2

Nuclear test ban verification: work in progress

Oliver Meier

On 10 September 1996 the UN General Assembly endorsed the Comprehensive Nuclear Test Ban Treaty (CTBT) by 158 votes to three. After decades of difficult negotiations the international community had not only agreed to end nuclear testing, but it had also reached consensus on the verification requirements for such a restriction. One of the major stumbling blocks to the conclusion of a universal interdiction on nuclear testing had been conflicting attitudes towards 'efficient' and 'effective' verification. This chapter considers the debate about the verifiability of a nuclear test ban by examining the verification discussions leading to the 1963 Limited Test Ban Treaty (LTBT), the 1974 Threshold Test Ban Treaty (TTBT), the 1976 Peaceful Nuclear Explosions Treaty (PNET) and the CTBT itself.

The CTBT's verification system, which is currently being set up by the provisional CTBT Organization (CTBTO) in Vienna, Austria, is widely believed to be sufficient to assure compliance and to detect cheating. This chapter outlines the regime, as well as the status of its implementation. Unfortunately, however, the story does not end there. Four years after the CTBT was opened for signature, prospects for its entry into force are still uncertain, with some key countries still refusing to sign and ratify the accord. As of 20 October 2000, 160 states had signed the Treaty, and 66 had ratified it.[1] The chapter concludes by summarising the key challenges that need to be overcome before the CTBT can enter into force and its verification system becomes fully functional.

The Limited Test Ban Treaty[2]

In the early 1950s concern about the consequences of fallout from atmospheric nuclear tests triggered international pressure to end such activity. Given the advent of the nuclear arms race, though, it was difficult to agree on a ban, since both the

East and the West wanted to test their emerging nuclear weapon designs. In addition, they pursued different arms control strategies. The US and other Western governments initially linked the test ban issue to general progress in arms control, while the Soviet Union wished to treat it as a separate matter.

During the Cold War, the East and the West also held different views on the verification requirements for a test ban. The US favoured a 'verification first' approach, arguing that talks could only take place after strict standards for verification had been agreed. Many in Washington saw verification as a technical problem and argued that the technical possibilities for verification should determine the scope of a test ban. For its part, the Soviet Union purported to place verification in a broader 'political' context in which arms control *per se,* preferably of the purely declatory variety, was seen as building confidence, rather than requiring verification to enhance confidence in its own implementation.[3] In reality, the Soviet Union was opposed to any kind of intrusive verification, especially on-site measures, such as inspections or monitoring stations, which it saw as 'legalised espionage'.

A breakthrough came in 1957, when the Soviet Union accepted, for the first time, that monitoring stations could be placed on its territory. The administration of US President Dwight D. Eisenhower subsequently proposed the establishment of a group of scientific experts, which would analyse verification measures for a test ban. An international Conference of Experts convened in Geneva in July–August 1958. Their report, presented on 21 August 1958, concluded that a 'control system' of some 170 monitoring stations, using different verification technologies, would be sufficient to detect, with high probability, tests involving yields of more than one kiloton (kt).[4]

The scientists identified seismology as the technology with the greatest potential for monitoring a nuclear test ban, but they argued that some on-site inspections (OSIs) would be necessary.[5] The Conference of Experts was the first of a series of such meetings that would be central to establishing international consensus on the verification requirements for a comprehensive test ban.[6] The meetings prepared the ground for political negotiations, kept the test ban issue alive in times of political tension, created a common understanding of the problems that needed to be addressed, and sometimes developed novel solutions to such problems.[7]

In November 1958 the existing nuclear weapon states—the Soviet Union, the UK and the US—began tripartite negotiations on a comprehensive test ban. In January 1959 the West dropped its insistence that a test ban be linked to progress in general disarmament, thereby removing a major obstacle to a treaty restricting nuclear explosions. Once tripartite talks were underway, all negotiating states agreed to observe a three-year test moratorium, lasting until 1961.[8] During the discussions, the different verification concepts of the interlocutors again became clear.

The number of OSIs was the most visible point of disagreement: Washington wanted more than Moscow was willing to tolerate. But these disagreements were rooted in deeper conflicts about the nature of the OSIs, including triggering mechanisms and the decision-making procedure.[9]

Negotiations broke down after an American U-2 spy plane was brought down over the Soviet Union in 1960 and the Berlin Wall was constructed in 1961. For a short period test ban talks assumed a multilateral character, after negotiations moved, in March 1962, to the new Eighteen Nation Disarmament Committee in Geneva. The Cuban missile crisis of October 1962 convinced the leaderships of both superpowers that progress in nuclear arms control was urgently needed if similar confrontations were to be avoided in future.

