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OPERATIONALIZING NUCLEAR DISARMAMENT VERIFICATION

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SUMMARY

● This SIPRI Insights paper seeks to contribute to the operationalization of nuclear disarmament verification. It explores existing solutions to define a baseline for new arms control and disarmament verification regimes, and considers the requirements for verification under the 2017 Treaty on the Prohibition of Nuclear Weapons (TPNW). Existing solutions might be sufficient to enable several near-term disarmament steps and to lay the foundations for a comprehensive nuclear disarmament verification regime supporting the TPNW.

However, more technical work is needed to achieve all the preconditions for a nuclear weapon-free world, particularly on verifying the dismantlement of nuclear weapons. At the same time, a more favourable political context could reduce the extent to which technical challenges are perceived as obstacles to nuclear disarmament. Even in the absence of new disarmament treaties, the operationalization of disarmament verification can begin at a conceptual and discursive level, by adopting a more policy-oriented approach to disarmament verification.

I. Introduction

In recent years, the international community has increasingly sought to address the technical and political challenges associated with verifiable nuclear disarmament. Such efforts contribute to the long-term goal of the complete elimination of nuclear weapons, and can facilitate more gradual nuclear arms control steps. While nuclear disarmament refers to both the process towards and the end goal of eliminating nuclear weapons, nuclear disarmament verification can be defined as the activity of 'gathering and analysing information to make a judgement about parties' compliance or non-compliance' with a treaty or agreement promoting disarmament in either of these two senses.[1] Thus, an interest in verification unites both supporters of the 'step-by-step' approach and those who highlight the urgency of the complete elimination of nuclear weapons.

Past and ongoing work on arms control, non-proliferation and disarmament verification provides a considerable pool of knowledge that can be drawn on to verify future reductions in nuclear weapons, as well as their complete elimination. Yet there has been relatively little reflection on how existing know-how on verification should be applied going forward. This is largely because the implementation of verification solutions depends on political decisions about arms control and disarmament commitments, which are difficult to anticipate in advance. History also shows that even when states parties have agreed on the relevant normative framework, decisions on practical arrangements related to verification can be highly controversial.[2] It is particularly difficult to imagine a verification regime capable of sustaining a nuclear weapon-free world. However, a comprehensive disarmament verification regime might soon be needed if the 2017 Treaty on the Prohibition of Nuclear Weapons (TPNW) enters into force.

[1] United Nations Institute for Disarmament Research (UNIDIR) and VERTIC, *Coming to Terms with Security: A Handbook on Verification and Compliance*, 2003, p. 1.
[2] Fischer, D., *History of the International Atomic Energy Agency: The First Forty Years* (IAEA: Vienna, 1997).

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Table 1. Summary of Russian–US nuclear arms reduction treaties and verification measures

Treaty (signed / in force)	Commitments	Verification measures
Interim Agreement on Offensive Arms (SALT I) 1972 / 1972–77	Freeze on land-based intercontinental ballistic missile (ICBM) launchers; limits on sea-launched ballistic missiles (SLBMs)	No interference with, or concealment measures impeding, national technical means (NTM) of verification
SALT II* 1979	No more than 2250 deployed strategic warheads each; limits on multiple independently targetable re-entry vehicles (MIRVs); freeze on land-based ICBM launchers	Like SALT I
INF 1987 / 1988	Ban on land-based ballistic and cruise missiles with a range of 500 to 5500 kilometres	No interference with, or concealment measures impeding, NTM; exchange of data on proscribed systems; on-site and short-notice inspections (to confirm data and to verify the elimination of proscribed systems); portal and perimeter monitoring (to monitor access points of missile production or assembly facilities); static display (of missiles, launch canisters and launchers); notification (of plans to move and eliminate proscribed missiles)
START I 1991 / 1994–2009	No more than 6000 deployed strategic warheads; no more than 1600 strategic delivery vehicles	No interference with, or concealment measures impeding, NTM; exchange of data on declared items (including telemetry); on-site and short-notice inspections (to confirm data); portal and perimeter monitoring (to monitor movements of mobile ICBMs); exhibitions (to demonstrate distinctive features and confirm technical characteristics of items, and show results of conversion); notification (e.g. of movements of items between declared facilities); display of items (to make them observable to NTM)
START II* 1993	No more than 3000–3500 deployed strategic warheads; ban on MIRVs on ICBMs; no more than 1700–1750 SLBMs each	Like START I
SORT 2002 / 2003–12	No more than 1700–2200 deployed strategic warheads	No verification provisions
New START 2010 / 2011–21	No more than 1550 deployed strategic warheads; no more than 800 strategic delivery vehicles (of which no more than 700 can be deployed)	Like START I, but no portal and perimeter monitoring

*Never entered into force

This paper seeks to contribute to the operationalization of nuclear disarmament verification by exploring existing solutions in order to define a baseline for new regimes, and considering the requirements for verification under the TPNW. Section II provides an overview of disarmament regimes and initiatives, and section III envisions a comprehensive nuclear disarmament verification regime to monitor the implementation of the TPNW. Yet the discussion is relevant beyond the TPNW: the challenges of achieving verifiable and complete disarmament would have to be addressed by any other legal framework seeking to achieve that goal, which is also endorsed by Article VI of the 1968 Treaty on the Non-Proliferation of Nuclear

Weapons (NPT).[3] Political questions, such as how to enforce compliance in a nuclear weapon-free world, are beyond the scope of this discussion.

II. Mapping disarmament verification solutions

This section explores previous and ongoing verification work relevant to nuclear disarmament, including past and currently operational verification regimes, such as those supporting bilateral United States–Russian arms control treaties, as well as the NPT-mandated International Atomic Energy Agency (IAEA) Safeguards. It also discusses proposals and initiatives that have not yet been implemented. This broad, while by no means exhaustive, overview helps to distinguish between verification solutions that have been used in practice and potential solutions that could serve as building blocks for new arms control and disarmament verification regimes in the future.

Arms control verification: Bilateral US–Soviet/Russian treaties

The early history of US–Soviet/Russian arms control provides several examples of treaties that lacked collaborative verification regimes (see table 1 for an overview of treaties and verification measures). These include the 1963 Partial Test Ban Treaty, the 1972 Strategic Arms Limitations Treaty (SALT) I, the 1974 Threshold Test-Ban Treaty (TTBT) and the 1979 SALT II. The treaties mainly relied on national technical means (NTM) of verification, which included technical tools under national control, such as satellite imagery, electronic surveillance and communications intercepts.[4] One exception was the 1988 Joint Verification Experiment, in which US and Russian technical experts collaborated to measure the explosive yields of nuclear tests by each side; this effort helped facilitate the belated ratification of the TTBT in 1990.[5]

With the exception of the 2002 Strategic Offensive Reductions Treaty (SORT), since the 1980s bilateral arms control treaties have included increasingly cooperative and intrusive verification regimes. Building on the SALT precedent, they have focused on limiting nuclear weapon delivery vehicles. The 1987 Intermediate-Range Nuclear Forces (INF) Treaty was a landmark agreement that banned all ground-launched ballistic and cruise missiles with a range of 500–5000 kilometres. It therefore reduced—and verifiably eliminated—an entire category of weapons. The INF Treaty introduced a historic verification regime that involved an extensive exchange of data on all declared facilities, including the number

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[3] Article VI of the NPT stipulates that 'Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control'. Treaty on the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty, NPT), opened for signature 1 July 1968, entered into force 5 Mar. 1970.

[4] Ifft, E. M., 'Verification lessons learned from strategic arms reductions', Deep Cuts Working Paper no. 2, Jan. 2014.

