By Zia Mian, Tamara Patton, and Alexander Glaser

Addressing Verification in the Nuclear Ban Treaty

The UN General Assembly last December called for negotiations this year to produce a "legally binding instrument to prohibit nuclear weapons, leading to their total elimination." The nuclear ban treaty talks will have to engage the issue of confirming compliance by the parties with the specific prohibitions established by such a treaty and, in addition, can establish guiding principles for the process of eliminating nuclear weapons and maintaining the resulting nuclear-weapon-free world.

During the first round of treaty negotiations in March leading to the draft text presented in May, there appeared to be broad agreement among states on most of the core prohibitions but debate over a few others.[1] States by and large seemed to agree on the treaty including, as basic obligations, a ban on the development, production, possession, transfer, use, and threat of use of nuclear weapons and on the provision of assistance, encouragement, and inducement for these activities. There were differences among states over whether the treaty should include measures on the elimination of existing nuclear-weapon-stockpiles or whether such measures should await later negotiations with the nine states having nuclear weapons today, who at some time may decide to join the ban treaty.[2]

There also were differences among states on how to treat verification. The ban treaty talks and the larger disarmament process they seek to put in place will need to consider how to assure compliance with their commitments for three classes of states: (1) established non-nuclear-weapon states that join the treaty, (2) transitional nuclear-weapon states that commit to eliminate their weapon stockpiles when joining the treaty, and (3) legacy nuclear-weapon states with latent capabilities after having joined the treaty.

As part of establishing a perspective on verification, the ban treaty process will need to make some broad choices about the eventual arrangements for a nuclear-weapon-free world, recognizing that there are many possible such end states and that some of these will be more resilient than others. This presents an opportunity to establish forward-looking guidelines on ensuring the greatest possible transparency,

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Delegates at the UN conference to negotiate a nuclear weapons prohibition treaty hold opening-day talks at the United Nations in New York on March 27.

accountability, and irreversibility in the process for achieving and maintaining the elimination of nuclear weapons. The International Atomic Energy Agency (IAEA) can play an important part in shaping and implementing the verification process. By its statute, the IAEA is charged to further "the establishment of safeguarded worldwide disarmament…in conformity with any international agreements entered into pursuant to such policies."[3]

Building on the NPT

Many of the key prohibitions envisaged for the ban treaty already are captured by the nuclear Nonproliferation Treaty (NPT). Under Article II of the NPT, each non-nuclear-weapon state undertakes "not to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices; and not to seek or receive any assistance in the manufacture of nuclear weapons or other nuclear explosive devices."[4] Under Article III.1, each non-nuclear-weapon state is bound to accept safeguards through IAEA monitoring and inspections "as set forth in an agreement to be negotiated and concluded with the [IAEA]…for the exclusive purpose of verification of the fulfilment of its obligations assumed under this Treaty."

There are 172 non-nuclear-weapon states with comprehensive safeguards agreements with the agency, and 124 states have in place additional protocols that require more extensive reporting by states of their nuclear activities and permit the IAEA increased rights of access to information and sites.[5] Of the 130 states-participants in the negotiations, only seven do not have comprehensive IAEA safeguards agreements in force, and all but one of these have agreed to do so. This means that almost all of these 130 states already have in place verification structures that could provide assurance these states are in compliance with many of the expected core ban treaty provisions (table 1).

Further, among the 130 states seeking to agree on the ban treaty, 94 states are also members of nuclear-weapon-free-zone treaties. Each of these treaties includes an obligation, separate from that in the NPT, to conclude a safeguards agreement with the IAEA. This language varies between the zone treaties and became more precise and demanding with the most recent agreement (the 2006 Central Asian Nuclear-Weapon-Free-Zone Treaty) requiring states to conclude with the IAEA a comprehensive safeguards agreement and an additional protocol to that agreement.[6] Most nuclear-weapon-free-zone treaties also have provisions, in case of compliance concerns, for special inspections that can be conducted at the request of states-parties by the IAEA or the zone's implementation body.

This opens the way for the ban treaty to put in place a multilateral arrangement that adopts IAEA safeguards as part of its verification regime, as a parallel obligation to that of the NPT and nuclear-weapon-free-zone treaties, including provisions for special inspections. As is already the case for states that are parties to the NPT and a nuclear-weapon-free-zone treaty, one safeguards agreement with the IAEA is sufficient to satisfy multiple obligations. It also can ease concerns that a state may seek to demonstrate its commitment to nuclear disarmament by joining the ban treaty but use this as an excuse to leave

the NPT and thereby end up outside a verification regime.

