Advancing Nuclear Test Verification without Entry into Force of the CTBT

Mao Sato
Ex CTBTO, Tokyo, Japan

ABSTRACT
Seventy-six years after the atomic bombs exploded over Hiroshima and Nagasaki, the world continues to face challenges to the existing arms control framework, part of the broader problem of the stagnation of multilateralism. There is a desperate need to reinvent the architecture of nuclear disarmament. While it seems almost impossible for the political deadlock to be broken with regard to entry into force of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), the power of science continues to create a unique avenue for confidence-building measures (CBMs) to meet the needs of both nuclear-weapon states and non-nuclear-weapon states. This paper re-examines the value of science as a tool for arms control verification by separating the issue of the CTBT’s non-entry into force from the immediate application of its verification regime. The progress of nuclear-test-ban monitoring can be measured against scientific indicators, irrespective of the status of the remaining Annex II countries. The CTBT has already practically satisfied its core function of monitoring nuclear testing with the existing structure. The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization has been progressing as an agent of CBMs, the development of civilian and scientific applications of the verification regime, and a capacity-building effort to attract more states to join the cause, and by doing so, sustaining nuclear-test-ban moratoriums.

Introduction

The year 2021 marks the 76th commemoration of the atomic bombings of Hiroshima and Nagasaki in Japan. Tomihisa Taue, the Mayor of Nagasaki city, has repeatedly asked to the world, “Why is it that we humans are still unable to rid ourselves of nuclear weapons?” (Taue 2020). On the contrary, the United States’ withdrawal from the existing disarmament agreements such as the Intermediate-Range Nuclear Forces Treaty in 2019 and the Joint Comprehensive Plan of Action in 2018 highlighted differing strategic needs among the nuclear-weapon states (NWS) and indicated that the stagnation of multilateralism creates a negative environment surrounding arms control regimes (Gogna 2020, 4). The recent developments serve as a reminder that establishing international...
norms on arms control and nonproliferation requires a long-term perspective. In this regard, the pending entry into force of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is not an exception.

Despite the Trump administration’s announcement in the Nuclear Posture Review in February 2018 that it would not pursue ratification of the CTBT, and the unlikelihood that the other Annex II states\(^1\) possessing nuclear capability will ratify the CTBT in the near future to bring it into force, the CTBT Organization (CTBTO)\(^2\) has been increasing the number of signatures and ratifications and steadily installing more monitoring facilities since its establishment. Today, 185 states have signed and 170 have ratified the CTBT, with the Union of the Comoros being the latest ratification in 2021 (CTBTO 2021g). While the CTBTO continues to operate as an interim organization, a robust verification regime to detect nuclear testing has been developed by two scientific components of the CTBT verification regime called the International Monitoring System (IMS), which covers engineering and maintenance of monitoring facilities, and the International Data Centre (IDC), which operates and analyzes data transferred from the IMS. These detection systems are constantly gathering data generated by seismic, hydroacoustic, infrasound, and radionuclide monitoring stations (Hansen 2006, 75). The IMS already covers more than 90% of the planned 337 facilities worldwide, which are listed in the Annex to the Protocol of the CTBT, to gather huge amounts of scientific data (CTBTO 2021c).

This fact raises a question: What factors have contributed to the substantial progress that has been made in monitoring nuclear tests? This research question is based on the hypothesis that the Nuclear Non-Proliferation Treaty (NPT), the cornerstone of nuclear disarmament and nonproliferation, has become a model for the entire disarmament framework. In reality, one can argue that the progress of NPT implementation is built upon deterrence theory – that is, a strategic balance of power to ensure peace (Quackenbush and Zagare 2016, 2). The text of the treaty’s Article VI is carefully written for all state parties, but especially the NWS, to pursue negotiations toward nuclear elimination in good faith as an ultimate goal. But this is without any binding legal requirements and does not specify the way or the time frame to conclude such a negotiation because no NWS would give up its nuclear deterrent capability without having confidence in its opponents’ progress toward nuclear disarmament (Ford 2007, 409).

Previous research (Sagan 2009, 14; Bunn 2003, 9; Rydell 2018, 55; Hajnoci 2020, 88; Fukui 2017, 12; Lozova 2015, 96) has focused mainly on 1) the legal effect on the CTBT ratifications by the remaining Annex II states as an indicator to measure the progress for the implementation of Article VI of the NPT, which requires NWS to make good-faith efforts to regulate, constrain, reduce, and eliminate nuclear weapons (Sagan 2009, 14) and 2) the effective provisional operation of verification installations even though further improvement seems impossible due to the dim prospects for the treaty’s entry into force.

---

\(^1\)The remaining Annex II States are the Democratic People’s Republic of Korea (DPRK), Egypt, India, Iran, Israel, Pakistan, the People’s Republic of China and the United States. The DPRK, India, and Pakistan have neither signed nor ratified the treaty.

\(^2\)It is technically called the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization before the treaty’s entry into force, and the administrative organ of the organization is called the Provisional Technical Secretariat; yet it is generally known as the CTBTO and this term is used hereafter in this article.
because of the remaining Annex II states. These reviews cannot fully explain the notion that the remaining Annex II states’ scientific contributions prior to their ratification of the CTBT have already helped the successful detection of nuclear tests that the Democratic People’s Republic of Korea (DPRK) conducted. Or, they fail to explain why the number of signatories and ratifications is increasing today: why would a country such as Comoros be attracted to the CTBT, given that entry into force of the treaty seems unrealistic? In other words, in spite of political unwillingness of the remaining Annex II states to ratify the CTBT to bring it into force, the CTBTO has been progressing with the development of immediate scientific applications; hence, there is an academic space to fully examine this phenomenon.

The author suggests that the immediate application of the verification regime be studied separately from the issue of the entry-into-force status of the CTBT because factors to promote the immediate application can be measured both quantitatively (e.g. monitoring stations’ installment and the coverage rate of the installed facilities) and qualitatively (e.g. improved data processing and analysis). There have been substantial achievements for verification capability developed through the peaceful means of science and technology, while the status of entry into force is mainly a result of the national security environment. Irrespective of the status of the CTBT, full monitoring station installment, with analyzed data of high quality, has already practically satisfied its core function of monitoring nuclear testing, albeit in a provisional mode. The current challenge therefore lies in making the existing verification structure sustainable, reaching out to the countries that are still outside the verification structure, and improving the quality of data and the level of analysis conducted at monitoring stations in developing nations.