[5] See Center of International Security and Cooperation, 'Joint verification experiment', Stanford University, [n.d.].

of launchers and missiles they contained.[6] It also introduced an inspection protocol, which entailed on-site inspections of selected missile assembly facilities and all storage facilities; deployment zones; and repair, test and elimination facilities for a period of 13 years.[7] Between 1988 and 2002, a total of 540 US inspections took place at 133 Soviet/Russian sites, and the Soviet Union/Russia conducted 311 inspections at 31 US sites. Representing an unprecedented degree of intrusiveness, resident inspectors were even permitted in order to enable continuous on-site monitoring. Afterwards, verification was limited to NTM.[8] However, NTM proved insufficient to address a dispute over noncompliance, which began in 2013. In February 2019, the USA formally announced its intention to withdraw from the INF Treaty in response to alleged Russian violations, and Russia said that it would do the same.[9]

In the 1991 Strategic Arms Reduction Treaty (START I), Russia and the USA committed to limit their strategic nuclear delivery vehicles—intercontinental ballistic missiles (ICBMs), sea-launched ballistic missiles and heavy bombers—to 1600. A fixed number of nuclear warheads was attributed to each delivery system, with the total not to exceed 6000.[10] In order to verify these limits, START I provided for on-site inspections, exhibitions, and monitoring of the production facilities for ICBMs and the associated mobile launchers (providing confidence that such difficult-to-detect mobile systems would not be deployed outside of the restricted areas).[11] Moreover, unhindered access to telemetry (data generated during missile tests that is transmitted to the ground) gave both countries a better understanding of the characteristics of each other's missiles and warheads.[12]

The most recent US–Russian arms control treaty is the 2010 New Strategic Arms Reduction Treaty (New START). New START continued the process of verified reductions in the number of deployed strategic nuclear warheads. It had simpler counting rules than START I, which facilitated flexibility in carrying out the reductions. Both sides reached the New START limits—no more than 1550 strategic nuclear warheads deployed on 700 delivery platforms—by the February 2018 deadline. The lessons learned from START I informed the design of a less costly verification regime for New START. Although it permits fewer types of inspections to verify the extensive data exchanged by the parties on the numbers, types and locations of their strategic forces, New START allows more short-notice, on-site inspections.

[6] Russell, J., 'On-site inspections under the INF Treaty: A post-mortem', VERTIC Briefing Paper 01/02, Aug. 2001.

[7] Congressional Research Service (CRS), *Russian Compliance with the Intermediate Range Nuclear Forces (INF) Treaty: Background and Issues for Congress*, CRS Report for Congress R43832 (US Congress, CRS: Washington, DC, updated 18 Jan. 2019).

[8] Russell (note 6).

[9] Sanger, D. E. and Broad, W. J., 'US suspends nuclear arms control treaty with Russia', *New York Times*, 1 Feb. 2019; and President of Russia, 'Meeting with Sergei Lavrov and Sergei Shoigu', 2 Feb. 2019.

[10] VERTIC and UNIDIR, *Coming to Terms with Security: A Handbook on Verification and Compliance* (VERTIC and UNIDIR: Geneva and London, 2003).

[11] Woolf, A. F., *Monitoring and Verification in Arms Control*, Congressional Research Service (CRS) Report for Congress R41201 (US Congress, CRS: Washington, DC, 23 Dec. 2011).

[12] Woolf (note 11).

New START will expire in 2021, but it can be extended for up to 5 years if both parties agree.[13]

At the time of writing, the US–Russian arms control process seems to have stalled. In addition to (and partly as a result of) the collapse of the INF Treaty, there are currently few signs that the USA and Russia will agree to extend New START, let alone initiate a new round of arms control negotiations. Even if the political context becomes more conducive to arms control, further nuclear weapon reductions might not be possible without parallel discussions on advanced conventional precision-strike capabilities, space weapons and missile defence, which are increasingly seen to affect strategic stability.[14] Such a broader approach may require the development of new verification solutions.

Bilateral cooperation supporting post-cold war disarmament steps

Alongside START I and unilateral nuclear weapons reductions in the 1990s, Russia and the USA engaged in unprecedented cooperation that involved dismantling thousands of Soviet-era nuclear weapons and collaboratively converting weapon-origin nuclear material. Although such efforts are generally understood as transparency measures or nuclear security cooperation, they successfully tackled many challenges related to disarmament verification, notably the verified disposition of fissile materials. This cooperation was crucial for the implementation of the agreed nuclear weapon reductions, which might not otherwise have been possible due to the economic crisis that followed the collapse of the Soviet Union.[15]

The first US–Soviet/Russian nuclear security initiative, the Cooperative Threat Reduction (CTR) Programme (also known as the Nunn–Lugar Programme), was launched in 1991. It was motivated by proliferation concerns related to the nuclear and other weapons of mass destruction (WMD) that Belarus, Kazakhstan and Ukraine had inherited from the Soviet Union. Under the programme, the USA provided economic and technical assistance to Russia and these three Soviet successor states to ensure the safe transfer, storage and dismantlement of such capabilities, including 'missiles, launchers, submarines, and bombers' associated with strategic nuclear warheads. Although the CTR programme demonstrated an unprecedented level of transparency, Russians reportedly 'remained reluctant to involve their US counterparts in the actual dismantlement of nuclear warheads'.[16] By 2009, over 7000 nuclear weapons had been dismantled under the programme.[17] The CTR programme also provided employment opportunities for former nuclear weapon experts to 'undermine incentives

[13] Woolf (note 11).

[14] See e.g. Pifer, S., 'The future of US–Russian arms control', Carnegie Endowment for International Peace, 2016.

[15] See e.g. Nicks, D., 'RIP, Megatons for Megawatts', *Time*, 25 Sep. 2013.

[16] Ellis, J. and Perry, T., 'Nunn–Lugar's unfinished agenda', *Arms Control Today*, vol. 27, no. 7 (Oct. 1997), pp. 14–22.

[17] Bernstein, P. I. and Wood, J. D., *The Origins of Nunn–Lugar and Cooperative Threat Reduction: Case Study 3*, Center for the Study of Weapons of Mass Destruction, National Defense University, Apr. 2010.

these individuals might otherwise encounter to sell their knowledge to potential proliferant nations'.[18]

Another major US–Russian initiative at the time was the public–private partnership agreement concerning the disposition of highly enriched uranium (HEU) extracted from nuclear weapons, informally known as 'Megatons to Megawatts' (1993–2013). Under the agreement, Russia down-blended weapon-origin HEU into low-enriched uranium (LEU) and sold it to the USA to be used in civilian power reactors. As part of this effort, nuclear material sufficient for 20 000 warheads was successfully converted into peaceful use.[19] Extensive monitoring helped to build confidence on both sides: the presence of US monitors in Russia increased confidence that the HEU did indeed originate from dismantled Russian warheads, and Russia was allowed to verify that the LEU received by Americans was used only for civilian nuclear power plants.[20]

A similar effort to collaboratively dispose of weapon-origin plutonium ran into problems on the US side. The 2000 Plutonium Management and Disposition Agreement (PMDA) sought to mitigate the safety and security risks as well as the costs of storing plutonium extracted from the large number of nuclear weapons dismantled in the 1990s. While Russian reactors were able to turn excess plutonium into fuel by irradiating it in fast-neutron reactors, the US method—mixing plutonium oxide with uranium oxide—was economically unsustainable.[21] In October 2016, Russia suspended cooperation under the PMDA, referring to the US inability to meet its obligations.[22] The agreement's failure demonstrates the impact of political tensions on nuclear security cooperation, as well as the technical difficulty of disposing of weapon-origin plutonium.

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The Trilateral Initiative, which was launched in 1996, also focused on weapon-origin fissile materials. This cooperative project involving Russia, the USA and the IAEA examined the possibility of extending IAEA safeguards to weapon-origin fissile materials.[23] It established a Joint Working Group to address the related financial, technical and legal challenges. The project made progress on developing verification solutions that avoided the disclosure of sensitive nuclear weapon-related information to inspectors, and it came close to producing a model verification agreement to use as a basis for potential future agreements between the IAEA and states wishing

[18] Woolf, A. F, *Nonproliferation and Threat Reduction Assistance: US Programs in the Former Soviet Union*, Congressional Research Service (CRS) Report for Congress RL31957 (US Congress, CRS: Washington, DC, 6 Mar. 2012).