But test ban opponents, especially in the US, continued to argue that a comprehensive interdiction would be unverifiable, because small underground tests could not be detected by a monitoring system. To avoid such difficulties, the US proposed, on several occasions, a limited ban on atmospheric and underwater nuclear testing. On 2 July 1963, Soviet Premier Nikita Krushchev accepted the West's proposal to keep underground nuclear tests outside the scope of the Treaty. Tripartite discussions resumed on 15 July 1963, and the LTBT was negotiated in just 10 days.[10]

Representatives of the Soviet Union, the UK and the US signed the LTBT in Moscow on 5 August 1963, and the Treaty entered into force on 10 October 1963. It is of unlimited duration and open for signature by all states. More than 100 nations have acceded to it. Under the accord, parties are obliged 'to prohibit, to prevent, and not to carry out any nuclear weapon test explosion, or any other nuclear explosion, at any place under its jurisdiction or control . . . in the atmosphere; beyond its limits, including outer space; or under water, including territorial waters or high seas; or . . . in any other environment if such explosion causes radioactive debris to be present outside the territorial limits of the State under whose jurisdiction or control such explosion is conducted . . .'.[11]

Treaty members had to rely on their national technical means (NTM)[12] to assess compliance. Given that both sides were confident that atmospheric tests would not go undetected, the LTBT contains no formal verification mechanism. Advances in satellite technology enabled the Soviet Union and the US to identify above ground nuclear explosions via optical sensors and radiation and electromagnetic pulse detectors.[13] There was also no mechanism to verify compliance with the prohibition of cross-border contamination by nuclear debris, which would have required an international mechanism to measure minute traces of radioactivity.[14]

The Threshold Test Ban Treaty

Notwithstanding the *détente* between the Soviet Union and the US in the 1970s, the military and political context was not conducive to agreement on a low threshold or comprehensive test ban. Both sides' militaries were pressing for the development of new nuclear weapon technologies. Little progress towards negotiation of a nuclear test ban was made in the years immediately following the conclusion of the LTBT. But advances in verification technology made it harder for test ban opponents in the US and elsewhere to use verification as an argument against the prohibition of nuclear tests. Increased technical capabilities and an improved understanding of the differences between seismic waves created by earthquakes and those caused by explosions (nuclear and conventional) led the technical community to believe that 'a threshold somewhere between 5 and 30 kt was technically feasible, using verification by technical means only'.[15] Despite such advances in remote monitoring, the US refused to relax its demands for a stringent OSI regime.[16] Moscow, however, insisted that a comprehensive test ban could be verified using only NTM.

The TTBT[17] was signed in Moscow on 3 July 1974, and fulfilled two objectives: continuation of the arms control process without hampering nuclear weapons research and development. The Treaty (a bilateral agreement not open to other states) established a 150kt threshold for military tests, which was to take effect on 31 March 1976. While advances in verification technology had made agreement on a lower threshold or a comprehensive test ban easier, the TTBT did not take advantage of these opportunities. In contrast to the LTBT, however, the TTBT did contain basic verification provisions, which were detailed in a two-page protocol. But verification was again left to NTM, such as satellites and national seismic stations.[18] The parties agreed not to interfere with each other's NTM, although the TTBT did 'not expressly prohibit concealment measures because there were no plausible scenarios for hiding the signals from very high-yield underground tests'.[19]

The 150kt threshold of the TTBT created a different kind of verification problem: how could the parties tell the difference between a 150kt test and one with a yield of 151kt, the latter constituting a treaty violation? To alleviate this problem, they consented to an information exchange, which helped to establish the basic parameters for measuring the yields of each other's tests through remote monitoring. Specifically, they agreed to share the exact locations of nuclear test sites, information about the geology of these sites, the co-ordinates of past nuclear tests, and, in order to calibrate their monitoring stations, the yield, date, time, depth and co-ordinates of two nuclear tests. They also agreed that nuclear weapon tests would be conducted only within declared sites. Even though these verification provisions appear limited today, the TTBT was the first bilateral nuclear arms accord that went beyond national technical means of verification.

At the same time, there was improved scientific understanding of the verification requirements of a multilateral and comprehensive test ban. In 1971, 1973 and 1976, the Conference of the Committee on Disarmament (CCD)—the successor to the Eighteen Nation Disarmament Committee—organised informal meetings with seismologists to discuss international verification of a test ban. These meetings led to the establishment of the Ad Hoc Group of Scientific Experts to Consider International Co-operation Measures to Detect and Identify Seismic Events, which became known as the Group of Scientific Experts (GSE). The GSE, which met twice a year, was open to all members of the CCD—and, later, the Committee (then Conference) on Disarmament (CD)—and experts from invited non-member states.

The GSE delivered its first report to the CD in March 1978, and in July elaborated the technical details of the proposed monitoring system.[20] The reports established parameters for the international monitoring system that would become part of the CTBT. The GSE recommended the setting up of:

- an international network of seismographic stations;
- an international communication facility; and
- several international data centres.[21]

The GSE conducted three extended technical tests (GSETTS)—in 1984, 1991 and 1995—using existing seismological stations to study the ability of an international seismic network to monitor a ban on nuclear testing. The participating stations later formed the core of the CTBT international monitoring system. The third and final test established an International Data Centre in Arlington, Virginia, US, which would eventually become the prototype for the CTBT International Data Centre in Vienna, Austria.

