive underground nuclear tests in violation of the CTBT; and, second, to assess the technical progress made over the past decade in maintaining high confidence in the reliability, safety and effectiveness of the nation's nuclear arsenal under a test ban. The Comprehensive Test Ban Treaty Organization is putting in place new monitoring stations to detect nuclear tests—an effort the U.S should urgently support even prior to ratification.

In this context it is interesting to note briefly how monitoring capability was characterized in the U.S. Senate debate of October 1999. Two Senate committees held hearings on short notice that month; neither one had testimony from experts in explosion monitoring.<sup>6</sup> But numerous statements concerning monitoring were made during the floor debate, including some that seem substantially incorrect. A repeated statement was that “the United States cannot detect nuclear explosions below a few kilotons of yield.” This may have been an accurate statement in about 1958 when CTBT negotiations began, but 50 years later, as reviewed by Sykes (2002), we can monitor better than this by orders of magnitude. Successful methods of discriminating between earthquakes and underground explosions, based on the analysis of teleseismic body waves and surface waves, were developed in the 1960s and improved in later decades. To reliably monitor events smaller than magnitude 4, regional seismic signals are needed. Several methods of analyzing spectral ratios of the regional waves  $P_n$ ,  $P_g$ ,  $S_n$ , and  $L_g$  have been developed

5. See for example George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, *Toward a nuclear-free world*, Wall Street Journal commentary, 15 January 2008 (available at [http://www.nti.org/c\\_press/TOWARD\\_A\\_NUCLEAR\\_FREE\\_WORLD\\_OPED\\_011508.pdf](http://www.nti.org/c_press/TOWARD_A_NUCLEAR_FREE_WORLD_OPED_011508.pdf)).

6. The Senate Foreign Relations Committee had no questions for the record in its one hearing prior to the October 1999 Senate floor debate and did not follow custom in producing a report for the Senate on the CTBT. In contrast the Strategic Arms Reduction Treaty (START) debate had 1,100 questions for the record.

to discriminate between earthquakes and explosions (Taylor *et al.* 2002). Scientists continue to gain experience in determining which spectral ratios are most successful in different regions. This work can be difficult simply because of the great number of small earthquakes and mine blasts that require some level of attention in the effort to monitor globally for small nuclear explosions. But there is demonstrated success, and no fundamental difficulties exist provided the necessary resources are available to do the work.

More than one speaker in the Senate debate of 1999 claimed that “a 70-kiloton test can be made to look like a 1-kiloton test, which the CTBT monitoring system will not be able to detect.” It is widely recognized that signals from a test conducted underground in a sufficiently large and deep cavity can have their seismic signals reduced by a factor of 70, but the concept has been validated only at subkiloton yield and faces practical difficulties at yields above a few kilotons, even without trying to hide the operation.<sup>7</sup>

In light of the Shultz *et al.* recommendation quoted above on the need to examine improvements in monitoring capability, and also in light of the way in

which monitoring capability was characterized in the first U.S. Senate debate on CTBT ratification, SSA members may wish to know of recent reports and technical papers that provide some detailed information and assessments on monitoring capability.

1. During the years 2000 to 2002, a committee of the U.S. National Academy of Sciences (NAS) reviewed technical issues pertinent to CTBT ratification. The committee, which included former directors of Los Alamos and Sandia National Laboratories and nuclear weapons designers,<sup>8</sup> concluded that the United States has the technical capabilities to maintain confidence in the safety and reliability of its existing weapons stockpile without periodic nuclear tests (NAS 2002). It noted that verification of the CTBT would be accomplished through a combination of the International Monitoring System (IMS) established under the treaty, publicly available geophysical data collected for other purposes, and information gathered by U.S. military and intelligence agencies. Together these assets would provide a high probability of detection of nuclear tests with explosive yields down to about one kiloton in all locations

7. With the energy of a 70-kiloton blast, gas pressure in the cavity ( $\sim 1$  km deep, diameter  $\sim 200$  m) would be increased to about 150 times atmospheric pressure. The surface area of the walls of such a cavity (difficult if not impossible to construct) would be about 12 hectares. The smallest cracks in that vast area would be pathways for the release of radionuclides, only 0.1 percent of which in this case would result in detection at great distance by the radionuclide network being developed for the IMS. The seismic network, together with the radionuclide network, would be easily capable not only of detecting but also of identifying such a test.