[19] World Nuclear News, 'Russia completes Megatons to Megawatts work', 29 Aug. 2013.

[20] Lawrence Livermore National Laboratory, 'A transparent success: "Megatons to Megawatts" Program', *Science and Technology Review*, Apr./May 2013.

[21] Lubkin, A., 'What went wrong with US plutonium disposition', *Bulletin of the Atomic Scientists*, 24 Apr. 2018.

[22] Center for Energy and Security Studies, Panel on Fissile Materials, 'Decree by the President of the Russian Federation on the suspension of the Plutonium Management and Disposition Agreement', Unofficial translation, 3 Oct. 2016.

[23] Shea, T. E., and Rockwood, L., 'Nuclear disarmament: The legacy of the Trilateral Initiative', Deep Cuts Working Paper no. 4, Mar. 2015.

to remove fissile materials from military use.[24] However, the initiative ended in 2002 due to changes in the political environment.[25]

While not all of the cooperative efforts described above were successful, they demonstrate how transparency and cooperation can contribute to nuclear disarmament. They also highlight the importance of political trust between Russia and the USA—a commodity that seems lacking in the present era, which is characterized by the breakdown of arms control and the end of the cooperative initiatives discussed here.[26]

Non-proliferation verification: International Atomic Energy Agency safeguards

The IAEA has six decades of experience inspecting nuclear facilities and verifying declarations related to nuclear materials and activities. Although the agency's mandate is restricted to promoting the safe use of nuclear science and technology for peaceful purposes and preventing proliferation, it has also been involved in a small number of disarmament verification missions.

IAEA safeguards

Since the NPT's entry into force in 1970, all non-nuclear weapon states parties to the treaty are required to conclude a safeguards agreement with the IAEA. Most non-nuclear weapon states have in place a Comprehensive Safeguards Agreement (CSA), based on the INFCIRC/153 (Corrected) verification standard, which was developed soon after the NPT's negotiation. A CSA obligates countries to declare the type and quantities of nuclear materials in their possession and gives the IAEA the authority to independently verify that those materials are not diverted for military use.[27]

The IAEA deploys various verification tools, including non-destructive and destructive assay, containment and surveillance systems, and environmental sampling.[28] It also conducts on-site inspections, and ongoing monitoring and evaluation. For a long time, the IAEA was only authorized to inspect declared facilities. However, largely as a result of the discovery of Iraq's clandestine nuclear weapon programme in the early 1990s, a new verification standard was developed to address the problem of undeclared activities. In 1997, the IAEA's Board of Governors approved the Model Additional Protocol to the CSA (INFCIRC/540), which authorizes the agency 'to provide assurances as to the absence of undeclared nuclear material and activities in a State',

[24] Rockwood, L., 'How the IAEA verifies if a country's nuclear program is peaceful or not: The legal basis', *Bulletin of the Atomic Scientists*, vol. 74, no. 5 (2018), pp. 317–25.

[25] Shea, T., 'The Trilateral Initiative: A model for the future?' *Arms Control Today*, 11 June 2008.

[26] Dvorkin, V., 'Brief commentary on the termination of the Nunn–Lugar Program', Carnegie Moscow Center, 6 Feb. 2015; and Kramer, A. E., 'Vladimir Putin exits nuclear security pact, citing "hostile actions" by US', *New York Times*, 3 Oct. 2016.

[27] International Atomic Energy Agency, 'More on safeguards agreements', [n.d.].

[28] Destructive and non-destructive assay are methods used to determine an item's nuclear material content by physically destroying the sample or not, respectively. 'Containment' refers to the process of ensuring 'the physical integrity of an area or items', for example by using seals. 'Environmental sampling' involves taking samples from various surfaces in the environment (e.g. air, water, sediment, vegetation or soil) to find traces of nuclear material. International Atomic Energy Agency, 'IAEA safeguards glossary', International Nuclear Verification Series no. 3, 2001; and IAEA, 'Verification and other safeguards agreements', [n.d.].

meaning expanded access to sites and information.[29] In December 2018, Additional Protocols were in force in 134 countries and Euratom.[30]

IAEA involvement in nuclear disarmament verification

The IAEA was tasked with retroactively verifying South Africa's dismantlement of nuclear weapons when, in March 1993, South Africa announced that it had previously developed and subsequently dismantled a limited nuclear deterrent capability.[31] This announcement came approximately two years after the country had joined the NPT as a non-nuclear weapon state and signed a CSA with the IAEA. In response, verification measures in South Africa were extended to include facilities not normally covered by IAEA safeguards, such as those related to high explosive manufacturing and testing, and a nuclear weapon expert was included in the IAEA verification team.[32] Verification was complicated by the fact that key information had been lost during the non-verified dismantling process.[33] However, given South Africa's cooperation and transparency, in September 1993 the IAEA was able to conclude that the country's original declaration was complete and matched with inspection findings.[34] Following South Africa's ratification of a Model Additional Protocol in 2002, by 2011 the agency had also concluded that all nuclear material in the country remained in peaceful activities.[35]

The IAEA was also involved in verifying the absence of nuclear weapons programmes in Iraq and Libya. The former mission was based on United Nations Security Council Resolution 687 (1991), which required Iraq to place its 'nuclear-weapons-usable materials under the exclusive control, for custody and removal, of the International Atomic Energy Agency, with the assistance and cooperation of the [UN] Special Commission [UNSCOM]'.[36] By 1998, the IAEA had accounted for and removed all such material, and verified the destruction of relevant facilities and equipment. Yet it could not verify that there were no undeclared items or activities.[37] IAEA inspectors were expelled from Iraq in 1998, and returned in late 2002. After three months of additional inspections, on 7 March 2003 the IAEA Secretary General reported that the agency had 'found no evidence or plausible indication of the revival of a nuclear weapons programme in Iraq'.[38] A US-led coalition nevertheless invaded Iraq on 20 March 2003, based on a claim that it was hiding WMD. However, the US Iraq Survey Group later confirmed the

[29] International Atomic Energy Agency, 'Safeguards overview', [n.d.]; and IAEA, 'Model Protocol Additional to the Agreement Between State and the International Atomic Energy Agency for the Application of Safeguards (INFCIRC/540)', Sep. 1997.

[30] International Atomic Energy Agency, 'Status of the Additional Protocol', updated 6 Mar. 2019.

[31] Busch, N. E. and Pilat, J. F., 'South African rollback: Revisiting monitoring and verification lessons after 20 years', *Comparative Strategy*, vol. 33, no. 3 (2014), pp. 236–61.

[32] Kelley, R., Conversation with authors, 13 Mar. 2019.

[33] Heinonen, O., 'Verifying the dismantlement of South Africa's nuclear weapons program', ed. H. D. Sokolski, *Nuclear Weapons Materials Gone Missing: What Does History Teach?* (US Army War College Press: Carlisle Barracks, PA, Mar. 2014), pp. 88–99.

[34] Von Baeckmann, A., Dillon, G. and Perricos, D., 'Nuclear verification in South Africa', IAEA Bulletin, vol. 37, no. 1 (1995), pp. 42–48; and Busch and Pilat (note 31).

[35] International Atomic Energy Agency, Safeguards Statement for 2011.

[36] UN Security Council Resolution 687, 8 Apr. 1991.

[37] Arms Control Association, 'Iraq: a chronology of UN inspections', Special Report, Oct. 2002.

[38] International Atomic Energy Agency, Report by the Director General, 'The status of nuclear inspections in Iraq: An update', 7 Mar. 2003.