The Peaceful Nuclear Explosions Treaty

Even though the TTBT threshold was high by any standard, debates about its verifiability continued. The US, even after signing the Treaty, argued that its verification regime was insufficient because it contained no provisions for OSIs. One loophole that had to be closed was the conduct of so-called peaceful nuclear explosions (PNEs). Driven by the US, which had effectively ended its PNE programme by 1974,[22] talks began in October 1974 on a PNET, as foreseen in Article III of the TTBT. Again, discussions about verifiability were central to the outcome.

The product of these talks, which ended in April 1976, was sobering. The PNET established the same threshold for underground explosions conducted outside nuclear test sites as the TTBT: 150kt. This was designed to remove any potential advantage being gained from substituting nuclear weapon tests with PNEs.[23] But the Treaty contained neither a limit on the number of such (presumably) peaceful explosions, nor a ban on multiple PNEs. To ensure implementation of the TTBT's consultation and verification provisions, the parties agreed to establish a Joint Consultative Commission. In an Agreed Statement, Moscow and Washington also announced that they would not use PNEs to advance their knowledge about nuclear weapons technology, although this was not verifiable.

While the Treaty itself may have been 'worse than no solution'[24] to the problem of PNEs, an important advance was made in verification. Again, verification of PNEs was mainly left to NTM. But it was difficult to distinguish so-called group explosions (when several are conducted almost simultaneously at a single site). The Soviet Union wanted to maintain the option of conducting multiple nuclear explosions with a combined yield that might exceed 150kt.[25] Moscow, therefore, was willing to accept 'ways that will permit identification of each individual explosion and determination of the yield of each individual explosion'.[26] Under Article IV of the protocol to the PNET, OSIs could be requested at the site of a planned group explosion. The inspection team was allowed to bring its own equipment (detailed in the protocol) to determine the number and yield of nuclear explosions. Even though these provisions are rather modest by modern standards, the resulting PNET had a technical content that went beyond any other arms control agreement of the time.[27] Most important, OSIs had, for the first time, been included in an arms control accord between the Soviet Union and the US.[28]

Following the conclusion of the PNET, the Soviet Union, the UK and the US continued, from 1977 until 1980, trilateral talks on a comprehensive ban. The tripartite report presented to the CD in July 1980 contained no agreement on a comprehensive test ban, but it broke new ground on verification. The report included an agreement on the exchange of seismic data, the establishment of a committee of experts and OSIs.[29]

These recommendations were not pursued because the administration of US President Ronald Reagan, which came to office in 1981, stopped discussions with the Soviet Union on most arms control issues, including a CTBT. The administration believed that TTBT and PNET verification provisions were insufficient and accused the Russians of violating the former Treaty.[30] Moscow and Washington separately announced that they would observe the 150kt limit for nuclear explosions, but they did not implement any of the verification or confidence-building measures contained in the TTBT and PNET.[31]

While high-level agreement on verification could not be reached, the first 'track two' attempt at advancing the debate on verifiability was made. In 1986 the Natural Resources Defense Council, a US non-governmental organisation, and the Soviet Academy of Sciences signed an agreement that led to the installation of seismic monitoring equipment near one of the Soviet test sites, Semipalatinsk in Kazakhstan, and at the US Test Site in Nevada. Even though the agreement was opposed by the Reagan administration, as well as by Soviet hardliners, American and Soviet scientists operated seismic stations near a Soviet test site during a nuclear test moratorium and were later allowed to monitor Soviet tests from 600 miles away. For the first time, on-site and off-site monitoring in the Soviet Union had been conducted by an independent third party.[32] This non-governmental initiative, which was followed in 1987 by an official Joint Verification Experiment, played an important role in overcoming the Reagan administration's test ban 'blocking strategy'.[33]

Debate about the verification of a test ban changed when Soviet President Mikhail Gorbachev took office in March 1985. Soon the Soviet Union compromised on many US demands, paving the way for an understanding on TTBT and PNET verification. In 1987 the Soviet Union and the US started 'nuclear testing talks' on an extended verification protocol for the TTBT. But it was not until 1 June 1990, when Gorbachev and US President George Bush signed protocols to the TTBT and the PNET, that the two Treaties were ratified in the US and subsequently entered into force on 11 December 1990. The new 70-page TTBT protocol, which replaced the original, detailed the use of in-country seismic monitoring technologies, including: hydrodynamic yield measurements of all tests with a planned yield exceeding

50kt; seismic monitoring; and OSIs for all tests with a planned yield exceeding 35kt. It also allowed inspectors to take geological samples to confirm data collected by remote stations.[34]

While the TTBT and the PNET were 'lowest-common-denominator treaties meant to symbolize superpower cooperation without triggering verification dilemmas or domestic opposition',[35] they both helped to advance discussions on the verifiability of a comprehensive test ban. States were also able to gain first-hand experience of verification and confidence building. Consequently, these test ban agreements' limited verification measures and associated scientific research laid the ground for a multilateral and comprehensive ban on nuclear tests.

The Comprehensive Nuclear Test Ban Treaty

Negotiations on a CTBT began in the CD in January 1994. This was the first time a multilateral body had a mandate to negotiate a comprehensive ban.[36] The change of setting, as well as different ideas about the function and scope of such an accord, made for a slow start to talks in the CD's subsidiary body, the Ad Hoc Committee on a Nuclear Test Ban.