The ban treaty could adopt a simple verification obligation using language similar to that in the nuclear-weapon-free-zone treaties, while recognizing that some verification obligations already exist and more stringent verification may be necessary as nuclear-weapon states transition to join the treaty. For example, the treaty could require parties to maintain the nuclear disarmament and nonproliferation obligations they had in force as of January 1, 2017, and to accept as soon as possible the most stringent such measures available and to accept all future safeguards, monitoring, and verification obligations as agreed by the ban treaty conference of parties. This would create a stable, common verification baseline as of the start of the negotiations and a mechanism for the agreed evolution and improvement of the verification regime over time.

The final documents of the 2000 and 2010 NPT review conferences and the draft final document of the 2015 review conference each offered the same guidance on the issue of future verification in non-nuclear-weapon states and in nuclear-weapon states in the context of their nuclear disarmament: "The Conference… stresses that comprehensive safeguards and additional protocols should be universally applied once the complete elimination of nuclear weapons has been achieved."[7] This guidance could be adopted by the ban treaty process.

Weapons Elimination

Because the goal of the ban treaty is to strengthen the legal and normative basis for a process leading to the elimination of nuclear weapons, an important concern will be establishing guidelines for dealing with nuclear-weapon states committing to eliminate their weapons stockpiles through the ban treaty process. The UN resolution establishing the negotiating conference highlighted that, along with the ban treaty, "additional measures, both practical and legally binding, for the irreversible, verifiable and transparent destruction of nuclear weapons would be needed in order to achieve and maintain a world without nuclear weapons."[8]

Rather than trying to set up specific, detailed measures to eliminate nuclear weapons, the ban treaty could simply specify that any nuclear-weapon state seeking to join the treaty must do so through an arrangement agreed with the conference of parties to the treaty. This would allow the issue to be addressed on a case-by-case basis, reflecting the particular history, circumstances, and capabilities of the state seeking to accede to the treaty. This flexibility may be necessary given the diversity in the arsenals and programs of the nine states possessing nuclear weapons today.

In principle, any nuclear-weapon state wishing to join the ban treaty could sign the treaty, declare its weapons holdings, and accept international monitoring of the process of taking its weapons off deployment, disabling them, and placing them in secure storage pending their verified elimination as part of an agreed, time-bound plan. This is the model used in the Chemical Weapons Convention (CWC), which requires that states declare their chemical weapons and "provide access to chemical weapons…for the purpose of systematic verification" along with a "general plan for destruction," stipulating that "such destruction shall begin not later than two years after this Convention enters into force for it and shall finish not later than 10 years after entry into force of this Convention."[9] Following the CWC example, this plan could include destruction of delivery systems specially designed or certified by the state for nuclear weapons missions.

A state could choose to dismantle its nuclear weapons before joining the treaty and then offer up for verification its non-nuclear-weapon status, as was the case with South Africa's accession to the NPT.

Table 1: Ban Treaty Negotiation States and Safeguards

State participants in ban treaty negotiations	130	States include nearly all members of nuclear-weapon-free zones. The only state in a zone not currently participating in the negotiations and with unclear support is Kyrgyzstan, which abstained on the relevant UN resolution.
State participants with comprehensive safeguards agreements	123	States participating in the ban treaty negotiations without a comprehensive safeguards agreement (CSA) or a safeguards additional protocol (AP) in force are: Benin, Cabo Verde, Equatorial Guinea, Guinea, Liberia, Somalia, and Timor-Leste. All states except Somalia have initiated the process of establishing safeguards. Benin, Cabo Verde, Equatorial Guinea, Guinea, Liberia, and Somalia are also party to nuclear-weapon-free zones.
State participants with additional protocols	83	States participating in the ban treaty negotiations without an AP in force are: *Algeria, *Argentina, *Bahamas, *Barbados, Bhutan, *Benin, *Bolivia, *Brazil, *Brunei Darussalam, *Cabo Verde, *Cameroon, *Côte d'Ivoire, *Dominica, *Egypt, *Equatorial Guinea, *Ethiopia, *Grenada, *Guinea, *Guyana, *Honduras, Lebanon, *Liberia, *Malays ia, Maldives, *Myanmar, Nepal, Oman, *Papua New Guinea, Qatar, *St. Vincent and the Grenadines, San Marino, Saudi Arabia, *Senegal, *Sierra Leone, *Solomon Islands, *Somalia, Sri Lanka, *Sudan, Syrian Arab Republic, *Thailand, Timor-Leste, *Tonga, *Trinidad and Tobago, *Tunisia, *Venezuela, *Zambia, *Zimbabwe. 11 of these states have additional protocols that are signed, but not in force. (* State is a member of a nuclear-weapon-free zone.)