IAEA's conclusion that Iraq had no WMD or nuclear materials.[39] The Iraqi case thus highlighted the challenge of verifying the absence of undeclared items or activities, as well as the risk that the verification process is overtaken by political events.

In Libya, the IAEA was tasked with verifying the absence of a nuclear weapon programme after the country—following negotiations with the United Kingdom and the USA—admitted to having sought a uranium enrichment capability without declaring this to the IAEA.[40] The related materials and equipment were removed and dismantled in 2004—the same year that Libya signed the Model Additional Protocol to its CSA. The UK and USA dismantled the country's nascent uranium enrichment capabilities, and the IAEA verified the process.[41] Four years later, the IAEA reported that Libya's past nuclear weapon-related activities had been discontinued.[42]

Emerging and planned multilateral disarmament steps

Since the 1990s, there has been a broad international consensus on the need to conclude two multinational treaties related to disarmament. First, the Comprehensive Nuclear-Test-Ban Treaty (CTBT), negotiated in 1993–96, seeks to ban nuclear explosions on the surface of the earth, atmosphere, underwater and underground.[43] Although it has not yet entered into force, its verification regime, which detects nuclear explosions, is already operational. The Provisional Technical Secretariat of the CTBT Organization (CTBTO) oversees a verification regime consisting of an extensive International Monitoring System (IMS) that, once completed, will include 321 monitoring stations and 16 laboratories located in 89 countries. IMS data is transferred to the International Data Centre for seismic, hydro-acoustic, infrasound and radionuclide analysis.[44] The CTBT also provides consultation, clarification, on-site inspections and confidence-building measures.[45]

Second, a fissile material cut-off treaty would ban the production of fissile material (plutonium and HEU) for nuclear weapons. However, formal negotiations on the proposed treaty have not yet been launched, mainly due to disagreements about whether it should only prohibit the production of new material (that is, a cut-off agreement) or also cover existing stocks (in which

[39] Central Intelligence Agency, 'Comprehensive report of the special advisor to the DCI on Iraq's WMD', 30 Sep. 2004.

[40] ElBaradei, M., *The Age of Deception, Nuclear Diplomacy in Treacherous Times* (Metropolitan Books: New York, 2011).

[41] Arms Control Association, 'Chronology of Libya's disarmament and relations with the United States', Jan. 2018.

[42] See International Atomic Energy Agency, Report by the Director General, 'Implementation of the NPT Safeguards Agreement in the Socialist People's Libyan Arab Jamahiriya', GOV/2008/39, 12 Sep. 2008.

[43] Comprehensive Nulcear-Test-Ban Treaty (CTBT), Article I, opened for signature 24 Sep. 1996, not in force.

[44] 'Seismic monitoring' refers to detecting shockwaves in the earth, 'hydro-acoustic' to following sound waves in the oceans, 'infrasound' to tracking ultra-low frequency sound waves, and 'radionuclide' to measuring the atmosphere for radioactive particles. Comprehensive Nulcear-Test-Ban Treaty Organization (CTBTO), 'Who we are', [n.d.]; and CTBTO, 'Overview of the verification regime', [n.d.].

[45] CTBT (note 43), Article IV.

case a more suitable name would be the fissile material treaty).[46] Selecting the most appropriate verification mechanisms to implement this treaty will depend on how this question is resolved. While a narrow scope would cover production facilities and other facilities where the materials are present, a more comprehensive prohibition would also include other facilities, such as nuclear power reactors or fuel fabrication plants, and possibly undeclared locations.[47] If a narrow scope is chosen, the IAEA would be an effective verification authority, given its extensive experience in accounting for fissile materials.[48]

Recent initiatives focused on nuclear weapon dismantlement

The verification of US and Russian disarmament will eventually need to go beyond delivery vehicles and involve the dismantlement of warheads. At least three ongoing international initiatives have sought to address this challenge.

First, in 2000 the UK and the USA began to cooperatively explore arms control verification technologies and methodologies, including warhead and warhead dismantlement verification. The project was facilitated by the ability of the two countries to share classified information under the 1958 Mutual Defence Agreement.[49] It included a verification exercise in which two fictional nuclear-armed states negotiated a protocol to verify warhead dismantlement.[50]

Second, the UK–Norway Initiative, established in 2007, investigated the potential role of non-nuclear weapon states in the sensitive process of verifying nuclear warhead dismantlement.[51] It explored the challenges related to managed access (inspections at relevant facilities), information barriers (allowing verification without disclosing sensitive information) and confidence (the psychological factor in verification judgements).[52] After announcing in 2015 that it would expand the partnership to include more countries, the initiative was renamed the Quad Nuclear Verification Partnership.[53]

[46] The former option is seen to favour France, Russia, the USA and the UK—which have reportedly stopped fissile material production for weapons purposes—whereas Pakistan and India (and possibly China) still perceive the need to produce such material. United Nations Institute for Disarmament Research (UNIDIR), *A Fissile Material Cut-off Treaty, Understanding the Critical Issues*, 2010.

[47] Dunn, L. A., 'A FMCT: How can we get from here to there?', United Nations Institute for Disarmament Research (UNIDIR), 'Fissile materials: Scope, stocks and verification', Disarmament Forum 2, 1999, pp. 7–15.

[48] This mission should be distinct from the IAEA Department of Safeguards, but it could function under the supervision of the IAEA Director General. Kile, S. N. and Kelley, R. E., *Verifying a Fissile Material Cut-off Treaty: Technical and Organizational Considerations*, SIPRI Policy Paper no. 33 (SIPRI: Stockholm, Aug. 2012).

[49] VERTIC, 'Means to reinforce research on nuclear disarmament verification: Report on a series of regional conversations', Research Report no. 13, Nov. 2017.

[50] See National Nuclear Security Administration, Office of Nonproliferation and Arms Control, British Ministry of Defence and AWE, 'Joint US–UK report on technical cooperation for arms control', Oct. 2017; and Hauck, D. K. and Russell, I., 'Review of the US–UK warhead monitored dismantlement exercise', Los Alamos National Laboratory, 2016.

[51] Simpson. J. and Nielsen, J., 'The 2005 NPT Review Conference: Mission impossible?', *Nonproliferation Review*, vol. 12, no. 2 (2005), pp. 271–301.

[52] UK Norway Initiative, 'Information barrier: Can people trust equipment when they don't trust each other?'.

[53] VERTIC (note 49).

Third, the International Partnership for Nuclear Disarmament Verification (IPNDV) seeks to develop procedures and tools for nuclear disarmament verification. It focuses on warhead dismantlement and cooperation between nuclear-armed and non-nuclear weapon states in this context. The IPNDV, which has more than 25 participating countries, was established in 2014 by the Nuclear Threat Initiative and the US Department of State.[54] In its first phase, the IPNDV focused on the challenges related to the monitoring and inspection of nuclear weapon dismantlement.[55] The second phase, which began in 2017, addresses questions such as how to confirm that the declared object is indeed a nuclear weapon without disclosing sensitive details, how to build confidence in the nuclear weapon elimination process and which technologies could be used during that process.[56]

The verification of US and Russian disarmament will eventually need to go beyond delivery vehicles and involve the dismantlement of warheads

While these three partnerships have increased the understanding of disarmament verification challenges among non-nuclear weapon states, they have not involved active cooperation among nuclear weapon states beyond France, the UK and the USA; in 2018, China and Russia withdrew from the IPNDV, having participated as observers until then.[57] However, the Group of Governmental Experts on Nuclear Disarmament Verification, which was established by a 2016 UN General Assembly resolution, has participants from 25 countries, including 7 nuclear-armed states.[58]

Individual verification proposals

Individual analysts and institutions have proposed several new verification solutions. For example, a 2017 UN Institute for Disarmament Research report suggested that the non-deployment of non-strategic nuclear weapons be verified by moving the associated warheads to central storage facilities away from delivery systems.[59] Another proposal is to freeze the production of tritium, which is used to boost fission and must be regularly replaced in nuclear weapons.[60] Some studies have also explored the possibility of basing new verification solutions on artificial intelligence and

[54] Representatives from the following countries or groupings have attended IPNDV activities (* = observers): Argentina, Australia, Belgium, Brazil, Canada, Chile, China*, the EU, Finland, France, Germany, the Holy See, Hungary, Indonesia, Italy, Japan, Jordan, Kazakhstan, Mexico, the Netherlands, Nigeria, Norway, Pakistan*, the Philippines, Poland, Russia*, South Korea, Sweden, Switzerland, Turkey, the United Arab Emirates, the UK and the USA. IPNDV, 'Partners', [n.d.].