On verification, however, negotiators could draw on a rich body of scientific work.[37] Four decades of international discussions on CTBT verification had led to a common understanding of the capabilities of many verification technologies, especially seismic. The GSE, in particular, constituted an international core group of scientists (the 'detection club') that was able to advise negotiators in Geneva.[38] The GSE made a powerful argument that a global network of seismic stations would be the core of the verification system and that the International Monitoring System (IMS) should use hydroacoustic, radionuclide and infrasound stations.

Positive experiences in arms control verification generally had been acquired in the 10 years prior to the conclusion of the CTBT. In 1987, for example, the US–Soviet Agreement on Intermediate-range Nuclear Forces had been concluded, with intrusive verification arrangements. This positive experience was reinforced by implementation of the 1991 Strategic Arms Reduction Talks (START) Treaty. In 1990, he member states of NATO and the Warsaw Treaty Organization signed the Conventional Armed Forces in Europe (CFE) Treaty, and, in 1992, the CD concluded negotiations on the Chemical Weapons Convention.[39] This latter multilateral agreement contained an unprecedented verification regime that was to be implemented by an international organisation.[40] The final push for conclusion of the CTBT came in May 1995, when the Nuclear Non-Proliferation Treaty (NPT) Review and Extension Conference agreed that a universal and internationally and effectively verifiable CTBT should be concluded no later than 1996.

In the course of 1995 it became clear that a CTBT would most likely prohibit 'any nuclear weapon test explosion or any other nuclear explosion'.[41] The main role of the CTBT verification regime, therefore, was clear: the IMS would have to be able to detect and identify any nuclear explosion, no matter where it occurred. By December 1995, the Verification Working Group's technical experts had reached broad consensus on the number and distribution of stations, which determined the eventual design of the IMS.[42] But this still left a number of important questions about scope unanswered, such as whether so-called hydronuclear experiments and other subcritical tests would be permitted and whether the Treaty should also cover test preparations. In the end, acceptable compromises were made on these and other questions.

Negotiations concluded in August 1996. India vetoed the Treaty's adoption in the CD because it was included in a list of 44 states that had to ratify the CTBT before it could enter into force.[43] Australia initiated its transfer to the UN General Assembly, where it was adopted and opened for signature on 24 September 1996.[44]

The CTBT verification system

The agreed verification system is robust and effective enough to assure member states that attempts to cheat the system will be detected with a high degree of probability, even though it does not use all available verification technologies.[45] The IMS will consist of 321 monitoring facilities and 16 radionuclide laboratories, located in some 90 countries. Four types of stations are to be established:

- seismological;
- infrasound;
- hydroacoustic; and
- radionuclide.

The seismic network will form the core of the verification system. Seismic waves generated by earthquakes, explosions or other phenomena will be detected using 50 primary and 120 auxiliary seismic stations, distributed globally. In addition, 11 underwater hydroacoustic stations are being set up.[46] Sixty land-based infrasound stations will use sonar to detect atmospheric tests, while 80 radionuclide stations will measure radioactive particles in the atmosphere from atmospheric nuclear tests or underground tests that vent. Sixteen radionuclide laboratories will analyse filters from the stations, as well as samples taken by inspectors.

The four different technologies operated by the IMS are complementary and are able to detect tests in different environments. It is also becoming increasingly clear that synergy between the different technologies may considerably improve the System's detection capability.[47] During the negotiations, a one-kiloton threshold for fully coupled underground nuclear explosions was used as a guide. In many instances, the IMS will be able to detect much smaller tests.[48] The task of realising the potential for complementarity will rest with the International Data Centre (IDC), which will receive and process information from all IMS monitoring facilities and will distribute data to member states.

After a slow start, implementation of the CTBT verification system is making good progress.[49] The future CTBTO will consist of a Conference of the States Parties, an Executive Council and a Technical Secretariat. A Preparatory Commission is in charge of setting up the verification system until the Treaty enters into force. Its two Working Groups—on verification and finance—have been making the necessary political decisions to guide the work of the Provisional Technical Secretariat (PTS).

Remaining challenges

The debate about the CTBT's verifiability did not end, however, with its opening for signature. Three issues are at the centre of the current debate:

- the question of OSIs;
- the confidentiality of monitoring data; and
- the possibilities for evading detection.

Given the test ban's negotiating history, it was not surprising that the purpose and scope of OSIs were among the most controversial aspects of verification discussions during the CTBT negotiations. But the OSI provisions agreed are among the most intrusive in multilateral arms control. An OSI may be requested by any party and will be conducted only if at least 30 of the Executive Council's 51 member states support the proposal.[50] An OSI request may be based on information collected by the IMS, and/or, more controversially, on 'any relevant technical information' obtained by NTM 'in a manner consistent with generally recognised principles of international law'.[51] During an OSI—which can last for a maximum of 70 days—a team of no more than 40 persons can inspect up to 1,000 square kilometres.