This approach, however, would make the eventual verification process more difficult and time consuming and leave greater uncertainty.

In 1989, South Africa decided to terminate its nuclear weapons program. The highly enriched uranium (HEU) cores of its six existing weapons and for a seventh planned weapon were melted down, other key weapons components were destroyed or damaged so they could be not reused, and documents on weapons design and manufacturing were destroyed. In 1991, South Africa joined the NPT and signed a safeguards agreement with the IAEA. After South Africa in March 1993 revealed its nuclear weapons program, the IAEA inspections had to expand to include confirmation that the nuclear weapons, components, and related manufacturing equipment had been destroyed and that nuclear weapons laboratory and engineering facilities had been decommissioned or converted to peaceful purposes and the former weapons material accounted for.

This IAEA assessment included suggestions to South Africa about other components and information that could be destroyed and what destruction should involve.[10] The IAEA recommended that "destruction" of nuclear components should be such that "the critical dimensions of destroyed components would no longer be measurable or reproducible, that the intended function would no longer be recognisable or that a destroyed item could not be reconstituted faster or more economically than it could be redesigned or rebuilt."[11]

In September 1993, the IAEA reported that it had "found no indication to suggest that there remain any sensitive components of the nuclear weapons programme which have not been either rendered useless or converted to commercial non-nuclear applications or peaceful nuclear usage."[12] The lead IAEA inspectors concluded that

> [t]he IAEA's assessment of the completeness of South Africa's inventory of nuclear facilities and materials and its assessment of the status of the former nuclear weapons programme - as in all cases where a large nuclear programme comes under safeguards - is not free from uncertainty.

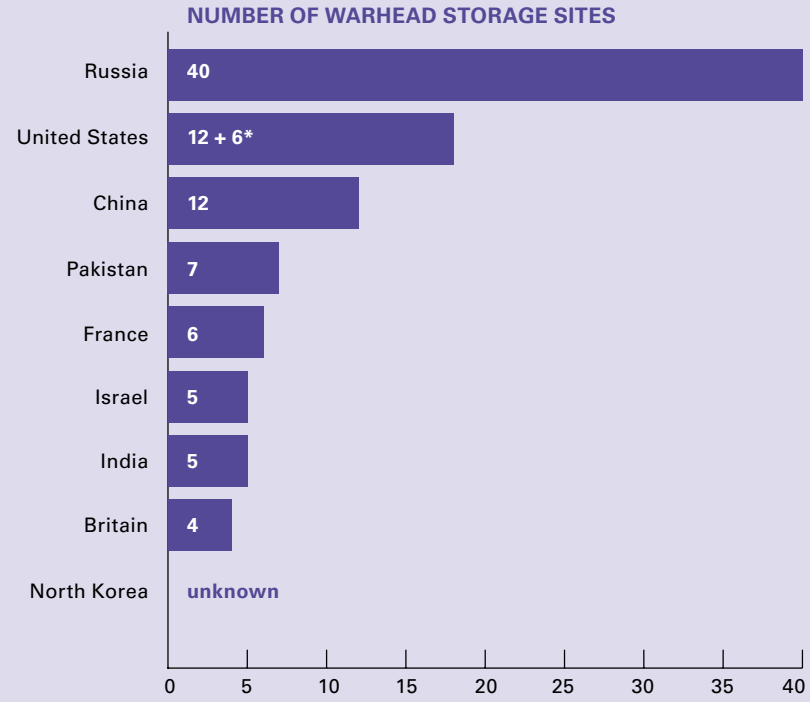
In the case of South Africa, the results of extensive inspection and assessment, and the transparency and openness shown, have led to the conclusion that there were no indications to suggest that the initial inventory is incomplete or that the nuclear weapon programme was not completely terminated and dismantled.[13]