[55] Hinderstein. C., 'International partnership for nuclear disarmament verification: Laying a foundation for future arms reductions', *Bulletin of the Atomic Scientists*, vol. 74, no. 5 (2018), pp. 305–11.

[56] Hinderstein (note 55).

[57] G7 Foreign Ministers' Communiqué, Toronto, Canada, 23 Apr. 2018.

[58] The group consists of experts from 25 countries—Algeria, Argentina, Brazil, Chile, China, Finland, France, Germany, Hungary, India, Indonesia, Japan, Kazakhstan, Mexico, Morocco, the Netherlands, Nigeria, Norway, Pakistan, Poland, Russia, South Africa, Switzerland, the UK and the USA. UN General Assembly, Resolution on 'Nuclear Disarmament Verification', A/RES/71/67, 14 Dec. 2016.

[59] Podvig, P. and Serrat, J., 'Lock them up: Zero-deployed non-strategic nuclear weapons in Europe', United Nations Institute for Disarmament Research, 2017.

[60] Kelley, R., 'Tritium cut-off to starve weapons to death', Presentation at SIPRI Expert Workshop, Mar. 2018.

machine learning.[61] While such techniques may provide opportunities for monitoring, particularly in processing data that is increasingly available through commercial satellite imagery, concerns about cyber security and data integrity are likely to limit their application in other disarmament verification-related missions.

The basis of new arms control and disarmament verification regimes

Past verification solutions and pioneering work on new initiatives provide plenty of lessons and building blocks for new, further-reaching arms control and disarmament verification regimes in the future. It is unclear whether—and in what form—the arms control process between Russia and the USA will resume. However, past experience in bilateral treaty verification, together with new verification solutions, can facilitate new steps towards disarmament. For instance, Russia and the USA could jointly agree to limit non-strategic nuclear weapons (e.g. based on the above-mentioned proposal not to deploy such weapons) or to prohibit nuclear-armed cruise missiles (e.g. drawing on the verification experience of the INF Treaty).[62] Nuclear disarmament in North Korea might also be within reach, provided that credible security guarantees can be offered in return.[63]

There is general agreement that verifying warhead dismantlement is technically challenging, which can prevent further-reaching disarmament measures. This section has described a number of ongoing initiatives and proposals that seek to address this problem. While technical verification solutions are meant to increase trust, some degree of trust is also needed to allow for collaborative verification.[64] Moreover, the CTR experience demonstrates that transparency and extensive cooperation in other aspects of the process can generate sufficient confidence in disarmament even without verifying the actual dismantlement of warheads.[65]

While technical verification solutions are meant to increase trust, some degree of trust is also needed to allow for collaborative verification

While arms control treaties have historically been based on bilateral verification, the IAEA is a unique international authority with long-standing non-proliferation verification experience. Thus, it is likely to be an important actor in future disarmament efforts. It could play a major role in the proposed fissile material (cut-off) treaty, the negotiation of which would represent a significant and long-overdue step towards multilateral disarmament,

[61] International Atomic Energy Agency (IAEA), 'Emerging technologies workshop, trends and implications for safeguards', 13–16 Feb. 2017; Federation of American Scientists, 'Monitoring and verification in the digital age: seven recommendations for improving the process', Sep. 2017; and Boulanin, V. (ed.) *AI and Nuclear Weapons, How Recent Advances of AI Could Impact Strategic Stability: Euro-Atlantic Perspectives* (SIPRI: Stockholm, forthcoming 2019), p. 114.

[62] See the proposal by Sweden and Switzerland, United Nations, General Assembly, Open-ended Working Group taking forward multilateral nuclear disarmament negotiations, A/AC.286/WP.39, 10 May 2016; and Weber, A., 'Nuclear-armed cruise missiles should be banned', Asia Pacific Leadership Network for Nuclear Non-Proliferation and Disarmament/TODA, Peace Institute Policy Brief no. 12, May 2018.

[63] Carlson, J., 'Denuclearizing North Korea: The case for a pragmatic approach to nuclear safeguards and verification', 38 North Special Report, Jan. 2019.

[64] See also Bowen, W. Q. et al., *Trust in Nuclear Disarmament Verification* (Palgrave Macmillan: Cham, 2018).

[65] See also Bowen et al. (note 64).

alongside the ratification of the CTBT. The next section of this paper explains how the IAEA could also help ensure the irreversibility of disarmament when more nuclear-armed states are ready to give up their weapons.

III. Assessing verification challenges related to the Treaty on the Prohibition of Nuclear Weapons

The negotiation of the TPNW and the growing abolitionist momentum in recent years have inspired fresh thinking on how existing verification solutions could ultimately be combined into a coherent framework to facilitate the elimination of nuclear weapons. Drawing on such analysis, as well as previous ideas expressed mainly in connection with the 2007 Model Nuclear Weapons Convention (NWC), this section explores the basic institutional and technical requirements for establishing a global nuclear disarmament verification regime. The discussion can provide guidance on how to strengthen the TPNW's verification provisions, which have been widely criticized for their lack of specificity.[66]

However, much of the controversy surrounding the TPNW goes beyond verification. On the one hand, scepticism about the treaty is rooted in more general reservations about a nuclear weapon-free world. In such a world, former nuclear-armed states would submit to an intrusive verification regime, trusting both each other and the regime's ability to detect cheating, and a relevant international body to enforce compliance—a prospect that many regard as a pipe dream. On the other hand, proponents of the TPNW tend to view the treaty as primarily a tool with which to enforce the stigma surrounding nuclear weapons, and thereby to increase political pressure to disarm; they might not prioritize verification, either.

Both critics and supporters of the TPNW might therefore agree that the path towards complete disarmament is not a straight line, but rather a patchwork of different regimes based on distinct legal frameworks or arrangements negotiated separately over time. Yet since individual nuclear-armed states might choose to join the TPNW in the short or medium term, the treaty needs a verification regime. Even if no nuclear-armed state will ever join the TPNW, envisioning a verification regime for the treaty is useful for promoting more holistic thinking on nuclear disarmament verification, which will be needed if progress on disarmament is made in the future.

TPNW verification provisions

The TPNW, which was negotiated in order to strengthen the NPT's disarmament pillar, is the first legally binding agreement to prohibit the development, deployment, possession, use and threat of use of nuclear weapons. It also bans the stationing of nuclear weapons on states parties' territory, as well as the assistance, encouragement or inducement of any activity prohibited by the treaty. As of April 2019, the TPNW had been signed

[66] See e.g. Ford, C., 'The Treaty on the Prohibition of Nuclear Weapons: A well-intentioned mistake', Remarks at the University of Iceland, Reykjavik, 30 Oct. 2018.