Inspectors' rights during OSIs were not only a contentious issue in the negotiations, but they remain problematic in the Preparatory Commission (PrepCom). Progress is slow in developing an Operations Manual for OSIs.[52] Some states, which are fearful of overly intrusive OSIs, are attempting to constrain them through a

Chronology of the CTBT

1958 Group of Experts (from Canada, Czechoslovakia, France, Poland, Romania, Soviet Union, UK and US) convenes in Geneva on 1 July. Report presented on 21 August 1958. UK–US–Soviet Conference on Discontinuance of Nuclear Tests opened in Geneva (31 October) (Recess 5 December 1960–March 1961; adjourned 29 January 1962)

1962 Eighteen Nation Disarmament Committee puts issue of a comprehensive test ban on its agenda (4 March) and establishes subcommittee on nuclear test ban (21 March 1962)

1963 The LTBT signed in Moscow by Soviet Union, UK and US (5 August)

1968 International meeting of seismic experts in Sweden at invitation of Stockholm International Peace Research Institute

1970 Nuclear Non-Proliferation Treaty enters into force, making full-scope nuclear safeguards for non-nuclear weapon states mandatory (5 March)

1974 The TTBT signed in Moscow by Soviet Union and US (3 July)

1976 The PNET signed by Soviet Union and US (28 May). Establishment of Group of Scientific Experts (GSE) by Geneva Conference of the Committee on Disarmament (CCD) (July)

1977 Trilateral test ban negotiations begin (until 1980)

1978 First comprehensive GSE report to CCD (9 March)

1980 GSE Global Telecommunication System technical tests (until 1983)

1982 Ad Hoc Committee at Conference on Disarmament (until 1983)

1984 First GSE technical test (GSETT-1)

1986 Natural Resources Defense Council–Soviet Academy of Sciences verification experiment

1987 Joint Verification Experiment at test sites in Nevada, US, and Semipalatinsk, Kazakhstan (August–September). US–Soviet 'nuclear testing talks' on verification protocol (until 1990)

1990 Additional Verification Protocols to TTBT and PNET signed in Washington by Soviet Union and US (1 June)

1991 Second GSE technical test (GSETT-2)

1994 Negotiations on CTBT begin in Conference on Disarmament, Geneva (January). Third GSE technical test (GSETT-3) with prototype International Data Centre, Arlington, Virginia, US

1996 The CTBT opened for signature (24 September)

1997 Provisional Technical Secretariat of PrepCom for CTBTO established in Vienna, Austria (March)

1999 Article XIV Special Conference, Vienna (6–8 October)

2000 International Data Centre in Vienna assumes responsibility for IMS data analysis and distribution (20 February) highly detailed manual; others favour giving on-site inspectors greater liberty and flexibility. International experts are also assisting in identifying elements of an OSI infrastructure, including an Operations Support Centre, Information Data Bank and an equipment storage and maintenance facility.

Access to, and distribution of, verification data were other issues that proved difficult to resolve in the test ban negotiations. Some countries—led by the US—opposed an independent analytical capability, fearing 'politicisation' of the Organization. Many associated problems still preoccupy the PrepCom. States without significant national technical and analytical means will naturally look to the IDC for more precise information once initial suspicions of non-compliance are aroused. Citing the CTBT's 'confidentiality' provision, some states continue to object to the use of IDC information for other purposes, like early warning of natural disasters, assisting humanitarian relief organisations and scientific research.[53]

Finally, debates about verifiability continue. After India and Pakistan conducted a series of nuclear test explosions in May 1998, uncertainties about the number and yields were used to question the effectiveness of the IMS. However, 'the most surprising verification failure in the whole episode was not that of the nascent international monitoring system, but that of US NTM,[54] which failed to pick up test preparations. The US should, therefore, have an interest in supplementing its NTM for monitoring a test ban by ratifying the CTBT, supporting the IMS and ensuring its full implementation.[55] Instead, doubts about 'verifiability' were partly responsible for the Senate's refusal to give advice and consent to US ratification.[56] Test ban opponents argued that the IMS could not reliably detect very small nuclear tests, and that this 'grey area' provides an opportunity for cheating.[57] These developments highlight the need for an informed, balanced debate in the US about the benefits and shortcomings of the CTBT and its verification provisions.[58]

Meanwhile, the PrepCom has to continue to implement the verification system, so that it is ready when the Treaty enters into force.[59] In so doing, it will have to scale political, financial and legal hurdles. Among the dangers confronting the PrepCom is a lack of financial support. So far, member states have generally paid their dues on time.[60] It is important to maintain this level of political and financial backing for the CTBT. The PrepCom also has to solve problems relating to its ambivalent legal status. The CTBTO will only be able to conclude, for example, the legal arrangements with member states that are necessary for setting up and maintaining IMS stations after the Treaty has entered into force.[61]

But all of these difficulties can be overcome. And even with only about one-third of IMS stations reporting to Vienna, some of the synergies between the different verification technologies are already apparent. The international community has almost achieved the goal that has occupied politicians, diplomats, activists, arms control and technical experts for several decades: an effective and efficient verification system to ensure compliance with a CTBT.