**Methodology**

This qualitative study is based on literature reviews, reviews of technical and media reports, and the author’s personal experience part of a team to promote entry into force and the universalization of the CTBT. It examines three benefits generated by the immediate application of the verification regime prior to entry into force: benefits for international peace and security, benefits for development objectives, and benefits for overall scientific improvement of the verification regime. The article begins by discussing the ways in which science and technology have played a concrete role in improving CBMs throughout the history of nuclear disarmament. It then examines the civil and scientific application\(^3\) of the verification regime and capacity-building effort to further advance its capability and create an incentive for the remaining countries to join the cause. The article concludes that the progress of nuclear-test-ban monitoring can be measured against scientific indicators that are beyond the deterrence-based argument in relation to Article VI of the NPT. This article focuses on multilateralism and the verification regime of the IDC and IMS; it does not deal with the value of on-site inspection, another pillar of the CTBT verification regime.

\(^3\)The CTBTO uses the term “civil and scientific application” referring to the civilian means of IMS and IDC data to deal with issues other than nuclear testing.
Science for Confidence-Building Measures

The importance of scientific verification to build confidence among states was evident from the beginning of the history of the nuclear disarmament initiative because nuclear testing has proved to be verifiable. Most of the initial nuclear tests conducted during the Cold War were analyzed by individual states with their own monitoring facilities, mainly by the use of radioactive and seismic monitoring capabilities (Kalinowski 2006, 2). The first benchmark moment of limiting nuclear testing occurred in the 1960s, when the United States and the Soviet Union reached a bilateral agreement, the Partial Test Ban Treaty (PTB), which prohibits any nuclear tests conducted in the atmosphere, in outer space, or under water (Kalinowski 2006, 2). This treaty, however, did not include verification provisions. In the 1970s, these two powerful nuclear states started the negotiations for the Treaty on the Limitation of Underground Nuclear Weapon Tests, also known as the Threshold Test Ban Treaty (TBT), under which the yield of nuclear tests cannot exceed 150 kilotons (Kalinowski 2006, 2). Under the TTB, the United States and the Soviet Union agreed for the first time to exchange the relevant seismic data as a verification measure (Hansen 2006, 7). The two countries worked on the so-called the Joint Verification Experiments to assess methods to determine the yields of a nuclear explosion of each country through exchanges of nuclear experts, which finally led the ratification of the TTB in 1990 (Center for Arms Control and Non-proliferation 2017).

Scientific activities have been carried out despite political deadlock throughout the history of the nuclear test ban. The most significant aspect of two decades of scientific activities by the Group of Scientific Experts (GSE) at the Conference of the Committee on Disarmament in Geneva in 1976 was the fact that scientists were given an independent role in security-related negotiations, for the first time in history, before diplomats were able to consult with each other (Kalinowski 2006, 3). Once the negotiations began, the GSE’s primary responsibility was to design and test a global seismological verification system to detect underground nuclear testing as a component of the IMS, and experts from hydroacoustic, infrasound, and radionuclide monitoring field joined the negotiations at a later stage (Dahlman et al. 2011, 161). The GSE’s work continued until the treaty was opened for signature in 1996, and their continuous scientific work is recognized as a successful effort toward promoting a disarmament treaty in a politically challenging environment (Dahlman et al. 2011, 161). Based on this history, the executive secretaries of the CTBTO have historically promoted the significance of scientific breakthroughs and technological advancement to increase the number of the CTBT ratifications, highlighting the value of science as a tool to provide platforms for political process. The technical readiness of the verification regime has led to recognition of the CTBTO by the international community as a highly professional international organization in advance of the CTBTO’s entry into force (Kimball 2018, 3). Because the CTBTO can already provide technical inputs about nuclear-weapon tests, the United Nations Security Council can collectively condemn a nation that violates its obligation under the relevant Security Council resolutions.4 The most relevant example is the successful detection of all

4In the case of DPRK, the UN Security Council adopted resolutions to condemn the nuclear tests by the DPRK as a violation of Security Council resolutions 1718 (2006), 1874 (2009), 2087 (2013), 2094 (2013), 2271 (2016), 2321 (2016), 2356 (2017), 2371 (2017), and 2375 (2017). A CTBT-specific resolution is 2310 (2016)..
The Journal for Peace and Nuclear Disarmament

six nuclear tests conducted by the DPRK. Even though the DPRK is not a signatory to the CTBT, nuclear tests conducted by the DPRK in 2006, 2009, 2013, 2016 (twice), and 2017 have all been detected at various global monitoring stations that are certified by the IMS.

It is evident that the accuracy of the detections has increased as more certified stations are installed. For instance, the first nuclear test in 2006 was detected at approximately 20 IMS-certified stations (CTBTO 2006b). The IMS is technically designed to detect explosions above one kiloton, but the first DPRK nuclear test produced only 0.7 kilotons of nuclear yield (Hoell 2019, 3). Nevertheless, the IMS proved that it could detect explosions below this threshold. The nuclear test in 2009 was detected by 61 global seismic stations (CTBTO 2013a). In 2013, 96 IMS stations detected an unusual seismic activity in the DPRK, which released greater explosive force than previous ones (CTBTO 2013b). The three nuclear tests in 2006, 2009, and 2013 were then identified as having occurred at the Punggye-ri nuclear test site by using the detection data provided especially by monitoring stations in Japan and Russia (Ringbom et al. 2014, 47). In 2016, the DPRK declared that it had successfully conducted a hydrogen bomb test, but this declaration was not consistent with the data analyzed by the IDC (Nikitin et al. 2016, 21). It was identified as an underground nuclear test, detected at various seismic, infrasound, and radionuclide stations, including the ones in northern People’s Republic of China (PRC), Republic of Korea (RoK), and Japan (Ringbom et al. 2014, 47). While the second nuclear test conducted in 2016 had a relatively small yield and was mainly analyzed at 25 IMS certified stations, over 100 certified stations contributed to the analysis of the 2017 test, which had a larger yield than all the previous DPRK nuclear tests. Nearly 90% of the planned 337 IMS-certified facilities had been installed by then (CTBTO 2017a). These results clearly show that increasing the number of installed global monitoring facilities has enhanced the reliability of data gathered, marking substantial progress for nuclear test monitoring.