8. I was a member of this committee, as was Raymond Jeanloz, a long-time member of the AGU.

and environments—the atmosphere, the oceans, underground, and in near-Earth outer space. Monitoring capability was characterized in terms of the ability to detect and identify signals from nuclear tests both with and without any special attempts to conceal the signals and evade detection. When no attempts are made to conceal a test, the study concluded that underground explosions “can be reliably detected and can be identified as explosions, using IMS data, down to a yield of 0.1 kt (100 tons) in hard rock if conducted anywhere in Europe, Asia, North Africa, and North America.” In the context of serious attempts at evasion (which the committee noted would entail “layers of difficulty”), the bottom-line conclusion assuming a fully functional IMS was that “an underground nuclear explosion cannot be confidently hidden if its yield is larger than 1 or 2 kt.” The NAS report informed the joint statement issued by the SSA and AGU in 2007.

2. In the years since the NAS report was published, its conclusions on detection capability have been broadly confirmed by various studies using better data on levels of signals and noise obtained from practical experience with years of operation of sensitive array stations. See for example Kväerna *et al.* 2007, who describe signals at regional and teleseismic distances from the North Korean nuclear test of 9 October 2006. Kim and Richards (2007) also describe data from this event and show that a key to its identification as an explosion was the availability of a seismogram archive (in this case maintained by the Incorporated Research Institutions for Seismology, or IRIS, consortium) of signals from previous small earthquakes and small chemical explosions in the region. The high-frequency spectral ratio of regional *P* and *S* waves enabled identification of the 9 October 2006 event as an explosion with very high confidence. (Identification of the event as nuclear, from objective evidence, was possible from radionuclides.) Identification of underground explosions in this region can be done even down to a few percent of a kiloton, provided seismic data of the type available in October 2006 are available. It should however be recognized that signal-to-noise ratios can be poor in seismically active regions with sparse instrumentation. In this regard, the nuclear test of 30 May 1998 in Pakistan was more of a challenge to monitor because of concurrent earthquakes in Afghanistan (Barker *et al.* 1998). The IMS was then (and still is) incomplete in this region.
3. Hafemeister (2007, forthcoming) and Jeanloz (forthcoming) have presented extensive discussion to support their claims that the CTBT is “effectively verifiable,” using various definitions of this term as developed in the context of assessments of other arms control agreements. The basic issue here is that a comprehensive ban on nuclear testing cannot be monitored perfectly, because it is possible to conduct a nuclear test sufficiently small that its signals would be undetectable by specific monitoring networks.

**Indeed, our professional activities collectively include work that will impact some of the most important decisions our human society will ever make.**

The task of monitoring networks and those who analyze their data is, then, to perform well enough so that only a nuclear test too small to have military significance could avoid detection. This immediately raises the need for assessment of issues far removed from seismology.<sup>9</sup> Hafemeister and Jeanloz provide informative examples of how “effective verification” can usefully be defined and evaluated.

4. Two Congressional Research Service reports by Medalia (2007, 2008) are pertinent. The first summarizes national positions on the CTBT as taken by several different countries and recent legislative initiatives in the United States and gives a chronology of actions significantly related to the treaty. The second report is intended as a comprehensive discussion of the treaty’s pros and cons, focusing on U.S. perspectives and in particular on issues as they might be seen by a member of the U.S. Congress. (The U.S. Constitution gives the Senate the power to advise and consent to ratification of treaties. CTBT ratification is still on the Senate’s Executive Calendar. The House of Representatives and the Senate have equal roles in considering legislation that specifies how the CTBT would be managed by U.S. government agencies and in setting budgets to support operational monitoring and research and development to improve monitoring capability.) Medalia (2008) discusses monitoring capability, presenting some new material from individuals claiming to characterize what might be achieved in specific evasion scenarios by a country attempting to conduct a clandestine nuclear test.