Dr Oliver Meier is Arms Control and Disarmament Researcher at VERTIC. He has a PhD in Political Science from the Free University of Berlin, Germany. Before joining VERTIC, he was an analyst with the Berlin Information Center for Transatlantic Security (BITS) in Berlin and Geneva.

Endnotes

[1] Updates on the state of verification and other basic information on the CTBT can be found on the Preparatory Commission's website at www.ctbto.org.
[2] This Treaty is often referred to as the Partial Test Ban Treaty (PTBT).
[3] The Russians argued that 'science must not interfere with the task' of designing a test ban monitoring system. Quoted in Nancy Gallagher, *The Politics of Verification,* The Johns Hopkins University Press, Baltimore and London, 1999, p. 86.
[4] The US originally proposed a network of 650 stations; the Soviet Union preferred 100–110 land-based stations. See Matthew Evangelista, *Unarmed Forces: The Transnational Movement to End the Cold War*, Cornell University Press, Ithaca and London, 1999, p. 62.
[5] These findings were based on data from the first fully contained underground nuclear explosion, conducted at the US Test Site in Nevada on 19 September 1957, and several partially contained underground explosions. See Peter W. Basham and Ola Dahlman, 'International seismological verification', in Jozef Goldblat and David Cox (eds.), *Nuclear Weapon Tests: Prohibition or Limitation?,* Oxford University Press, Oxford, 1988, pp. 169–189; pp. 170–171.
[6] The Geneva Conference of Experts was 'part of a transnational effort' to advance arms control issues. For a good analysis of the role of non-governmental actors, especially in the Soviet Union and Russia, in achieving consensus on a comprehensive test ban and its verification systems, see Evangelista.
[7] See Martin B. Kalinowski, 'Nuclear Physics and Peace', *INES Newsletter,* no. 28, March 2000. Available at www.inesglobal.org.
[8] France conducted its first three nuclear tests in 1960, undermining the moratorium.
[9] In December 1962, both sides came very close to agreeing an annual quota for on-site inspections, with the Soviets offering three and the US wanting 8–10. If misunderstandings about each other's position had been avoided this might have been an early breakthrough towards a comprehensive test ban. See, for instance, Evangelista, pp. 78–79.
[10] The full title of the Treaty is the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water. The text of the LTBT and of other treaties can be found on the US Department of State's website at www.state.gov.
[11] Article I of the LTBT.
[12] As defined in arms control treaties, national technical means (NTM) of verification are usually understood to encompass all methods of remote sensing, such as satellites. 'Illegitimate' intelligence means—like espionage—are viewed as being outside of this definition. Of course, they contribute to national assessments of other states' capabilities. There is also a large grey area between NTM and espionage, to which many means of gathering intelligence belong. See, for example, Allan S. Krass, *Verification: How Much Is Enough?,* Taylor & Francis, London and Philadelphia, 1985, p. 7.
[13] This capability has been constantly expanded. Meanwhile the US has developed the space-based 'Nuclear Detonation Detection System' (NDS), which is based on all 24 'Global Positioning System' (GPS) satellites. This network provides 24-hour, global coverage for detecting and locating nuclear detonations. In addition the US possesses the Advanced Radiation Detection Capability Data Unit (ARDU), which processes nuclear detonation detection data from its Defense Support Program satellites. See Jozef Goldblat, 'The Nuclear Test-Limitation Treaties', in Serge Sur (ed.), *Verification of Current Disarmament and Arms Limitation Agreements: Ways, Means and Practices*, Aldershot (England) and Brookfield (US), Dartmouth, 1991 (United Nations Institute for Disarmament Research), pp. 95–122.
[14] See Trevor Findlay, *Paper for Project on Implementation of Multilateral Arms Control Agreements: Questions of Compliance: Nuclear Tests,* Geneva Centre for Security Policy, www.gcsp.ch.
[15] Coit D. Blacker and Gloria Duffy (eds.), *International Arms Control: Issues and Agreements,* Stanford University Press, Stanford, California, 1984, p. 137. For a summary of the discussion on differentiating between earthquakes and nuclear explosions, see Jack F. Evernden and Charles B. Archambeau, 'Some Seismological Aspects of Monitoring a CTBT', in Kosta Tsipis, David W. Hafemeister and Penny Janeway (eds.), *Arms Control Verification: The Technologies That Make It Possible,* Pergamon–Brassey's, Washington, DC, 1986, pp. 223–263.