The development of a noble-gas monitoring system, in particular the detection of radioactive xenon, is significant because this method is useful in detecting radioactivity unintentionally released in underground explosions (Kalinowski 2006, 6). Radionuclide stations are supported by the certified laboratories, which are capable of analyzing the data samples based on the request from state parties (Hansen 2006, 33). Analysis of noble gas measures the level of isotopes’ radioactivity – namely Xe-135, Xe-133, Xe-133m and Xe-131m, which are identified by the CTBTO – and examines atmospheric radioactivity to determine whether an explosion is from a nuclear-weapon test or nuclear reactor (Kalinowski 2006, 5). Although only 25% of the planned noble-gas monitoring stations had been installed by 2006, the IDC had accurately predicted the release of radioactive xenon, and recorded the large amount of radioactive xenon at certified stations, even as far away as Canada (CTBTO 2006b). However, for reasons that remain unknown, no radionuclide station detected the radioactivity release in the 2009 nuclear test (CTBTO 2013a). This result served as a reminder of the difficulty of accurately detecting radioactivity in remote places and the need to improve the radionuclide system further. By 2010, the noble-gas detection system had reached maturity, as most of the 40 planned radionuclide stations with noble-gas detection capability had been installed (CTBTO 2010b). Furthermore, Japan made a large financial contribution in 2017 to the CTBTO, specifically in order to fund two transportable radioxenon detection systems to be deployed in the northern and southern parts of Japan, conducting analysis on
background levels of xenon (CTBTO 2018c). This research was initially funded by the European Union (EU) to gather data by deploying a mobile noble-gas detection system to an area not previously covered by the regular IMS radionuclide stations (Tóth 2009). The background research aims to improve the characterization of the xenon from civilian sources (Tóth 2009). The outcome of this ongoing project, together with other radionuclide monitoring facilities in the region, contributes significantly to improving the accuracy of detections of suspicious activity in areas with low concentrations of xenon.

It is important to remember today that state signatories are entitled to join the IMS and IDC network and be part of the scientific discussion once they have signed the CTBT, even if they have not ratified it. All five countries that the NPT recognizes as NWS – namely the United States, Russia, France, the PRC, and the United Kingdom, have already signed the CTBT; therefore, they all host IMS stations and transmit data to the IDC. For instance, the first IMS station established in the PRC is a radionuclide station named RN21 that was certified in December 2016. Two primary seismic and two other radionuclide stations followed in 2017 to “fill an important geographical coverage gap in terms of event detection in the region”, particularly the analysis for the recent nuclear tests conducted by the DPRK (Kimball 2018, 8). Wang Yi, the PRC foreign minister, has officially stated that the CTBT verification regime is an essential pillar of international nuclear disarmament and plays an irreplaceable role (Kimball 2018, 8). Among the remaining Annex II states, Iran hosts one certified IMS station, Israel has three certified stations, and Egypt is planning to have the IMS certify two of its stations in the future (CTBTO 2021d). These politically divided states have been able to sustain a scientific dialogue through Working Group B of the CTBTO, which implements its vision of improving the technical capabilities of the verification system by holding meetings twice a year, despite the sensitivity of the issues that the participants discuss.

Another way to integrate more remaining states into the verification regime is to invite them to be observers. Pakistan has not signed the CTBT but has attended formal meetings since 1998; in this way, it has demonstrated positive support for the CTBT to set a precedent (Hoell 2019, 8). It is particularly significant because Pakistan is a non-NPT nuclear-armed state; its participation as an observer in the CTBT verification system therefore builds a bridge between NPT nonparties and NPT parties (Hoell 2019, 8). Pakistan is listed in the treaty as a host of infrasound and primary seismic stations in the IMS (Hoell 2019, 8). Pakistan and the CTBTO had a dialogue in the past on the possibility of establishing these IMS stations, while Pakistani scientists and academics have already participated in CTBT courses and conferences to enhance their knowledge of the verification technology (CTBTO 2018a). Once these stations are fully installed and certified as IMS stations, they will enhance the overall coverage rate to monitor the situation in South Asia.

**Sustainability Issues**

The credibility of the current monitoring structure is heavily influenced by the scientific commitment, meaning that scientific data to be transmitted from certified monitoring stations to the IMS is authenticated by the member states; hence conducting low-yield nuclear testing and stopping the transmission of data are a major breach of such a commitment. The CTBT stipulates in Article 1 that “Each State Party undertakes not
to carry out any nuclear weapon test explosion or any other nuclear explosion, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control”, but does not specifically include the term “zero-yield” in its official text (Gogna 2020, 1). CTBT negotiators in Geneva initially agreed that producing nuclear yields at any level of testing would be a violation of the CTBT, but they recognized the difficulty of definitively verifying a zero-yield ban, which would require establishing qualitative monitoring indicators for very small nuclear explosions (McGrath 2009, 414).

The lack of a clear definition of the zero-yield standard caused states to come up with their own interpretations. That approach resulted in mistrust, especially between the United States and Russia (Gogna 2020, 1). For instance, the United States takes the position that a subcritical hydrodynamic experiment is not a violation of the CTBT because it does not produce fission chain reactions, while a supercritical hydronuclear test, which produces self-sustaining fission chain reactions, is banned under the CTBT because it results in a very low-yield explosion of less than 0.1 ton of TNT (Gogna 2020, 3). Based on this interpretation, the United States conducted 28 subcritical experimental tests at the Nevada National Security Site between 2017 and 2020 (Nikitin and Dunham 2016, 1). Russia also has conducted such experiments since 1998. However, it has been claimed that Russian officials adhere to a different definition of “zero-yield” that theoretically permits them to conduct hydronuclear or very low-yield testing (McGrath 2009, 415).

This issue reemerged in 2019 when the head of the US Defense Intelligence Agency, Lt. General Robert Ashley, claimed that Russia had been violating the CTBT by carrying out low-yield tests in the Arctic chain of islands called Novaya Zemlya (Borger 2019). The CTBTO stated that the IMS and the IDC did not detect any unusual activity, and Russian delegation denied the allegation (Borger 2019). Three months after this exchange, a nuclear explosion was detected at the Russian naval test range of Nyonoksa on 8 August 2019 where an isotope power source exploded (BBC 2019). This caused the deaths of five Russian nuclear engineers and two military personnel, and several people were injured (BBC 2019). The IMS successfully detected this explosion with three seismic stations and an infrasound station in the region (Zerbo 2019). The Norwegian Radiation and Nuclear Safety Authority initially announced that radioactive iodine had been detected on the border with Russia (Reuters 2019). Two days later, Russian radionuclide stations certified as IMS stations in Dubna and Kirov, near Nyonoksa, went offline and Russian National Data Center operators reported the technical failure to the IDC (Murphy 2019). Subsequently, two more stations in Bilibino in eastern Siberia and Zalesovo stopped transmitting data to the IDC on 13 August 2019 (Zerbo 2019). Similarly, the PRC’s IMS stations frequently reported the blockage of data transmissions to the IDC throughout 2019 (Gogna 2020, 1).