Our SSA-AGU joint statement of December 2007 was suitable for its intended purpose, a minor revision of the short statement made originally in 1999—but today it may be out of date in its references to a detection capability at the magnitude 4 level. In my opinion, we can do much better than this in many parts of the world.

It is also my opinion that SSA members play a very important role in assessments of monitoring capability. Indeed, our professional activities collectively include work that will impact some of the most important decisions our human society will ever make. Whether you, the reader, regard nuclear weapons as part of the solution or part of the problem in maintaining a more peaceful world, we can expect that policymakers and interested members of the public will occasionally look to us as seismologists for technical advice. I therefore hope that we as members of the SSA will spend some time getting up to speed on issues related to seismic monitoring of nuclear explosions. ❧

## REFERENCES

- Barker, B., M. Clark, P. Davis, M. Fisk, M. Hedlin, H. Israelsson, V. Khalturin, W.-Y. Kim, K. McLaughlin, C. Meade, J. Murphy, R.
9. A new testing nation would likely have problems with venting and yields larger or smaller than expected. An experienced testing nation would have much less to gain from such clandestine tests.

- North, J. Orcutt, C. Powell, P. G. Richards, R. Stead, J. Stevens, F. Vernon, T. Wallace (1998). Seismology: Monitoring nuclear tests. *Science* **281**, 1,967–1,968.
- Hafemeister, D. (2007). Progress in CTBT monitoring since its 1999 Senate defeat. *Science and Global Security* **15**, 151–183.
- Hafemeister, D. (forthcoming). CTBT is effectively verifiable. *Arms Control Today*.
- Jeanloz, R. (forthcoming). Comprehensive Nuclear-Test-Ban Treaty and U.S. security. In *Reykjavik Revisited: Steps Toward a World Free of Nuclear Weapons*. Proceedings of the October 2007 Hoover Institution Conference. to be published by Hoover Press (<http://www.hooverpress.org>).
- Kim, W.-Y., and P. G. Richards (2007). North Korean nuclear test: Seismic discrimination at low yield. *EOS, Transactions, American Geophysical Union* **88** (14), 157, 161.
- Kværna, T., F. Ringdal, and U. Baadshaug (2007). North Korea's nuclear test: The capability for seismic monitoring of the North Korea test site. *Seismological Research Letters* **78**, 487–497.
- Medalia, J. (2007). *Nuclear Weapons: Comprehensive Test Ban Treaty*. CRS Report for Congress, December 19 (available at <http://www.fas.org/sgp/crs/nuke/RL33548.pdf>).
- Medalia, J. (2008). *Comprehensive Nuclear-Test-Ban Treaty: Issues and Arguments*. CRS Report for Congress, February 28 (available at <http://www.fas.org/sgp/crs/nuke/RL34394.pdf>).
- National Academy of Sciences (NAS) (2002). *Technical Issues Related to the Comprehensive Nuclear-Test-Ban Treaty*. Washington, DC: National Academy of Sciences, National Academy Press (available as pdf files via a search on “technical comprehensive” at <http://www.nap.edu>).
- Simons Foundation (2007). *Global Public Opinion on Nuclear Weapons*. <http://www.angusreidstrategies.com/uploads/pages/pdfs/Simons%20Report.pdf>.
- Sykes, L. R. (2002). Four decades of progress in seismic identification help verify the CTBT. *EOS, Transactions, American Geophysical Union* **83** (44), 497, 500.
- Taylor, S., A. Velasco, H. Hartse, W. S. Phillips, W. R. Walter, and A. Rodgers (2002). Amplitude corrections for regional discrimination. *Pure and Applied Geophysics* **159**, 623–650.

*Paul G. Richards*  
*Lamont-Doherty Earth Observatory*  
*Columbia University*  
*richards@LDEO.columbia.edu*