[16] Politicians on both sides used verification arguments to 'avoid making clear-cut choices between co-operation and competition'. The US was willing to go a long way to maintain this 'avoidance strategy'. When American scientists concluded in 1970 that it was possible to tell a nuclear explosion from an earthquake even at low seismic magnitudes and thereby 'removed the last shreds of plausibility from a continued US insistence on OSIs for a CTB', the report was classified and its results distorted by the US Advanced Research Projects Agency. See Gallagher, p. 220.
[17] The full title of the Treaty is the Treaty Between The United States of America and the Union of Soviet Socialist Republics on the Limitation of Underground Nuclear Weapon Tests.
[18] Article II of the TTBT specified that, 'for the purpose of providing assurance of compliance with the provisions of this Treaty, each Party shall use national technical means of verification at its disposal in a manner consistent with the generally recognised principles of international law'. TTBT, Article II.
[19] Gallagher, p. 160.
[20] The GSE eventually produced six reports: the first three identified the basic requirements for a CTBT verification system; and the final three reported on the results of the GSE's technical tests.
[21] See Peter W. Basham and Ola Dahlman, 'International seismological verification', in Goldblat and Cox (eds.), pp. 169–189.
[22] The US Plowshare Program had lost most of its domestic support by the mid-1970s. See Trevor Findlay, *Nuclear Dynamite. The Peaceful Nuclear Explosions Fiasco,* Brassey's Australia, Rushcutter's Bay, 1990, pp. 220–237.
[23] The full title of the Treaty is the Treaty on Underground Nuclear Explosions for Peaceful Purposes.
[24] Findlay, *Nuclear Dynamite, The Peaceful Nuclear Explosions Fiasco,* p. 253.
[25] In the end, a group of explosions for peaceful purposes were allowed a combined yield of up to 1.5 megatons.
[26] Article III, paragraph 2 of the PNET.
[27] Allen Greb, 'Survey of past nuclear test ban negotiations', in Goldblat and Cox (eds.), pp. 95–117.
[28] Findlay, *Nuclear Dynamite. The Peaceful Nuclear Explosions Fiasco,* pp. 259–260.
[29] Greb, p. 106.
[30] Gallagher, p. 190.
[31] According to the Treaties, both confidence building and verification would commence only after the documents of ratification had been exchanged.
[32] For a description of the experiment, see Philip G. Schrag, *Listening for the Bomb: A Study in Nuclear Arms Control Verification Policy,* Westview Special Studies in National Security and Defense Policy, Westview Press, Boulder, San Francisco and London, 1989.
[33] The Joint Verification Experiment (JVE) was conducted in August 1988. US and Soviet scientists evaluated hydrodynamic and teleseismic monitoring technologies. The Reagan administration had insisted that continuous reflectometry for radius versus time experiments (CORRTEX), an on-site hydrodynamic yield estimation method that has to be applied in or near the actual shaft of an underground test, should be added to the list of verification technologies. The JVE experts concluded that this new, highly intrusive verification method was not superior to conventional means of monitoring nuclear tests. The JVE, however, was an important confidence-building measure. See Jozef Goldblat, *The Nuclear Test-Limitation Treaties,* in Sur (ed.), p. 102, and Gallagher, p. 191.
[34] Protocol to the Treaty Between the United States of America and Union of Soviet Socialist Republics on the Limitation of Underground Nuclear Weapon Tests, Moscow, 1 June 1990.
[35] Gallagher, p. 149.
[36] For an analysis of the negotiating framework, see Rebecca Johnson, 'Nuclear Arms Control Through Multilateral Negotiations,' in Nancy W. Gallagher (ed.), *Arms Control: New Approaches to Theory and Policy*, Frank Cass, London, 1998, pp. 83–115.
[37] During the CTBT negotiations, interaction between the scientific community and negotiators was sometimes difficult. Scientists could not always deliver results on time, and diplomats forced new requirements on the scientists. See Gallagher, *Politics of Verification,* p. 231.
[38] For an account of the GSE until the early 1990s, see Thomas Schmalberger, 'In Pursuit of a Nuclear Test Ban Treaty, A Guide to the Debate in the Conference on Disarmament', United Nations Institute for Disarmament Research, Geneva, April 1991, UNIDIR/91/16, pp. 61–91.
[39] See the chapters in this volume by Pál Dunay and Annette Schaper.