Only in 2010, nineteen years after South Africa's initial report, was the IAEA able to include the country in its list of states where it could conclude "all nuclear material remained in peaceful activities."[14] Olli Heinonen, a former head of the IAEA Department of Safeguards, in a study of the South African case concluded that "it is clear that the process of verification after the fact of dismantlement having taken place meant time added to the clock for the IAEA in terms of providing assurances."[15]

In verifying the elimination of existing nuclear weapons programs, the ban treaty process will need to address existing nuclear arsenals, which range from about 7,000 weapons each in the United States and Russia to the fissile material equivalent of perhaps 10 weapons in North Korea.[16] It also will need to tackle the associated infrastructure, which for the United States and Russia produced tens of thousands of nuclear weapons over the past 70 years.[17] As a first step, the process will require monitoring up to about 100 sites believed to hold nuclear weapons today (figure 1). This task could be made simpler if nuclear-weapon states were to begin a transparent monitored process of consolidating their nuclear weapons complexes to fewer sites that were configured to be accessible to international inspectors and accounting for past weapons-related activities.[18]

It is reasonable to assume that a South African-style verification of warhead dismantlement and accounting of fissile material production would be a much more difficult task, may take several decades to complete, and may be fraught with large uncertainties. It would be much more manageable if verification was agreed in

Figure 1: Nuclear Warhead Storage Sites Worldwide



Source: Adapted from Hans M. Kristensen & Robert S. Norris, "Worldwide Deployments of Nuclear Weapons, 2014," *Bulletin of the Atomic Scientists,* 70 (5), 2014. The table lists locations as of 2014 believed to store nuclear weapons, including nuclear weapons laboratories, and sites for weapons assembly, storage, deployment, and dismantlement.

*The United States is the only country deploying nuclear weapons abroad at six sites in five countries (Belgium, Germany, Italy, the Netherlands, and Turkey).

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A U.S. delegation led by State Department official Sung Kim crosses the military demarcation line between North and South Korea May 10, 2008, carrying boxes of North Korean documents. North Korea had declared its separated plutonium inventory and provided 18,000 pages of records on the operation of its production reactor and reprocessing facility to permit verification in response to a U.S. proposal for "full access to records."

advance and nuclear warhead dismantlement and destruction and material disposition actually observed to ensure the process met agreed standards.

In anticipation and support of these future verification efforts, both nuclear-weapon and non-nuclear-weapon states ought to pursue with a greater sense of urgency joint efforts to develop and demonstrate inspection systems for verified warhead storage and dismantlement. Equally important, nuclear-weapon states ought to begin now to document warhead assembly, refurbishment, and dismantlement activities and movements of warheads and warhead components through the weapons complex in ways that international inspectors will find credible at a later time. This includes generating and preserving appropriate records for all relevant transactions. Modern cryptographic techniques, such as blockchaining, could help demonstrate the authenticity of these records in the future.[19] Although these records would not necessarily be made public now, they would help establish the provenance of treaty-accountable items and drastically simplify the verification challenges of nuclear disarmament.

Legacy Capabilities

As part of its verification of the disarmament of South Africa, the IAEA agreed with that government "to consult on future strategies for maintaining assurance that the nuclear weapons capability would not be regenerated."[20] Accordingly, the IAEA took up the government's invitation to provide the IAEA with "full access to any location or facility associated with" the former nuclear weapons program and to "grant access, on a case-by-case basis, to other locations or facilities that the IAEA may specifically wish to visit."[21]

The problem of legacy capabilities will be more significant for the nine current nuclear-weapon states. It will be most acute in the case of the United States and Russia, which have had the largest and most complex weapons programs by far. The scale of the challenge was captured in a 1997 National Academy of Sciences report, which assessed that

> [i]f all nuclear warheads were eliminated, the current nuclear weapon states, and probably a dozen or more other countries, could in a national emergency produce a dozen simple fission weapons in as little as a few months, even if no effort had been made to maintain this capability. On the other hand, the production of a hundred lightweight thermonuclear bombs or warheads equipped with modern safety and security devices might take several years, even if special efforts had been made to maintain the capability to produce such weapons.[22]

The timescale and the size of reconstituted nuclear forces identified by this report depends fundamentally on the access to nuclear weapons-usable fissile material, i.e., plutonium and HEU. Therefore, the ban treaty process must consider adding, either as an immediate obligation or as a goal of the treaty process, a prohibition on the production, stockpiling, and use of nuclear weapons-usable materials for any purpose. For the existing stockpiles of fissile materials—about 1,350 tons of HEU and 510 tons of separated plutonium—the treaty could make recommendations for a framework to deal with the disposition and elimination of these materials and, for the interim period, envision their international custody (figure 2).[23]