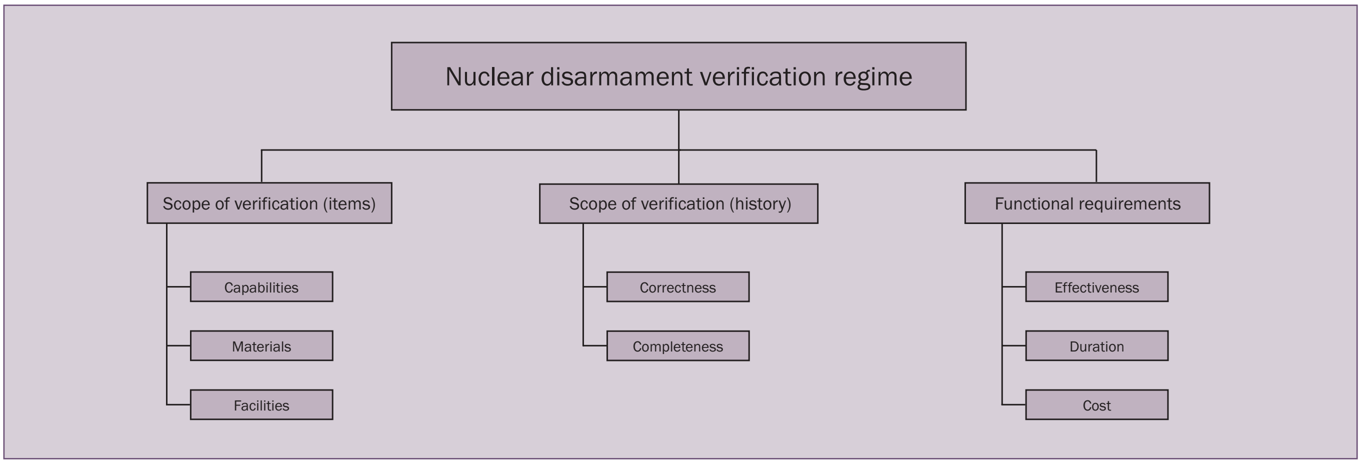

Figure 1. The elements of a nuclear disarmament verification regime

Credit: Fedchenko, V., Communication with authors, 12 Nov. 2018.

by 70 states and ratified by 23. It will enter into force 90 days after 50 states have either ratified or acceded to it.[67]

Although the TPNW does not specify the details of a new verification regime, it highlights the need to develop such a regime when nuclear-armed states are ready to engage in the discussion. Instead of a single treaty outlining a complex verification system, the TPNW negotiators opted for a multi-stage process, in which a principal treaty outlining objectives and commitments is later complemented by a follow-on agreement or agreements on specific verification solutions.[68]

The treaty's verification provisions set general guidelines for disarmament, which can take place either before or after a nuclear-armed state joins the TPNW. Article 4.1 stipulates that a state party that joins the treaty after dismantling its nuclear weapons 'shall cooperate with the competent international authority . . . for the purpose of verifying the irreversible elimination of its nuclear-weapon programme'.[69] Article 4.2 applies to countries that wish to join before they disarm. Such states parties 'shall immediately remove [nuclear weapons] from operational status, and destroy them as soon as possible . . . in accordance with a legally binding, time-bound plan for the verified and irreversible elimination of that State Party's nuclear-weapon programme, including the elimination or irreversible conversion of all nuclear-weapons-related facilities'.[70]

In both cases, (former) nuclear-armed states must 'conclude a safeguards agreement with the [IAEA] sufficient to provide credible assurance of the non-diversion of declared nuclear material from peaceful nuclear activities and of the absence of undeclared nuclear material or activities in that State Party as a whole'.[71] While this implies a high safeguards standard, the TPNW

[67] The TPNW has been ratified by Austria, the Cook Islands, Costa Rica, Cuba, El Salvador, Gambia, Guyana, the Holy See, Mexico, New Zealand, Nicaragua, Palau, Palestine, Panama, Samoa, San Marino, Saint Lucia, South Africa, Thailand, Uruguay, Vanuatu, Venezuela and Viet Nam.

[68] For a discussion of the distinction between the two kinds of treaties, see Carlson, J., 'Can a fissile material cut-off treaty be effectively verified?' *Arms Control Today*, 1 Jan. 2005.

[69] Treaty on the Prohibition of Nuclear Weapons (TPNW), Article 4.1, opened for signature on 20 Sep. 2017, not in force.

[70] TPNW (note 69), Article 4.2.

[71] TPNW (note 69), Articles 4.1 and 4.3.

does not specify such a standard, instead leaving the issue to be determined on a case-by-case basis at a time when nuclear-armed states decide to join the treaty.[72] Non-nuclear weapon states are expected to maintain their existing non-proliferation safeguards agreements with the IAEA. At a minimum, this means a CSA (INFCIRC/153)—'without prejudice to any additional relevant instruments'.[73] It also means that countries that have already accepted a higher standard, notably the Model Additional Protocol, are not allowed to downgrade their safeguards obligations when joining the TPNW.

Envisioning a comprehensive nuclear disarmament verification regime

The TPNW leaves crucial questions regarding the scope of prohibited activities, materials and facilities, as well as the functional requirements for verification, largely unaddressed. The remainder of the discussion explores those questions. It starts from the assumption that, in principle, the process of verifying nuclear disarmament can be expected to follow a similar model to existing IAEA safeguards: after the disarming state declares relevant items and activities, the designated verification authority conducts analysis, inspections and monitoring to ensure the correctness and completeness of the declaration (see figure 1). However, the creation and maintenance of a nuclear weapon-free world would constitute an unprecedented verification challenge requiring new institutions and significant improvements to existing safeguards practices, which have until now focused on non-proliferation.

Institutional choices

It is not surprising that the TPNW assigns the IAEA a central role in maintaining a nuclear weapon-free world. The agency has robust experience in monitoring and inspections, and would therefore be capable of performing much of the work required to prevent former nuclear-armed states from rearming. However, the IAEA has no experience in dismantling nuclear weapon capabilities—nor does its current mandate allow it to participate in such activities.

Although safeguards under the TPNW would be similar to existing non-proliferation safeguards, they would require a significant expansion of the IAEA's verification activities and responsibilities, as well as a re-evaluation of its current NPT-based mission. To verify the TPNW, IAEA safeguards would need to 'cover a considerably higher amount of material and a larger number of facilities than today, including facilities that produce nuclear materials, handle or fabricate nuclear components, or transform components back into fissile materials; fabricate fissile materials into fuel; and assemble/disassemble

The IAEA has no experience in dismantling nuclear weapon capabilities—nor does its current mandate allow it to participate in such activities

[72] See Joyner, D., 'Safeguards provisions in the Treaty on the Prohibition of Nuclear Weapons', *Arms Control Law*, 11 Apr. 2018.

[73] TPNW (note 69), Article 3.2.

components into warheads'.[74] The agency's current safeguards system—which allows for significant variation among the verification agreements of different countries—would also need to be reformed (see the subsection on functional requirements below).

The IAEA's inability to engage in any activities directly related to nuclear weapons suggests the need for a new institution that would oversee the sensitive process of dismantling nuclear warheads, as well as the destruction or conversion of nuclear weapon-related infrastructure.[75] This is essentially why the TPNW refers to an unidentified international authority or authorities, which would be responsible for verifying the elimination of existing arsenals.

Former IAEA inspector Thomas Shea has proposed that this new authority be called the International Nuclear Disarmament Agency and be given five missions: (*a*) encouraging disarmament, (*b*) verifying each disarmament step, (*c*) eliminating mission-critical facilities, (*d*) verifying non-explosive military uses of weapon-usable materials, and (*e*) estimating the historical production or acquisition of fissile material and its disposition.[76] Similar proposals were also made prior to the negotiation of the TPNW.[77] For example, the Model NWC envisaged that an international agency responsible for nuclear disarmament verification would receive support from a global monitoring system and a central registry, to which states parties would submit their declarations, and which would in turn monitor warheads.[78] The idea can be seen to partly derive from the 1993 proposal by the German Foreign Minister, Klaus Kinkel, to establish a UN-based nuclear weapon register.[79] Building on these ideas, a more recent proposal for an International Monitoring System for Nuclear Disarmament and Nonproliferation Verification would unite different verification mechanisms and technologies—including information sharing based on NTM, commercial satellites and civil society reporting—to support the objectives of both the TPNW and the NPT.[80]

Of course, future progress on disarmament—which is likely to consist of several distinct steps—might not correspond to the above proposals. As demonstrated by the history of arms control, bilateral treaties among adversaries may not necessarily require the involvement of an international verification authority. However, some nuclear-armed states might prefer a more centralized system, especially as stockpiles of nuclear weapons approach zero.