Even though both Russia and the PRC eventually resumed transmissions of data from the certified stations, these incidents illustrate that the sustainability of the verification system depends on the willingness and continuous adherence of state signatories to the CTBT. This is particularly true for the United States, which hosts 39 IMS-certified stations (CTBTO 2021f), and Russia, which has 32 (CTBTO 2021e) because these two nations hold the largest number of monitoring stations. These powerful countries’ strong
adherence to the treaty obligations and continuous dialogue with the CTBTO based on the scientific data that they share with the organization are indispensable to sustaining the current nuclear monitoring system.

In order to gain sustainable support from signatory states, the technical credibility of the CTBTO remains an indispensable factor. The IMS’s xenon detection is considered to be a critical new method to potentially detect yield close to low level since it is not fully known how much xenon is leaked from each nuclear explosion (Dahlman et al. 2011, 86), as the 2009 DPRK nuclear test was detected only by seismological data without radioactive xenon. This uncertainty could serve as an important deterrent against low-yield nuclear tests, since an improved xenon sampling technique has the potential to detect low-yield nuclides at each IMS radionuclide monitoring facility (Dahlman et al. 2011, 86). Interpreting the radionuclide data with additional information obtained by each state, such as satellite imagery and seismological data, would increase the accuracy of overall data analysis (Dahlman et al. 2011, 87). Furthermore, scientific and technological advancement such as deployment of the mobile noble-gas system is an ongoing process today. Since only a few xenon stations exist outside the IMS monitoring structure, the evolution of an IMS radionuclide capability within the CTBT verification regime will certainly contribute further to create confidence-building measures on the issue of sustainability.

Civil and Scientific Applications of the Verification Regime

Because the full legal effect of the CTBT does not apply until the treaty has entered into force, advocates of a nuclear test ban might consider offering incentives as an indirect way of achieving that goal. Even though states are responsible for ensuring international peace and security, it is hard to imagine that the ratification of the CTBT is a policy priority for every state. The reasons for not joining the cause may vary; yet, allocation of sufficient funds to host IMS certified stations becomes a state obligation once committing to the CTBT. Therefore, creating incentives for the CTBT nonparties to commit themselves to the spirit of the treaty seems to be more realistic (Asada 2011, 20). In this respect, the prospect of an improved capability for data processing and analysis is a tool to attract remaining states to join the IMS and IDC networks. Even though the use of IMS data and IDC products was initially restricted to the verification of nuclear test ban, it was evident in early stage that the large amount of scientific data collected by the regime is potentially beneficial to civilian applications (Kalinowski 2006, 8). The CTBTO uses the term “civil and scientific application of the verification data”, referring to the civilian means to deal with issues other than nuclear testing, such as disaster prediction, and scientific means to deal with the analysis of data for wider scientific research, such as climate change and earth research. For instance, increased capability of detecting earthquakes and mining explosions in each country leads to enhancing general seismological ability not only for understanding the earth’s interior structure but also for regional detection of nuclear testing (Dahlman et al. 2011, 84). Ultimately, these civilian scientific developments help to improve the reliability of the organization to better analyze IDC’s verification products within the scope of this treaty (Dahlman et al. 2011, 159).
The decision to develop civil and scientific applications of the verification regime as a secondary purpose was agreed by consensus in 2005, including by remaining Annex II states such as Egypt, Iran, Israel, the PRC, and the United States. In order to make the massive data available for dual-use purposes, it had to be first approved by the Preparatory Commission (PrepCom), a policy-making organ that consists of state signatories to handle operational and administrative aspects of the treaty (Hansen 2006, 47). In spite of some concerns about the confidentiality of monitoring data, and debates on whether expanding the use of monitoring data other than nuclear weapon test verifications was a mandate within the CTBT, it was significant for the above-mentioned countries to explore this new application (Meier 2005). Articles IV(10) and IV(13) became the basis of the decision to design a program for the exchange of scientific data and for the development of data applications for peaceful purposes (Hansen 2006, 102–103).

The first remarkable event was an earthquake in northern Sumatra in Indonesia in 2004, when 71 detections in IMS stations occurred in certified seismic stations, six in hydroacoustic stations and one in an infrasound monitoring station (CTBTO 2005). Within two hours after the earthquake, the IDC shared the first list of earthquake event figures automatically generated by the computer system with state signatories, followed by timely information on aftershocks for the National Data Centers (NDCs) in each country to analyze (CTBTO 2005). The PrepCom officially decided that the CTBTO would provide accurately examined data on a trial basis from seismic and hydroacoustic stations and allow limited use of data for wider civilian institutions such as international tsunami warning organizations (CTBTO 2005). This decision allowed the CTBTO for the first time to distribute gathered data for humanitarian and disaster relief purposes, which indirectly contributes to enhancing the quality of the global scientific system (CTBTO 2005).

The tsunami early-warning system was then available when a magnitude 9.0 earthquake hit the northern part of Japan on 11 March 2011, another landmark opportunity for the IMS and the IDC to advance their capabilities. The Japanese government had already signed a tsunami early-warning agreement with the CTBTO in 2008 (CTBTO 2008). Therefore, IDC products were available in issuing warnings when this massive earthquake occurred. Moreover, radioactive particles and noble gases from the Fukushima Daiichi Nuclear Power Plant were detected at 35 IMS-certified radionuclide stations; the CTBTO made the first monitoring results available a few days after the incident (CTBTO 2011). A certified station in Takasaki, Japan, which is 200 kilometers away from the Fukushima plant, initially detected radioactive materials (CTBTO 2011). The materials gradually dispersed to eastern Russia, the west coast of the United States, and Europe within two weeks (CTBTO 2011). The CTBTO used an atmospheric transport modeling technique that it jointly developed with the World Meteorological Organization (WMO) to predict global dispersion of radioactive materials by calculating radionuclide emission through meteorological data (CTBTO 2011). The result proved to be 95% accurate as the radioactive particles reached the stations within hours of the predicted time (Golan-Vilella 2011). This result gave the CTBTO confidence that its system could be utilized for nuclear disaster mitigation purposes.
Following the nuclear power plant accident in Japan, Ban Ki-moon, the UN secretary general at that time, took the initiative to agree on mitigation measures for nuclear accidents in order to enhance cooperation among the UN organizations (CTBTO 2011). Ban highlighted this point in his address at the CTBT science and technology conference in 2011:

The Comprehensive Nuclear-Test Ban Treaty is recognized as a milestone in promoting nuclear non-proliferation and disarmament. Above and beyond the central mission, and even before entering into force, the CTBT is saving lives. When the devastating earthquake and tsunami hit Japan in March, the CTBTO quickly sent data to Japan and other Pacific communities and shared the valuable information with International Atomic Energy Agency (IAEA). When the Fukushima nuclear power plant was damaged, the PrepCom tracked the spread of radioactive materials, helping governments communicate to people about possible health effects. Since then, I have outlined a five-point strategy to enhance the global nuclear safety regime . . . the CTBT and its international monitoring system will make a significant contribution to this effort (YouTube 2011).