Any state wishing to build or reconstitute a simple nuclear arsenal would need first to produce tens to hundreds of kilograms of plutonium or HEU, which would increase the scale of the reconstitution, its complexity, and the time required, which together increase the risk of early detection. If the elimination of nuclear weapons was accompanied by a phaseout of nuclear power, reconstitution would be made even more difficult, and its verification would be made even easier.[24]

Weapons-Related Research

Along with access to fissile material, research and development efforts leading to a weapons capability will be a key challenge for a legacy nuclear-weapon state seeking to reconstitute a nuclear arsenal, as it is for a would-be nuclear proliferant state today. Because the ban treaty is expected to prohibit the development of nuclear weapons, the linked issue of prohibiting weapons-related research may also be important. Notably, there is an explicit constraint on such activities for states in the African nuclear-weapon-free zone.[25]

The NPT and the IAEA safeguards system have grappled with this question recently in the case of Iran. The IAEA report on Iran's nuclear program identified research and testing activities and management structures judged to have been "relevant to the development of a nuclear explosive device."[26] Among other things, these activities included specific kinds of computer modeling, the development of detonators, systems for triggering high explosives, hydrodynamic experiments, and neutron initiation.

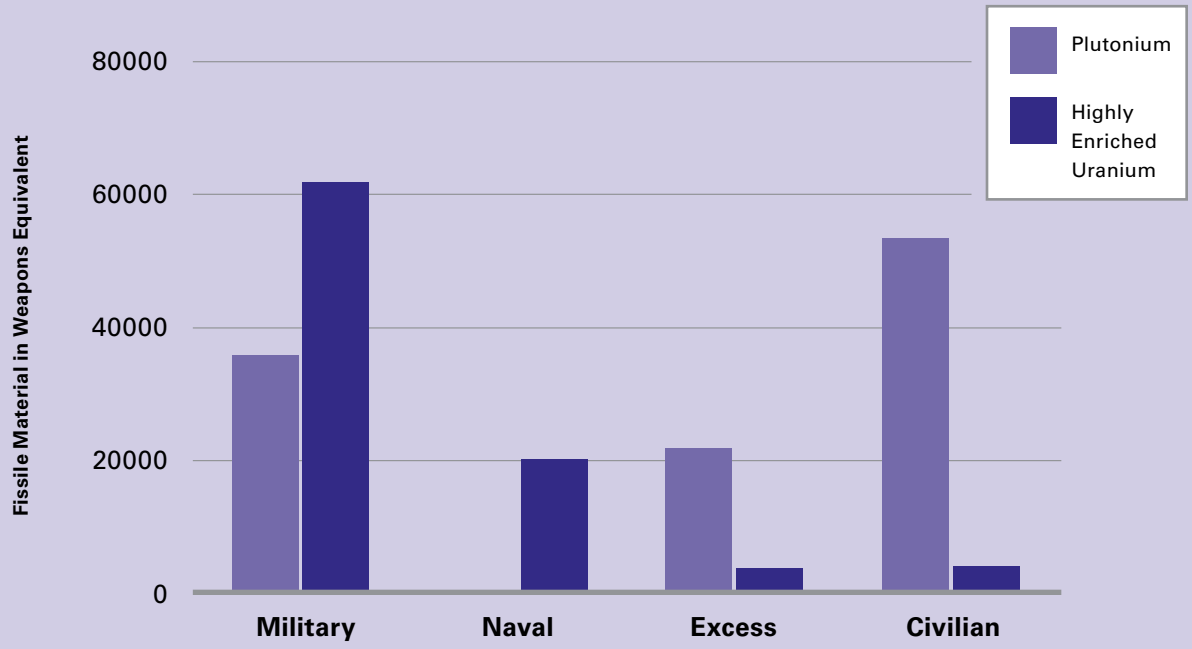
The 2017 Carnegie Endowment report "Toward a Nuclear Firewall" identified a similar set of "activities, materials, and equipment that should be inhibited because they are purely or strongly associated with nuclear weapons programs."[27] The critical weapons-related activities to be prohibited included

- milling of plutonium or uranium shells, spheres, or hemispheres;
- neutron generators;
- tritium technology;
- hydrodynamic codes and experiments;
- preparations for a nuclear test explosion, including devices using inert materials;
- modification of a delivery vehicle to carry a nuclear warhead;
- development of a re-entry vehicle; and
- weaponization.