[40] Implementation only started after entry into force of the CWC in 1997. But the negotiations demonstrated that disagreements over verification questions could be overcome and that the outcome would still be a viable verification system. It can also be argued that it is more complex to monitor the CWC than a CTBT.
[41] Article I of the Comprehensive Nuclear Test Ban Treaty. The formula was introduced by Australia in March 1995 and subsequently endorsed by the major nuclear weapon states. See Rebecca Johnson, 'The CTBT Endgame: the Major Obstacles', in Poole and Guthrie (eds.), *Verification 1996: Arms Control, Peacekeeping and the Environment*, VERTIC Yearbook, Westview Press, Boulder, Colorado and Oxford, UK, 1996, pp. 87–104.
[42] Joachim Schulze, 'Verification for CTBT Compliance: Developments during the 1995 Negotiations', in John B. Poole and Richard Guthrie (eds.), *Verification 1996*, pp. 105–124.
[43] The 44 states named in Annex 2 are: Algeria, Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Democratic People's Republic of Korea, Egypt, Finland, France, Germany, Hungary, India, Indonesia, Iran, Israel, Italy, Japan, Mexico, Netherlands, Norway, Pakistan, Peru, Poland, Romania, Republic of Korea, Russian Federation, Slovakia, South Africa, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America, Vietnam, Zaire.
[44] Only Bhutan, India and Libya voted against the Treaty in the General Assembly. Cuba, Lebanon, Mauritius, Syria and Tanzania abstained.
[45] Verification technologies that were under consideration but not included in the IMS include ground-based optical, ground-based electromagnetic pulse (EMP) detection networks, and satellites. The CTBT, however, specifically provides that additional monitoring technologies 'shall, when agreed, be incorporated in existing provisions in this Treaty'. Article IV, paragraph 11 of the CTBT.
[46] For a description of hydroacoustics as a monitoring technique, see Ruth Weinberg, 'Hydroacoustic Monitoring of the World's Oceans', *Verification Matters no. 8*, Verification Technology Information Centre (VERTIC), London, January 1995.
[47] A good summary of synergies between the different IMS components is given in Larry S. Walker, 'A Systems Perspective of Comprehensive Test Ban Treaty Monitoring and Verification', *Sandia Report*, Sandia National Laboratories, Albuquerque, New Mexico, US, November 1996, SAND96-2740/UC-700.
[48] Peter Marshall mentions the example of two 100 and 25 ton conventional test explosions in Kazakhstan, as well as a 2–2.5 ton underwater test explosion in the Red Sea, which were successfully identified and located by a partially completed IMS. See Peter D. Marshall, 'Achievements of the CTBT, Efficacy and Benefits of the Treaty Regime', presentation at the Third Anniversary of the Preparatory Commission in Vienna, Austria, 4 April 2000.
[49] The CTBT Preparatory Commission, charged with setting up the Organization and the IMS, was founded in November 1996. The Provisional Technical Secretariat and the PrepCom started work in March 1997. An update of the work of the PrepCom can be found in Trevor Findlay and Oliver Meier, 'Fulfilling the NPT: A Verifiable Test Ban', *Briefing Paper 00/1,* Verification Research, Training and Information Centre, London, April 2000.
[50] This was the outcome of a last minute deal between the US and China in the final stages of the negotiations. Rebecca Johnson, 'A Comprehensive Test Ban Treaty: Signed but not Sealed. A Review of the CTBT Negotiations in the Conference on Disarmament January–September 1996', *Acronym* no. 10, London, May 1997, p. 43.
[51] Article V (D), paragraph 37 of the CTBT.
[52] During the tenth session of Working Group B in August 1999, the Chairman, Ola Dahlman, complained that 'OSI is lagging behind the other elements of the verification system'. *Introductory Comments by the Chairman of Working Group B to the Tenth Session*, CTBT/PC-10/1/Annex II, Appendix I, 30 August 1999, p. 19.
[53] See, for example, CTBT/PC-10/1/Annex II, p. 6.
[54] Trevor Findlay, 'The Indian and Pakistani Tests: Did Verification Fail?', *Trust & Verify*, Verification Research, Training and Information Centre, London, no. 80, May 1998, pp. 1–4.
[55] A good summary of the history of the US nuclear detection network is contained in Charles A. Ziegler and David Jacobson, *Spying without Spies: Origins of America's Secret Nuclear Surveillance System,* Praeger, Westport, Connecticut and London, 1995.
[56] For a summary of the debate, see Oliver Meier, 'Verifying the CTBT: Responses to Republican Criticisms', *Disarmament Diplomacy*, no. 40, September–October 1999, pp. 19–21; and Daryl Kimball, 'What Went Wrong:

Repairing the Damage to the CTBT', *Arms Control Today,* no. 8, vol. 29, December 1999, pp. 6–9.
[57] Robert Suro, 'CIA Admits Test-Ban Shortcomings', *International Herald Tribune*, 4 October 1999. Colin Macilwain, 'US Senate ignores scientific advice in failing to ratify test ban treaty', *Nature 401*, 6755, 21 October 1999, p. 735. The possibility of evading the CTBT, in the context of the US debate on ratification, is discussed in Lynn R. Sykes, 'False and Misleading Claims about Verification during the Debate on the Comprehensive Nuclear Test Ban Treaty', *FAS Public Interest Report*, Journal of the Federation of American Scientists, Washington, DC, volume 53, no. 3, May–June 2000.
[58] To prepare for the next ratification debate in the US Senate, President Bill Clinton's administration has established a high-level task force under the leadership of retired General John Shalikashvili. See Statement of Secretary of State Madeleine K. Albright on the Comprehensive Test Ban Treaty, Davos, Switzerland, 28 January 2000, secretary.state.gov. Moreover, VERTIC has established an Independent Commission on the Verifiability of the Comprehensive Nuclear Test Ban Treaty to support an informed debate on current and future capabilities of the CTBT's verification system. Information on the Commission, which consists of eminent scientific experts, and its final report can be found on VERTIC's website at www.vertic.org or on the Commission's website at www.ctbtcommission.org.
[59] A good summary of progress is contained in the reader of a seminar that was conducted by the CTBTO on the third anniversary of the establishment of the PTS. See CTBTO PrepCom, 'Summary Report of Panel Discussion "CTBT Three Years On—Significance, Achievements, The Way Forward"', Vienna, Austria, 4 April 2000, www.clw.org.
[60] Collection rates from member states have been above 90%, higher than in most other international organisations.
[61] To enable the PrepCom to certify the IMS, 'facility agreements or arrangements' have to be negotiated between the PTS and member states. By April 2000, the PrepCom had concluded nine facility agreements.