# Opinion

## CTBT Monitoring: a Vital Activity for Our Profession

Late in 2007, the 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 and in the March/April 2008 issue of this journal.

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 itself has been stimulated for decades by funding to improve the ability to monitor nuclear test explosions[1]; and second because policymakers sometimes interact intensively with seismologists who bring their specialized skills to bear on the analysis of a particular seismic event, to detect and locate and identify it, and to estimate its yield if the event appears to have been an explosion[2]. Noting 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 on-going professional assessments of monitoring capability are needed for serious discussion and decisions on whether this treaty is adequately verifiable.

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

[1]Global and regional seismometer deployments costing on the order of a billion dollars have been made primarily for detection of nuclear explosions; and R & D 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 of 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.

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 lop-sided votes in the United Nations[3]. But it is a treaty that has not yet gone into effect, because although it has been signed by 178 nations (as of March 2008) since the treaty 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[4]. Of the recognized nuclear weapons states, the United Kingdom, France and Russia have signed and ratified; but China and the United States, both of which signed on to the treaty in 1996, have not ratified it. Ratification in United States requires the advice and consent of the U.S. Senate, which debated the treaty at 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 U.S. 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 on-site 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 Reagan, and more generally by consideration of the changes in U.S. policy that may accompany the next U.S. administration, recognizing that a CTBT has been a declared objective of the five Republican and four Democratic presidents from Dwight Eisenhower to Bill Clinton. With two articles in the Wall Street Journal and a forthcoming book, Shultz's group[6] recommends as an important step toward a world free of nuclear weapons that the United States and Russia, which possess close to 95% of the world's nuclear

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[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 1 against (United States), with 4 abstentions (Colombia, India, Mauritius, Syria). Essentially the same result with the U.S. casting the sole negative vote was recorded in 2003 and 2005. Two countries voted negatively in 2004 (U.S. and Palau) and 2006 (U.S. and North Korea), and more than 170 voted positively.

[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.

[6]See for example George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, *Toward a Nuclear-Free World*, Wall Street Journal Commentary, January 15, 2008 (available as http://www.nti.org/c_press/TOWARD_A_NUCLEAR_FREE_WORLD_OPED_011508.pdf).

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 of interest to note briefly how monitoring capability was characterized in the U.S. Senate debate of October 1999. Two Senate committees held hearings at short notice that month; neither one had testimony from experts in explosion monitoring[7]. But numerous statements concerning monitoring were made during the floor debate, including some that seem substantially incorrect. Thus, a repeated statement was that "the United States can not detect nuclear explosions below a few kilotons of yield." This may have been an accurate statement in about 1958 when CTBT negotiations began, but it is 50 years later, and 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 monitor reliably for events smaller than magnitude 4, regional seismic signals are needed. Several methods of analyzing spectral ratios of the regional waves *Pn*, *Pg*, *Sn*, and *Lg* have been developed, to discriminate between earthquakes and explosions (Taylor et al., 2002). Experience continues to be gained, to determine 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, requiring some level of attention in the effort to monitor globally for small nuclear explosions. But there is demonstrated success, and no fundamental difficulties 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

[7] The Senate Foreign Relations Committee had no question 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 START debate had 1100 questions for the record.

validated only at subkiloton yield and faces practical difficulties at yields above a few kilotons, even without trying to hide the operation[8].

In view of the Shultz et al recommendation quoted above, on the need to examine improvements in monitoring capability, and also in view of the way in which monitoring capability was characterized in the first U.S. Senate debate on CTBT ratification, members of the SSA may wish to know of recent reports and technical papers that provide some detailed information and assessments on monitoring capability.

(1) A committee of the U.S. National Academy of Sciences (NAS) during the years 2000 to 2002 reviewed technical issues pertinent to CTBT ratification. The committee included former directors of Los Alamos and Sandia National Laboratories and nuclear weapons designers[9], and 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 a kiloton in all locations 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, as they might be conducted, in the first case, without any special attempts to conceal the signals; and second, assuming that attempts might be made to evade detection. In the first case, this 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." And 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." This NAS report informed the joint statement issued by the SSA and AGU in 2007.

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[8] With the energy of a 70-kiloton blast, gas pressure in the cavity (~1 km deep, diameter ~ 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.

[9] I was a member of this committee, as was Raymond Jeanloz, a long-time member of the American Geophysical Union.

(2) In the years since this NAS report was published, its conclusions on detection capability have broadly been 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 Kværna et al (2007), who describe signals at regional and teleseismic distances from the North Korean nuclear test of October 9, 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 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 October 9, 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 May 30, 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, 2008) and Jeanloz (2008) 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 conceptually it is possible to conduct a nuclear test sufficiently small that its signals would be undetectable by specific monitoring networks. The task of monitoring networks and those who analyze their data is then to perform well enough that the only chance of a test being hidden would be for some type of nuclear experiment too small to have military significance. Immediately this raises the need for assessment of issues far removed from seismology[10]. Hafemeister and Jeanloz provide informative examples of how "effective verification" can usefully be defined and evaluated.

(4) Two Congressional Research Service reports are pertinent, by Medalia (2007, 2008). The first of these 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 this treaty. The second report is intended as a

[10] 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.

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 specifying how the CTBT would be managed by U.S. government agencies; and in setting budgets in support of operational monitoring, and of R & D 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 may be out-of-date for example 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 members of the SSA have a very important role to play 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.

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