The report noted that states where there is evidence of all these R&D activities should be subject to greater monitoring than states where there are few signs. It also identified the importance of "contextual factors," such as secrecy regarding such activities, military involvement, and the absence of activities that one would expect if these activities were part of a civilian program and of states being part of international agreements, in making such a judgment. The overall framework was characterized as an assessment of a state's nuclear activities in terms of "compatibility, cohesion, and consistency" with a peaceful or military purpose. The report concluded that, "as a general principle, activities that alone and/or in combination elicit warning that nuclear weapons are being pursued should not appear in states that have completed a nuclear disarmament process."[28] The ban treaty could give guidance that all nuclear R&D activities should be able to demonstrate they meet such criteria for a peaceful purpose.

Figure 2: Stockpiles of Fissile Materials

Figure 2. Fissile material stocks by category and their weapon equivalents. Estimated global stockpiles of plutonium and highly enriched uranium are sufficient for more than 200,000 nuclear weapons, assuming 4 kilograms of weapon-grade plutonium, 5 kilograms of reactor-grade plutonium, and 15 kilograms of highly enriched uranium per weapon-equivalent. All the military, naval and excess material and almost all of the civilian material are held by nuclear weapon states, mostly by the United States and Russia.



Source: Global Fissile Material Report 2015, International Panel on Fissile Materials, December 2015, http://fissilematerials.org/library/gfmr15.pdf.

Pedro Ugarte/AFP/Getty Images

Former Israeli nuclear technician Mordechai Vanunu flashes the V-for-victory sign as he leaves prison April 21, 2004, after an 18-year sentence for revealing details of Israel's secret nuclear-weapons program. In 2005, he told Israel's Channel 2 television that he had acted after becoming alarmed by the danger posed by Israel's nuclear weapons program. Under a policy of "strategic ambiguity," Israel neither confirms nor denies having the region's only nuclear weapons.

Technological and Societal Verification

The UN open-ended working group on nuclear disarmament negotiations in its 2015 report to the General Assembly helped lay the basis for the ban treaty talks and suggested some verification measures that could be part of such a treaty process, such as routine and challenge inspections, as well as measures for the use of on-site sensors, satellite photography, radionuclide sampling, and other remote sensors. The measures also include information sharing with other organizations, and citizen reporting and establishment of an international monitoring system, which includes making information available through a registry.[29]

Some of these measures go beyond what is part of the current IAEA safeguards system. The IAEA, however, already complements its on-site monitoring equipment and inspections with open-source information and satellite imagery as part of an "all source" approach.[30] Further technology advances in the areas of commercial satellite imagery, sensor networks, and information sharing can be harnessed to verify the ban treaty and nuclear weapons elimination and sustain a nuclear weapons-free world.

Large constellations of small satellites, some of which are already being deployed, aim to provide daily coverage of the entire planet. This qualitatively new capability could be combined with the large archives of existing satellite imagery to provide a "time machine" showing what has been happening at a particular site once it has been identified as a possible site of concern. More frequent imagery, combined with improvements in machine learning techniques, could also offer improved abilities to identify such sites. New means for tracking and authenticating warheads and unattended and remote-sensor networks at weapons storage sites are possible that could lay the basis for an international monitoring system to support the disarmament process. The ban treaty could include a commitment to continue developing specific measures to strengthen the verification of elimination and a nuclear weapons-free world, similar to the process envisioned in the Comprehensive Test Ban Treaty.[31]

It has long been recognized that any system of nuclear verification would gain from access to information that could be provided by scientists and technicians inside nuclear programs, as well as by ordinary citizens, with regard to possible violations of a treaty.[32] This would be especially important for exposing R&D activities that might be part of building or maintaining a nuclear weapons capability. Government and corporate scientists and technicians who blow the whistle and civil society groups have a long history of publicly reporting violations of national laws and international agreements. Many have paid a high price for exposing governmental or corporate secrets.