The CTBTO joined the other UN agencies for Ban’s initiative to form an agreement and later bilaterally signed a practical agreement with the IAEA for nuclear or radiological emergency response (CTBTO 2016). The CTBTO became an official member of the Inter-Agency Committee on Radiological and Nuclear Emergencies in 2012 and sponsors the Joint Radiation Emergency Management Plan to contribute real-time data on particulates and noble gases for nuclear-emergency preparedness (CTBTO 2016). Today, the CTBTO actively participates in the UN Disaster Risk Reduction platform to raise awareness about the civil and scientific applications of the verification system, in particular, tsunami early warning and nuclear-emergency preparedness (CTBTO 2015).

By enhancing the recognition of the CTBT among a wider audience through sustainable development objectives such as humanitarian operations and climate science, these applications of the CTBTO’s data and expertise help create an opportunity for advancing nuclear detection capability. Needless to say, measures to mitigate the risk of nuclear accidents contribute to the enhancement of radionuclide monitoring capability as a whole. Dual use of collected data may attract more member states to invest in the IMS and strengthen the relationship between the CTBTO and the scientific community, which is vital for the organization to continue recruiting competent staff to advance scientific and technical developments in nuclear test verification (Dahlman et al. 2011, 159). Furthermore, states need a continuous strong network with the scientific community to develop appropriate expertise on data analysis and interpretation of verification information (Dahlman et al. 2011, 159). It is indispensable for the sustainability of the existing system, and for the credibility and relevance of the organization, to incorporate new scientific techniques and procedures (Dahlman et al. 2011, 208). The ratification by Thailand in 2018 is an example of how science and technology have attracted countries to move toward universalization of the treaty. Thailand signed an agreement with the CTBTO to receive tsunami-related data directly from the IMS in order to improve its national system to respond to natural disasters (CTBTO 2018b). Civilian applications could serve as a renewed motivation to consider joining the CTBT verification regime.

The promotion of civilian applications also opens a new door for the CTBTO to raise awareness about its activities among interlocutors from the scientific community. For instance, the Cuban minister of science, technology, and environment officially made an
announcement about her country’s progress toward signing the CTBT by highlighting the value of science and technology to counter various global challenges and achieve the Sustainable Development Goals:

The CTBTO technologies not only provide the capacity to detect nuclear tests but also to warn about natural disasters, including earthquakes, so Cuba can benefit from access to information, collaboration with other nations and strengthen its seismological early warning system. This is a demonstration of how science can be used for peaceful purposes (CTBTO 2019).

During his visit to Cuba in 2019, Lassina Zerbo, the executive secretary of the CTBTO, reiterated this point when he referred to science as an avenue of cooperation beyond the realm of security in maintaining a communication channel and building trust in the international community (CTBTO 2019). These constructive dialogues came to fruition on 4 February 2021, when Cuba made a historic decision to sign and ratify the CTBT, leading the way for nuclear-weapon-free zone in the Latin American region (CTBTO 2021a). These examples suggest that what I call the “deterrence-based perspective” does not provide a complete picture. Under this perspective, the assumption is that the deciding factor on ratification for each of the Annex II holdout states is whether or not its nuclear-deterrence capability will be impaired by the ratification of the CTBT. But, as the examples show, scientific opportunity also serves as a meaningful incentive for the remaining Annex II states to be part of the verification system.

**Capacity Building through Science and Technology**

Enhancing the immediate functionality of the verification regime depends on the capacity to transmit quality data and build the analytical capability of each state. Therefore, it is imperative to maintain and improve local capacity, especially in less developed countries. The NDCs located in each signatory state serve as technical organizations to advise their own governments on CTBT verification; they therefore play a key role in the verification architecture (CTBTO 2012). Many countries had already established national monitoring systems for their own purposes when the CTBT was opened for signature in 1996. Yet many of them, including seismic facilities, needed to improve their capability to meet the CTBTO’s requirement to be part of the IMS (Hansen 2006, 33). Capacity-building programs were initiated to upgrade monitoring facilities and educate next-generation scientists, diplomats, and policy makers in order to have a better understanding of the scientific and political complexities surrounding the CTBT.

Unlike other nonproliferation frameworks to conduct independent inspections, such as IAEA safeguards agreements and the Chemical Weapons Convention, the CTBTO’s mandate remains to provide adequate gathered data to the member states, leaving it to the states to acquire appropriate expertise to interpret the data (Dahlman et al. 2011, 184–185). According to paragraph 18 of Part I of the CTBT Protocol, it is not the CTBTO, but state parties that make final judgments about the outcome of data examination (CTBTO 2004, 4). The IDC provides raw data as well as analyzed products and services to support state parties because its scientific products and reports have to remain politically neutral (Kalinowski 2006, 6). In order for responsible state parties to be able to draw a final conclusion, the IDC supplies a software package and a Very Small Aperture Terminal
comunication link at no charge, a combination informally known as “NDC in a box” (CTBTO 2004, 4). The IDC assists members’ states’ installation to establish a local data-transmission channel and offers technical advice for its maintenance (CTBTO 2004, 16). The IDC also conducts hands-on capacity-building training to those who work at NDC monitoring stations, aiming to enhance their knowledge of computer and communication technology with the most advanced scientific methods (CTBTO 2004, 12).