[74] Scheffran, J., 'Verification and security of transformation to a nuclear-weapon-free world: The framework of the Treaty on the Prohibition of Nuclear Weapons', *Global Change, Peace & Security*, vol. 30, no. 2 (2018), pp. 143–62.

[75] Shea, T., *Verifying Nuclear Disarmament* (Routledge: New York, 2018), pp. 9–12.

[76] Shea (note 75), pp. 9–10.

[77] See Paine, C. E., Cochran, T. B. and Norris, R. S., 'International arrangements for the transition to a nuclear weapon free world', Background Papers, Canberra Commission on the Elimination of Nuclear Weapons, Department of Foreign Affairs, Commonwealth of Australia, Aug. 1996, pp. 141–55.

[78] United Nations, General Assembly, Letter dated 17 Dec. 2007 from the Permanent Representatives of Costa Rica and Malaysia to the United Nations addressed to the Secretary-General, 17 Jan. 2008.

[79] Schaper, A., 'Verifying nuclear arms control and disarmament', ed. T. Findlay, *Verification Yearbook* (VERTIC: London, 2000).

[80] Patton, T., 'An international monitoring system for verification to support both the Treaty on the Prohibition of Nuclear Weapons and the Nonproliferation Treaty', *Global Change, Peace & Security*, vol. 30, no. 2 (2018), pp. 187–207.

The scope of verification

The TPNW's scope of verification would include capabilities (i.e. warheads and delivery vehicles), nuclear materials and all relevant facilities. The verification authority would need to verify the correctness and completeness of the disarming states' declarations, which would require access to past records on nuclear weapon production and stockpiles of fissile materials.

Capabilities. A comprehensive nuclear disarmament verification regime would need to be able to verify the dismantlement of nuclear warheads and their associated infrastructure and delivery vehicles. However, given the possibility of post facto disarmament verification provided in Article 4.1 of the treaty, the TPNW verification authority might not be directly involved in the dismantlement process. In that case, verification would be limited to materials and facilities, as well as documentation on nuclear weapon capabilities and the dismantlement process.

Ideally, even when a state joins the TPNW after disarmament, the dismantlement of nuclear weapons would be verified by other means, such as a separate treaty between, or among, adversaries. Since the perceived need for secrecy—a key obstacle for verifying warhead dismantlement—might be based on outdated notions, such a treaty might also provide an opportunity for nuclear-armed states to agree on relaxed classification requirements.[81] Indeed, by the time countries are jointly eliminating their arsenals, their perceived classification needs would likely be limited to non-proliferation considerations.

One challenge associated with disarmament verification would be its duration in individual countries, particularly those with the largest nuclear weapon arsenals. Verifying the destruction of Russian and US arsenals and numerous warhead storage sites could be made easier 'by consolidating and reconfiguring the nuclear weapons complexes into fewer sites, accessible to international inspectors', and 'well away from potential delivery systems'.[82] Yet the TPNW Article 4.2 demand for nuclear-armed states to 'immediately remove' their nuclear weapons from operational status may not be possible: this process could take several decades.[83] Nuclear-armed states wishing to join the TPNW may therefore prefer post facto disarmament verification—which, as highlighted in the South African case, has disadvantages over process verification. As suggested above, even in such a case, verification could be undertaken using a different legal framework.

The verification authority would need to verify the correctness and completeness of the disarming states' declarations, which would require access to past records on nuclear weapon production and stockpiles of fissile materials

In order to reduce the risk that know-how could be used to rebuild nuclear arsenals, support could be provided to help former weapon designers and experts find meaningful employment in the disarmament process or a related field, potentially drawing lessons from the CTR experience. This would also minimize the risk that sensitive information is inadvertently passed to personnel with no previous knowledge of nuclear weapon design.[84]

[81] Shea (note 75), p. 12.
[82] Scheffran (note 74).
[83] Shea (note 75), p. 5.
[84] See Scheffran, J., 'Verification and security in a nuclear-weapon free world: elements and framework of a nuclear weapons convention', UNIDIR, Disarmament Forum no. 3, Jan. 2010, p. 54.

Materials. One key element of a comprehensive nuclear disarmament verification regime would be accounting for all fissile materials, including HEU and plutonium originating from military programmes and materials in peaceful use.[85] The production of fissile material for nuclear weapons would also need to be capped. Thus, there would be a natural synergy between the TPNW verification regime and a fissile material (cut-off) treaty.[86] Regardless of which legal framework is eventually chosen to control fissile materials, the IAEA—or a new autonomous department within the agency—would be well suited to verify compliance with such controls.[87] Past work on the Trilateral Initiative could enhance the agency's ability to verify stocks of weapon-origin fissile material.

Industrial and medical processes involving dual-use materials would require monitoring, and the past production of fissile materials would need to be scrutinized: 'although it might be virtually impossible for any nuclear-weapon state to give a complete and accurate account, the documentation of past production must begin as early as possible to make sure that discrepancies are not strategically significant and potentially destabilizing'.[88] In addition to HEU and plutonium, other critical materials such as tritium might also need to be prohibited or controlled (see section II above). Naturally, the task of ensuring that nuclear materials are not diverted to military use would be made easier if more countries minimized their civilian use of HEU and plutonium, or substituted nuclear power with renewable energy sources.[89]

Facilities. In addition to IAEA safeguards on civilian nuclear facilities, comprehensive nuclear disarmament would require the elimination or conversion of all nuclear weapon-related facilities, including infrastructure designed for HEU enrichment, plutonium production, and nuclear weapon research, development, production, maintenance and testing.[90] Verifying such measures could be jointly conducted by the disarmament authority and the IAEA, with the former certifying 'that a given facility had in fact been used for the declared nuclear weapon purposes', and the latter verifying 'that it is no longer being used for any nuclear weapon purpose'.[91] However, as highlighted above, these duties would require an expansion of the IAEA's mission and capabilities.[92] The crucial question of whether inspections would be limited to declared facilities, or whether the TPNW would also allow for more intrusive inspections, is discussed in more detail below.

Functional requirements

The creation and maintenance of a nuclear weapon-free world would require a rigorous and effective verification regime. The low tolerance of uncertainty in such a world highlights the need for maximum effectiveness in the detection of undeclared materials and facilities. Since absolute certainty in detecting non-compliance might not be possible, the designers of the

[85] Shea (note 75), p. 3.
[86] United Nations Institute for Disarmament Research (UNIDIR), 'Nuclear disarmament verification: survey of verification mechanisms', 2016, p. 8.
[87] Kile and Kelley (note 48).
[88] Scheffran (note 84), p. 54.
[89] See Scheffran (note 84), p. 56.
[90] Shea (note 75), p. 58.
[91] Shea (note 75), p. 14.
[92] Kelley (note 32).

TPNW verification regime should focus on setting 'the threshold . . . low enough to make the significance of undetected breaches negligible'.[93] This means striking the right balance among the functional requirements of effectiveness, duration and cost of verification.

The current NPT-based IAEA verification criteria—particularly what constitutes 'significant quantity', 'detection time' and 'detection probability'—would need to be adjusted for the purposes of the TPNW. The need for timely detection would be particularly heightened, given that the former nuclear weapon states' previous experience in weaponization would reduce the time needed to turn fissile material into a nuclear weapon.