There is a limited history of individuals exposing nuclear weapons activities. The most famous example is Mordechai Vanunu, the Israeli technician jailed for 18 years for revealing details of Israel's nuclear weapons program in 1986. At trial, Vanunu defended his actions as necessary to force Israel to acknowledge its secret weapons program and open it for inspection so that Israel could disarm.[33] Among Vanunu's defenders was the late Nobel laureate Joseph Rotblat, a Manhattan Project physicist who became a founder of the Pugwash movement of scientists against nuclear weapons. Rotblat advocated that "the right and the civic duty of the citizen" to report improper nuclear activities should be embedded in any nuclear disarmament treaty. His 1993 proposal called for this right and duty to "become part of the national codes of law in the countries party to the treaty…[and be] explicitly expressed in a specific clause of that treaty."[34] The ban treaty should include such a Rotblat clause.

Conclusion

The inclusion of verification elements in the ban treaty is feasible and important. Most of the proposed core prohibitions are already covered in existing legal structures and associated verification mechanisms. In addition, the treaty's verification framework will be valuable in the process leading to the elimination of nuclear weapons and may be easier to manage in key regards than arms control treaties that set numerical limits on nuclear weapons.

The ban treaty could require parties to maintain the safeguards obligations they already have in force and establish the goal of convergence in transparency through all states accepting a comprehensive safeguards agreement and an additional protocol as a verification baseline. It also could provide guidelines for the process for nuclear weapons elimination,

including the need for verified declarations, warhead disabling, and monitored warhead storage pending warhead and facility dismantlement on an agreed schedule and with agreed criteria. The goal can be specified as making the disarmament process and outcome as transparent, accountable, and irreversible as possible. To facilitate future verification, nuclear-weapon states ought to begin now to document warhead assembly, refurbishment, and dismantlement activities.

The ban treaty process could consider, as an immediate obligation or as a goal of the treaty process, a prohibition on the production, stockpiling, and use of nuclear weapons-usable fissile material for any purpose. Finally, a treaty commitment to developing and accepting new verification technologies and requiring laws in states imposing obligations on all citizens to report possible prohibited activities and protecting those who do so can play an important role in verifying the ban treaty and nuclear weapons elimination and sustaining a nuclear weapons-free world.

ENDNOTES

1. For statements from the first round of negotiations on March 27-31, 2017, see http://www.reachingcriticalwill.org/disarmament-fora/nuclear-weapon-ban/statements; https://www.un.org/disarmament/ptnw/statements.html. The draft treaty is at http://www.reachingcriticalwill.org/images/documents/Disarmament-fora/nuclear-weapon-ban/documents/CRP1.pdf.

2. For a brief summary of the positions expressed in the first round of ban treaty discussions regarding key obligations, see Allison Pytlak, "News in Brief," *Nuclear Ban Daily,* March 30, 2017, pp. 10-13, http://www.reachingcriticalwill.org/images/documents/Disarmament-fora/nuclear-weapon-ban/reports/NBD1.4.pdf.

3. For an online version of the text of the Statute of the International Atomic Energy Agency (IAEA), see IAEA, "Statute of the IAEA," https://www.iaea.org/about/statute (art. 3.B(1)).

4. William C. Foster, the U.S. negotiator to the nuclear Nonproliferation Treaty (NPT), in testimony to the Senate Foreign Relations Committee said that, under NPT Article II, "the construction of an experimental or prototype nuclear explosive device would be covered by the term 'manufacture' as would be the production of components which could only have relevance to a nuclear explosive device." "Statement by ACDA Director Foster to the Senate Foreign Relations Committee: Nonproliferation Treaty, July 10, 1968," *Documents on Disarmament 1968,* U.S. Arms Control and Disarmament Agency, no. 52 (September 1969), pp. 498-504, http://unoda-web.s3-accelerate.amazonaws.com/wp-content/uploads/assets/publications/documents_on_disarmament/1968/DoD_1968.pdf.

5. For a list of states with IAEA safeguards and additional protocols, see IAEA, "Status List: Conclusion of Safeguards Agreements, Additional Protocols, and Small Quantities Protocols," October 7, 2016, https://www.iaea.org/sites/default/files/16/10/sg_agreements_comprehensive_status_list.pdf. See also IAEA, "The Structure and Content of Agreements Between the Agency and States Required in Connection With the Treaty on the Non-Proliferation of Nuclear Weapons," INFCIRC/153 (Corrected), June 1972; IAEA, "Model Additional Protocol to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards," INFCIRC/540, September 1997.

6. For an online version of the text of the Central Asian nuclear-weapon-free-zone treaty, see UN Office for Disarmament Affairs (UNODA), "Treaty on a Nuclear-Weapon-Free Zone in Central Asia (CANWFZ)," http://disarmament.un.org/treaties/t/canwfz/text.