The European Union (EU) specifically funds capacity-building projects “to provide technical assistance to countries in Africa, Latin America and the Caribbean aimed at fully integrating State Signatories into the CTBT monitoring and verification system” (Council Decision 2010). For instance, in exchange for the commitment from the recipient states, the selected 29 African and eight Latin American countries are provided with technical and material assistance to set up Secure Signatory Accounts (SSAs), which is a basic communication channel through this scheme (Council Decision 2010). In order to raise awareness of the system more broadly, the CTBTO also established the Virtual Data Exploitation Centre (vDEC) on the official website with the EU fund, allowing partial access to IMS data to scientists and researchers globally to conduct research and publish findings at CTBTO conferences (CTBTO 2021h). A user must specify what their objectives are when they request data from the vDEC on the website, which then can be internally assessed by the CTBTO technical staff prior to data sharing (Vaidya et al. 2009). These initiatives aim to support the universalization and long-term sustainability of the verification system.

Furthermore, the EU provides funding to hold regional group trainings on IMS data processing and IDC analysis based on the needs of NDCs and SSAs in close coordination with the IDC staff. When Namibia hosted an EU-funded regional workshop to gather scientific experts from Anglophone African countries to increase the accuracy of seismic analysis, the IDC staff invited experts from Comoros to participate in the training (CTBTO 2017b), so that the scientists could indirectly influence policy makers in their country to eventually sign and ratify the treaty. After years of these accumulated efforts, Comoros finally deposited its instrument of ratification on February 2021 to become the most recent ratifying state to the CTBT (CTBTO 2021b). Dhoïhir Dhoukamal, the foreign minister of Comoros, stated in a meeting that CTBT ratification expresses the country’s firm commitment to a world free from nuclear threats, and its contribution not only to international peace and security, but also sustainable development (CTBTO 2021b). In this sense, the capacity-building initiative has been serving as an incentive for some developing nations to maintain an international norm against nuclear testing, especially for the states where nuclear disarmament is not a primary concern.

Nuclear disarmament is not necessarily a policy priority for every state, yet all states, not only NWS but also NNWS, have a responsibility to participate in the universal adherence to the CTBT. Under Article VI of the NPT, NNWS are given a responsibility not to acquire nuclear weapons (Dahlan et al. 2011, 27). In this regard, it is important to create added value for the remaining countries to receive direct benefits outside the traditional mandate of nuclear-test monitoring. This can offset the financial burden that is associated with being a member of the CTBT while improving the quality of national implementation mechanisms to sustain long-term commitment by all states (Zanders 2002, 24). Countries such as Colombia have not been able to ratify the CTBT for a long time because of the constitutional restraints and the domestic legislative structure to
shoulder costs to establish and sustain NDC operations (Fukui 2017, 9). Fulfilling the individual needs of state signatories through capacity building will contribute to the long-term interests of all parties (Zanders 2002, 28).

Investing in human capital is a way of improving the immediate application of the verification regime. In 2006, the first CTBT scientific symposium was held in Vienna to mark the 10th anniversary of the day the treaty was opened for signature, bringing hundreds of participants from scientific, academic, and diplomatic communities together (CTBTO 2006a). It was a tremendous opportunity to bring scientific experts and high-level political figures, regardless of the status of the ratification of their countries, into the same room to discuss the future of the CTBT. This interdisciplinary effort has taken a unified multilateral approach because there is often a gap between scientists and policy makers in understanding. In a 2010 speech, CTBTO Executive Secretary Tibor Tóth stressed that “to be able to make informed decisions (on arms control), we need many more knowledgeable diplomats and policy makers; and we need many more verification experts who understand the political complexities” (CTBTO 2010a). The complexity of multilateralism and verification mechanisms often hampers the progress of the overall treaty-ratification process due to the lack of balanced knowledge on both. Since the first symposium in 2006, CTBT Science and Technology conferences have been held biennially to strengthen relationships between scientific communities and policy makers from all countries, extending the invitation to the non-Annex II states. Later, a youth component was added to the conference to promote education and intergenerational interactions. This is particularly valuable to those who are from the remaining non-ratifying countries to raise awareness of the importance of a nuclear test ban beyond any political prejudice.

Conclusion

Seventy-six years after the first atomic-bomb detonations, preserving multilateralism and reinventing the arms-control framework is an urgent task for politicians and policy makers. Meanwhile, throughout the history of nuclear disarmament negotiations, science and technology have played a continuous role in ensuring confidence-building measures among politically divided states. The CTBT is at the center of this issue; the organization’s relevance and credibility have been recognized by the international community as a group of scientific and technical experts backed by 185 signatory states and 170 ratifiers. Operating in a provisional mode pending entry into force for more than 20 years, the CTBT verification regime nevertheless is constantly increasing the number of signatures and ratifications and has expanded a network of monitoring facilities since its establishment. The substantial progress for nuclear-test monitoring was made based on three benefits for the state signatories, generated by the provisional applications of the verification system – namely, scientific commitment as a tool for CBMs to ensure international peace and security, contribution to development objectives, and improvement of overall scientific capability of the verification regime.

The CTBT verification regime serves the national-security interests of each state by initiating a fact-based dialogue with the largest scientific monitoring mechanism in the world. This global monitoring system has a very high probability of detecting any military nuclear explosions on earth today by having installed 92% of the 337 planned
certified facilities. Thus, enhancing the CTBTO’s ability within the given framework prior to entry into force to develop scientific expertise ensures the credibility of the CTBT. Advancing science and technology further within the scope of the existing treaty scheme, especially maturing the xenon-detection technique, is an ongoing process to maintain the relevance of the CTBTO as a science-based, technical organization.

As the number of installed monitoring facilities increases, detection reliability improves. The detection of the DPRK nuclear tests provides an example of the CTBTO’s scientific contribution prior to the CTBT’s entry into force, which directly serves the interests of the UN Security Council to ensure international peace and security. Some of the remaining Annex II states – namely, the PRC, the United States, Iran, and Israel – host monitoring stations certified by the IMS, making daily scientific contributions. While the issue of low-yield nuclear testing highlights the challenges to the sustainability of the present verification system, which depends on the willingness of the current state signatories to meet their obligations with regard to data transmissions, it proves that the CTBT before entry into force can still verify the nuclear-test moratoriums in the meantime with a continuous scientific commitment by the NWS. Tsunami early warning and nuclear-emergency preparedness are two civilian-application programs officially approved by the PrepCom, which further enhances the IMS’s capability as a whole by expanding the use of the data to humanitarian and disaster-mitigation objectives as a secondary application. Measures to reduce the risk of nuclear accidents, for instance, provide an opportunity to practice techniques for atmospheric transport modeling; hence, these dual-use capabilities directly contribute to sustaining nuclear-test-ban verification. Moreover, these features prove that deterrence-based progress on the implementation of Article VI of the NPT by NWS is not the only fact surrounding the CTBT today. Scientific opportunity serves as an incentive for the remaining key countries to be part of the community that is working to improve verification coverage and the quality of data to be gathered. Educating practitioners and investing in human capital such as local scientists, policy makers and youth is another essential pillar of CTBTO activities today to advance the universalization of the treaty.