As suggested above, the current non-proliferation safeguards system, which applies different verification requirements in different countries, would hardly be sufficient to sustain a nuclear weapon-free world. At a minimum, universal acceptance of the IAEA Model Additional Protocol, or some higher future verification standard, would probably be necessary to deter and detect potential violations.[94] Some have argued that challenge inspections would also be necessary to verify the TPNW.[95] While this might be the case, care should be taken to prevent the politicization of such a tool—notably by subjecting any allegations of non-compliance themselves to rigorous examination.[96]

Efforts should also be made to minimize the duration of the verified elimination process. During this critical period the disarming state would be subject to intrusive inspections, which might become subject to domestic controversy over time. Further, a lengthy process might feed uncertainty among adversaries with reciprocal disarmament commitments.

The need for high performance in terms of effectiveness and speed, together with an extensive institutional framework and scope of verification, implies that a comprehensive nuclear disarmament verification regime would be expensive. Nevertheless, it would probably cost more to maintain and modernize current nuclear weapons arsenals. The conversion of weapon-grade nuclear material could also be made economically profitable, as demonstrated by the Megatons to Megawatts programme. When making decisions about who finances the verification regime, one should try to prevent the risk of politicization. Related to this point, Shea suggests that the section of the TPNW which states that the costs of nuclear disarmament verification 'should be borne by the States Parties to which they apply' be reconsidered, as this could give the disarming state excessive control over the process.[97]

In the future, the burden of verification might be partly shared with civil society, whose role in societal verification is believed to increase with progress on disarmament.

In the future, the burden of verification might be partly shared with civil society, whose role in societal verification is believed to increase with

[93] Goldblat, J. 'How to deter violations of disarmament and non-proliferation agreements', Assessing Compliance with Arms Control Treaties, International Group on Global Security, Sep. 2007, pp. 54–62.

[94] See Nystuen, G., Egeland, K and Hugo, T. G., 'The TPNW: setting the record straight', Norwegian Academy of International Law, Oct. 2018.

[95] Scheffran (note 84); and Schaper (note 79).

[96] Kelley (note 32).

[97] Shea (note 75), p. 6.

progress on disarmament.[98] It has also been argued that internalizing the disarmament norm within democratic cultures might increase the likelihood that whistle-blowers will unveil clandestine activities proscribed by the TPNW.[99]

While no single verification measure alone can provide complete certainty, the combination of different solutions—together with the general increase in international trust—could 'improve verification to such an extent as to constitute "sufficient criteria" for effective verifiability'.[100]

IV. Conclusions

Regardless of divergent views on the desired pace of disarmament and the likelihood of achieving the political conditions for the complete abolition of nuclear weapons, there is a broad consensus on the need to develop nuclear disarmament verification solutions. While much work remains to be done, the international community already has considerable experience in many key areas of verification.

Indeed, existing solutions might be sufficient to enable several near-term disarmament steps, and to lay the foundations for a comprehensive nuclear disarmament verification regime. However, more technical work is clearly needed to achieve all the preconditions for a nuclear weapon-free world, particularly on verifying the dismantlement of nuclear weapons. The political challenges seem even more formidable, making even modest steps towards disarmament seem out of reach in the current political environment. However, this might change with time. A more favourable political context, with increased levels of cooperation and trust, could also reduce the extent to which technical challenges are perceived as obstacles to warhead dismantlement.

There are many incremental steps between near-term gradual disarmament and the end goal of total abolition. These steps range from increasingly ambitious arms control and disarmament agreements to single countries unilaterally giving up their nuclear weapons, or doing so as part of reciprocal agreements with adversaries. All such steps will require verification regimes tailored to specific objectives and commitments. Ultimately, those separate regimes could be brought together under a single umbrella such as the TPNW or a similar legal framework. However, the need for such a regime would arise much sooner if individual nuclear-armed states decided to join the TPNW.

Even in the absence of new disarmament treaties, the operationalization of disarmament verification can begin at a conceptual and discursive level by promoting a more policy-oriented approach to disarmament verification in four ways. First, multilateral conferences on disarmament verification could be convened within the UN framework, involving both nuclear and

[98] Societal verification refers to the engagement of 'a self-selected sector of the public in verification', involving 'information that is either generated by or is made openly accessible to the general public, the scientific community, the private sector, and NGOs'—for example by commercial satellites. Stubbs, C. W. and Drell, S. D., 'Public domain treaty compliance verification in the digital age', *IEEE Technology and Society Magazine*, vol. 32, no. 4 (winter 2013), pp. 57–64.

[99] Schaper (note 79).

[100] Schaper (note 79).

non-nuclear states. Although discussing TPNW verification might seem premature to many countries, the initial focus could be on gradual, realistic disarmament steps for the short to medium term. In this context, nuclear-armed states could also be encouraged to report the history of their nuclear weapons production, including fissile material stocks.

Second, given that the most important disarmament steps are likely to be taken as part of agreements between or among nuclear-armed adversaries, another approach would be to hold discussions on disarmament verification among these countries—for example, in the format of the P5 process.[101]

Third, even if political will is lacking at the government level, the discussion could be invigorated through the establishment of a worldwide network or association of nuclear arms control and disarmament verification experts, including former US and Russian experts involved in previous arms control and disarmament efforts. In order to help draw lessons on verification and trust building from such efforts, it might also be useful to declassify related documents.

Fourth and finally, more effective coordination and information sharing among the IAEA Department of Safeguards, the CTBTO, the proposed fissile material (cut-off) treaty and other relevant verification frameworks could help to pave the way for the creation of a comprehensive nuclear disarmament verification regime.

[101] See Dunn, L. A., 'Redefining the US agenda for nuclear disarmament: Analysis and reflections', Livermore Papers on Global Security no. 1, Center for Global Security Research, Lawrence Livermore National Laboratory, Oct. 2016, p. 72. The P5 process refers to meetings among the five permanent members of the UN Security Council—China, France, Russia, the UK and the USA—which are also the five recognized nuclear weapon states under the NPT, to discuss progress towards meeting their disarmament commitments under the treaty. The process began in 2009.

Abbreviations

CSA	Comprehensive Safeguards Agreement
CTBT	Comprehensive Test Ban Treaty
CTBTO	Comprehensive Test Ban Treaty Organization
CTR	Cooperative Threat Reduction
HEU	Highly enriched uranium
IAEA	International Atomic Energy Agency
ICBM	Intercontinental ballistic missile
IMS	International Monitoring System
INF	Intermediate-Range Nuclear Forces Treaty (1987)
IPNDV	International Partnership for Nuclear Disarmament Verification
LEU	Low-enriched uranium
MIRVs	Multiple independently targetable re-entry vehicles
New START	New Strategic Arms Reduction Treaty (2010)
NPT	Non-Proliferation Treaty (1968)
NTM	National technical means
NWC	Model Nuclear Weapons Convention (2007)
PMDA	Plutonium Management and Disposition Agreement (2010)
SALT I	Strategic Arms Limitations Treaty (1972)
SALT II	Strategic Arms Limitations Treaty (1979)
SLBMs	Sea-launched ballistic missiles
SORT	Strategic Offensive Reductions Treaty (2002)
START I	Treaty on the Reduction and Limitation of Strategic Offensive Arms (1991)
START II	Treaty on Further Reduction and Limitation of Strategic Offensive Arms (1993)
TPNW	Treaty on the Prohibition of Nuclear Weapons (2017)
TTBT	Threshold Test-Ban Treaty (1974)
UNIDIR	United Nations Institute for Disarmament Research
UNODA	United Nations Office for Disarmament Affairs
WMD	Weapon of mass destruction

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OPERATIONALIZING NUCLEAR DISARMAMENT VERIFICATION

TYTTI ERÄSTÖ, UGNĖ KOMŽAITĖ, PETR TOPYCHKANOV

CONTENTS

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