7. 2000 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, "Final Document," NPT/CONF.2000/28 (Parts I and II), 2000, p. 4. See 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, "Final Document," NPT/CONF.2010/50 (Vol. I), 2010, p. 25. For a repetition of this language, see 2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, "Draft Final Document," NPT/CONF.2015/R.3, May 21, 2015, p. 4.

8. UN General Assembly, "Taking Forward Multilateral Nuclear Disarmament Negotiations," A/RES/71/258, January 11, 2017.

9. For an online version of the text of the Chemical Weapons Convention, see Organisation for the Prohibition of Chemical Weapons, "Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction," n.d., https://www.opcw.org/fileadmin/OPCW/CWC/CWC_en.pdf.

10. The IAEA recommended among other things destruction of "photographs and drawings which could reveal significant dimensions or the design of the nuclear material core and any components that would simplify engineering design or reveal dimensions of other sensitive components." IAEA General Conference, "The Denuclearization of Africa (GC(XXXVI)/RES/577): Report by the Director General," GC(XXXVII)/1075, September 9, 1993, attach. 1, pp. 8-9.

11. Ibid., p. 9.

12. Ibid., p. 11.

13. Adolf von Baeckmann, Garry Dillon, and Demetrius Perricos, "Nuclear Verification in South Africa," *IAEA Bulletin,* No. 1 (1995), pp. 42-48.

14. Olli Heinonen, "Verifying the Dismantlement of South Africa's Nuclear Weapons Program," in *Nuclear Weapons Materials Gone Missing: What Does History Teach?* ed. Henry D. Sokolski, November 2014, p. 174, https://ssi.armywarcollege.edu/pdffiles/PUB1238.pdf.

15. Ibid.

16. Hans M. Kristensen and Robert S. Norris, "Status of World Nuclear Forces," n.d., https://fas.org/issues/nuclear-weapons/status-world-nuclear-forces (accessed March 1, 2017).

17. Hans M. Kristensen and Robert S. Norris, "Global Nuclear Weapons Inventories, 1945-2013," *Bulletin of the Atomic Scientists,* Vol. 69, No. 5 (2013): 75-81.

18. International Panel on Fissile Material (IPFM), "Global Fissile Material Report 2013: Increasing Transparency of Nuclear Warhead and Fissile Material Stocks as a Step Toward Disarmament," October 2013, http://ipfmlibrary.org/gfmr13.pdf.

19. Dominic Frisby, "In Proof We Trust," *AEON,* April 2016, https://aeon.co/essays/how-blockchain-will-revolutionise-far-more-than-money; Joon Ian Wong, "Even the U.S. Military Is Looking at Blockchain Technology—To Secure Nuclear Weapons, *Quartz,* October

2016, https://qz.com/801640/darpa-blockchain-a-blockchain-from-guardtime-is-being-verified-by-galois-under-a-government-contract.

20. IAEA General Conference, "Denuclearization of Africa (GC(XXXVI)/RES/577)," p. 4.

21. Ibid., p. 12.

22. Committee on International Security and Arms Control, National Academy of Sciences, *The Future of U.S. Nuclear Weapons Policy* (Washington, DC: National Academy Press, 1997), p. 97.

23. The idea of international plutonium storage was extensively discussed in the 1970s and 1980s, in particular as part of the International Nuclear Fuel Cycle Evaluation. More recently, it has been proposed as a confidence-building measure for Japan's growing stockpile of separated plutonium. Fred McGoldrick, "IAEA Custody of Japanese Plutonium Stocks: Strengthening Confidence and Transparency," *Arms Control Today,* September 2014.

24. Harold Feiveson et al., *Unmaking the Bomb: A Fissile Material Approach to Nuclear Disarmament and Nonproliferation* (Cambridge, MA: MIT Press, 2014), pp. 173-183.

25. Article 3(a) of the African Nuclear-Weapon-Free Zone Treaty includes an undertaking "[n]ot to conduct research on, develop, manufacture, stockpile or otherwise acquire, possess or have control over any nuclear explosive device by any means anywhere." For an online version of the text of the Treaty of Pelindaba, see UNODA, "Treaty on a Nuclear-Weapon-Free-Zone Treaty in Central Asia (CANWFZ)," http://disarmament.un.org/treaties/t/pelindaba/text.

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