Science and technology play a crucial role in creating a realistic, indirect avenue for resuming political dialogue to maintain nuclear-test-ban moratoriums. Even before entry into force, the world is more secure with the CTBT monitoring system since there is no alternative global detection platform to replace it.

**Disclosure Statement**

No potential conflict of interest was reported by the author(s).

**Notes on Contributor**

*Mao Sato* is a former Associate External Relations Officer at the Legal and External Relations Division of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization. The views expressed in this article are solely those of the author.
Disclaimer

The views expressed in this article are those of the author and do not necessarily represent the views of the Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization.

References

Asada, M. 2011. “The Treaty on the Non-proliferation of Nuclear Weapons and the Universalization of the Additional Protocol.” *Journal of Conflict and Security Law* 16 (1): 3–34. doi:10.1093/jcsl/krr007.

BBC. 2019. “Russian Nuclear Accident: Medics Fear 'Radioactive Patients'.” https://www.bbc.com/news/world-europe-49432681

Borger, J. 2019. “Russia 'Probably' Violating Nuclear Test Ban Treaty, Top US Official Says.” *The Guardian*, May 29. https://www.theguardian.com/world/2019/may/29/russia-nuclear-test-ban-treaty-probably-violating-us

Bunn, G. 2003. “The Nuclear Nonproliferation Treaty: History and Current Problems.” *Arms Control Today* 33 (10): 4.

“Council Decision 2010/461/CFSP.” 2010. *Official Journal of the European Union*. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:219:0007:0020:EN:PDF

Center for Arms Control and Non-proliferation. 2017. “The Threshold Test Ban Treaty (TTBT).” https://armscontrolcenter.org/wp-content/uploads/2017/05/The-Threshold-Test-Ban-Treaty-TTBT_New-Temp2.pdf

CTBTO. 2004. *Frequently Asked Questions about NDC*. Vienna, Austria: CTBTO publication.

CTBTO. 2005. “Northern Sumatra Earthquake and the Subsequent Tsunami on 26 December 2004.” https://www.ctbto.org/press-centre/press-releases/2005/northern-sumatra-earthquake-and-the-subsequent-tsunami-on-26-december-2004/

CTBTO. 2006a. “CTBTO Preparatory Commission Holds Two Day Scientific Symposium.” https://www.ctbto.org/press-centre/news-stories/2006/ctbto-preparatory-commission-holds-two-day-scientific-symposium/

CTBTO. 2006b. “9 October 2006 First DPRK Nuclear Test.” https://www.ctbto.org/specials/testing-times/9-october-2006-first-dprk-nuclear-test/

CTBTO. 2008. “Signing of Tsunami Warning Agreement between Japan and the CTBTO.” https://www.ctbto.org/press-centre/press-releases/2008/signing-of-tsunami-warning-agreement-between-japan-and-the-ctbto/

CTBTO. 2010a. “Creating the ‘Buy-in’ to Strengthen Arms Control and Disarmament.” https://www.ctbto.org/press-centre/news-stories/2010/creating-the-buy-in-to-strengthen-arms-control-and-disarmament/?textonly=1

CTBTO. 2010b. “Noble Gas Detection System Reaches Maturity.” https://www.ctbto.org/press-centre/news-stories/2010/noble-gas-detection-system-reaches-maturity/

CTBTO. 2011. “Fukushima Related Measures by the CTBTO.” https://www.ctbto.org/press-centre/news-stories/2011/fukushima-related-measure-by-the-ctbto/

CTBTO. 2012. “National Data Centre Capacity Building.” https://www.ctbto.org/press-centre/highlights/2012/national-data-centre-capacity-building/

CTBTO. 2013a. “2013 DPRK Announced Nuclear Test Media Questions Answers on Radionuclide Detection.” https://www.ctbto.org/the-treaty/developments-after-1996/2013-dprk-announced-nuclear-test/media-questions-answers-on-radionuclide-detection/

CTBTO. 2013b. “Update on CTBT Findings Related to the Announced Nuclear Test by North Korea.” https://www.ctbto.org/press-centre/news-stories/2013/update-on-ctbt-findings-related-to-the-announced-nuclear-test-by-north-korea/

CTBTO. 2015. “The CTBTO’s Contribution to Disaster Risk Reduction.” https://www.ctbto.org/press-centre/news-stories/2015/the-ctbto-contribution-to-disaster-risk-reduction/
CTBTO. 2016. “IAEA & CTBTO Sign Practical Arrangement on Nuclear Emergencies.” https://www.ctbto.org/press-centre/news-stories/2016/iaea-ctbto-sign-practical-arrangement-on-nuclear-emergencies/

CTBTO. 2017a. “2017 September DPRK Nuclear Testing.” https://www.ctbto.org/the-treaty/developments-after-1996/2017-sept-dprk/

CTBTO. 2017b. “Namibia Capacity Building Workshop.” https://www.ctbto.org/press-centre/news-stories/2017/namibia-capacity-building-workshop/

CTBTO. 2018a. “CTBT Visits Pakistan.” https://www.ctbto.org/press-centre/news-stories/2018/ctbt-visit-to-pakistan/

CTBTO. 2018b. “Thailand Ratifies the CTBT.” https://www.ctbto.org/press-centre/press-releases/2018/thailand-ratifies-the-comprehensive-nuclear-test-ban-treaty/

CTBTO. 2018c. “Transportable Radioxenon Systems (TXLS) Enhance the CTBTO’s Radionuclide Monitoring Technology in Japan.” https://www.ctbto.org/press-centre/news-stories/2018/transportable-radioxenon-systems-txls-enhance-the-ctbto-radionuclide-monitoring-technology-in-japan/

CTBTO. 2019. “Executive Secretary Inaugurates Science Diplomacy Events in Cuba and in the Dominican Republic.” https://www.ctbto.org/press-centre/news-stories/2019/executive-secretary-inaugurates-science-diplomacy-events-in-cuba-and-in-the-dominican-republic/?tonly=1

CTBTO. 2021a. “Cuba Joins the Comprehensive Nuclear-Test-Ban Treaty.” https://www.ctbto.org/press-centre/news-stories/2021/cuba-joins-the-comprehensive-nuclear-test-ban-treaty/

CTBTO. 2021b. “Comoros Becomes 170th State to Ratify the CTBT.” https://www.ctbto.org/press-centre/press-releases/2021/comoros-becomes-170th-state-to-ratify-the-ctbt/

CTBTO. 2021c. “CTBT Ending Nuclear Explosion.” https://www.ctbto.org/fileadmin/user_upload/public_information/2021/CTBT_FactSheet_English_Aug_2021.pdf

CTBTO. 2021d. “Facility Agreements.” https://www.ctbto.org/member-states/facility-agreements/

CTBTO. 2021e. “Facility Agreements. Russian Federation.” https://www.ctbto.org/the-treaty/country-profiles/?country=143&cHash=261836126dea6488d9bc8f4047e8b657

CTBTO. 2021f. “Facility Agreements. United States of America.” https://www.ctbto.org/the-treaty/country-profiles/?country=184&cHash=e699720b55370091ef3c3cc4eb4ed5d2

CTBTO. 2021g. “Status of Signature and Ratification.” https://www.ctbto.org/the-treaty/status-of-signature-and-ratification/

CTBTO. 2021h. “vDEC.” Accessed 2021. https://www.ctbto.org/specials/vdec/

Dahlman, O., J. Mackby, S. Mykkeltveit, and H. Haak. 2011. Detect and Deter: Can Countries Verify the Nuclear Test Ban? Springer Science & Business Media.

Ford, C. A. 2007. “Debating Disarmament: Interpreting Article VI of the Treaty on the Non-proliferation of Nuclear Weapons.” Nonproliferation Review 14 (3): 401–428. doi:10.1080/107367007016111720.

Fukui, Y. 2017. “CTBT: Legal Questions Arising from Its Non–Entry into Force Revisited.” Journal of Conflict and Security Law 22 (2): 183–200. doi:10.1093/jcsl/krw027.

Gogna, S. 2020. The CTBT and the Possible U.S., China Nuclear Testing. Centre for Air Power Studies (CAPS), Forum for National Security Studies.

Golan-Villegà, R. 2011. “CTBT Monitors Assist in Fukushima Aftermath.” Arms Control Today 41 (4): 31.

Hajnoczi, T. 2020. “The Relationship between the NPT and the TPNW.” Journal for Peace and Nuclear Disarmament 3 (1): 87–91. doi:10.1080/25751654.2020.1738815.

Hansen, K. A. 2006. The Comprehensive Nuclear Test Ban Treaty: An Insider’s Perspective. Stanford, California: Stanford University Press.

Hoell, M. 2019. “Comprehensive Nuclear-Test-Ban Treaty is in Danger: Here’s How to Save It.” European Leadership Network.

Kalinowski, M. B. 2006. Comprehensive Nuclear-test-ban Treaty Verification. Verifying Treaty Compliance, 135–152. Berlin, Heidelberg: Springer.

Kimball, D. G. 2018. “Revitalizing Diplomatic Efforts to Advance CTBT Entry into Force.” Arms Control Association Policy White Paper.
Lozova, V. V. 2015. “The CTBT: Possible Subsequent Domino Effect of the US Ratification in the Context of the Global Nuclear Nonproliferation Regime.” Вісник Одеського національного університету. Серія: Соціологія і політичні науки 20, Вип. 2: 95–101.

McGrath, K. 2009. “Verifiability, Reliability, and National Security: The Case for US Ratification of the CTBT.” Nonproliferation Review 16 (3): 407–433. doi:10.1080/1073670903255102.

Meier, O. 2005. “CTBTO Releases Test Ban Monitoring Data for Tsunami Warning.” Arms Control Today 35 (3): 39.

Murphy, F. 2019. “Global Network's Nuclear Sensors in Russia Went Offline after Mystery Blast.” Reuters, August 19. https://www.reuters.com/article/us-russia-blast-ctbto/global-networks-nuclear-sensors-in-russia-went-offline-after-mystery-blast-idUKL5N25F1JN

Nikitin, M., and B. Dunham. 2016. Comprehensive Nuclear-Test-Ban Treaty: Background and Current Developments. Washington D.C: Congressional Research Service.

Quackenbush, S. L., and F. Zagare. 2016. “Modern Deterrence Theory: Research Trends, Policy Debates, and Methodological Controversies.” In Oxford Handbooks Online. New York: Oxford University Press.

Reuters. 2019. “Norway Detects Radioactive Iodine by Russian Border Days after Blast.” Reuters, August 15. https://www.reuters.com/article/us-russia-blast-norway-idUSKCN1V510N

Ringbom, A., A. Axelsson, M. Aldener, M. Auer, T. W. Bowyer, T. Fritioff, and I. Hoffman. 2014. “Radioxenon Detections in the CTBT International Monitoring System Likely Related to the Announced Nuclear Test in North Korea on February 12, 2013.” Journal of Environmental Radioactivity 128: 47–63. doi:10.1016/j.jenvrad.2013.10.027.

Rydell, R. 2018. “A Strategic Plan for Nuclear Disarmament: Engineering A Perfect Political Storm.” Journal for Peace and Nuclear Disarmament 1 (1): 49–65. doi:10.1080/25751654.2017.1410386.

Sagan, S. D. 2009. “Shared Responsibilities for Nuclear Disarmament.” Daedalus 138 (4): 157–168. doi:10.1162/daed.2009.138.4.157.

Taue, T. 2020. “Nagasaki Peace Declaration.” https://nagasakipeace.jp/content/files/abm/download2020english.pdf

Tóth, T. 2009. “Building up the Regime for Verifying the CTBT.” Arms Control Today 39 (7): 6.

September. https://www.armscontrol.org/act/2009-09/building-up-regime-verifying-ctbt

Vaidya, S., R. Engdahl, R. Le Bras, K. Koch, and O. Dahlman. 2009. “Strategic Initiative in Support of CTBT Data Processing: VDEC (Virtual Data Exploitation Centre).” CTBTO International Scientific Studies.

YouTube. 2011. “United Nations Secretary General Ban Ki-Moon Addresses the Science and Technology Conference 2011.” https://www.youtube.com/embed/ZIsFJPkSGWk

Zanders, J. P. 2002. “The Chemical Weapons Convention and Universality: A Question over Quantity?” Disarmament Forum. No. 4.

Zerbo, I. (@SinaZerbo). 2019. Twitter. https://twitter.com/SinaZerbo/status/1163094836569882625