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Negotiating Nuclear Verification: Arms Control, Disarmament and Non-Proliferation

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About the VCDNP

The Vienna Center for Disarmament and Non-Proliferation (VCDNP) promotes international peace and security by conducting research, facilitating dialogue, and building capacity on nuclear non-proliferation and disarmament.

The VCDNP is an international non-governmental organisation, established in 2010 by the Federal Ministry for European and International Affairs of Austria and the James Martin Center for Nonproliferation Studies at the Middlebury Institute of International Studies at Monterey.

Our research and analysis provide policy recommendations for decision-makers. We host public events and facilitate constructive, results-oriented dialogue among governments, multilateral institutions, and civil society. Through in-person courses and online resources on nuclear non-proliferation and disarmament, we train diplomats and practitioners working in Vienna and around the world.

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The first session of the UN Atomic Energy Commission met in New York on June 14, 1946. Credit: United Nations

Introduction

As of April 2026, nuclear arms control, disarmament and non-proliferation face significant and unprecedented challenges. The last nuclear arms control treaty between the two largest nuclear powers has expired with nothing to replace it. As many nuclear-armed States actively modernise their arsenals, raise their stated ceilings on nuclear arms and develop new kinds of nuclear weapons, meaningful steps towards nuclear disarmament have frozen and, in some cases, been walked back. Even non-proliferation is in dire straits, as the global community seems to be able neither to agree nor to agree to disagree on current regional and global challenges.

Verification is a key tool for ensuring the effectiveness of arms control, disarmament and non-proliferation. As progress stalls in all three fields, there is a risk that the capacity of future negotiators will be diminished when the time comes to negotiate future agreements. While verification approaches and concepts across arms control, disarmament and non-proliferation may overlap, there are also important distinctions between them. Any successful verification systems, however, require: (1) technical expertise to ensure that verification is feasible, effective and acceptable to all parties; and (2) political and diplomatic expertise to negotiate and implement them.

Against this backdrop, the Vienna Center for Disarmament and Non-Proliferation (VCDNP) initiated a project on negotiating nuclear verification. The first phase of the project was to hold a workshop for diplomats, military experts and policymakers from national capitals, each of which could play a role in future nuclear negotiations. The VCDNP gathered 25 individuals from all United Nations regional groupings, including both nuclear- and non-nuclear-weapon States under the Treaty on the Non-Proliferation of Nuclear Weapons, for three days of intensive discussion, interactive activities and a tabletop exercise (TTX) simulating the negotiation of verification approaches. The TTX focused the verification of nuclear warheads themselves.

One of the key objectives of the workshop was to strengthen capacity of States to think effectively about the political, technical, legal and institutional aspects of nuclear verification. These include, among other issues:

- how negotiators balance confidence in verification measures with sensitivities surrounding intrusiveness;
- how a verification system can be implemented effectively without endangering proliferation-sensitive or classified information;
- how different actors define the scope and focus of verification, including both the context of negotiations between nuclear-armed States and between nuclear- and non-nuclear-armed States;
- what is important for negotiators to understand about verification technologies; and
- how the human factor can affect the course of nuclear negotiations, including the importance of individual relationships and language.

The second phase of the project included an assessment of the workshop and its outcomes as well as input from former nuclear negotiators to identify key lessons for potential future negotiators and provide additional substantive contributions to this report. The report combines a summary of the lessons learned from this project as well as those from past negotiations on nuclear verification with a set of recommendations and conclusions for further action in advancing nuclear arms control, disarmament and non-proliferation verification.

United States President Dwight D. Eisenhower delivering his "Atoms for Peace" speech to the United Nations General Assembly in 1953. Credit: United Nations / New York

How We Got Here: An Abridged History of the Verification of Arms Control, Disarmament and Non-Proliferation

The search for effective verification in the nuclear field is almost as old as the nuclear field itself. This section offers an abridged history of that search. While it does not detail the contours of every nuclear agreement to date, it lends perspective as to how negotiators thought about the verification measures necessary to inspire confidence that parties adhered to an agreement and the political, legal, technical and institutional challenges to feasibly implementing those measures.

In November 1945, following the first and only use of nuclear weapons in war, Canada, the United Kingdom and the United States agreed on a joint declaration on atomic energy, which called for "effective enforceable safeguards against" the use of atomic energy "for destructive purposes", though without specific proposals for verification.[1] The first resolution of the United Nations General Assembly (UNGA) also recognised the challenges associated with atomic energy for destructive purposes and established the United Nations Atomic Energy Commission (UNAEC), which was meant to make proposals, inter alia, "for effective safeguards by way of inspection and other means to protect complying States against the hazards of violations and evasions."[2]

1 Joint Declaration on Atomic Energy, 1945. Available at: https://www.trumanlibrary.gov/library/public-papers/191/presidents-news-conference-following-signing-joint-declaration-atomic.

2 United Nations General Assembly, Establishment of a Commission to Deal with the Problems Raised by the Discovery of Atomic Energy, A/RES/1(I), 24 January 1946. Available at: https://docs.un.org/en/a/res/1%28i%29.

It was in this resolution that inspections were first formally proposed as a form of verification, but the scope and intrusiveness of those inspections were undefined.

In March 1946, a board of consultants in the United States presented a Report on the International Control of Atomic Energy, better known as the Acheson-Lilienthal Report. One of the contentions in the report was that inspections would play an important role in any control system.[3] At the same time, the report cautioned that such measures alone would be insufficient, noting that “a system of inspection superimposed on an otherwise uncontrolled exploitation of atomic energy by national governments will not be an adequate safeguard.”[4]

In June 1946, the United States presented the so-called Baruch Plan to the UNAEC, largely driven by the ideas described in the Acheson-Lilienthal Report.[5] The Baruch Plan retained the verification focus of “by means of inspections and other means” from the UNGA resolution from the previous year, but did not elaborate on the operationalisation of those means. The UNAEC continued to debate aspects of nuclear verification, such as where inspectors could go and what measurements they could take, until 1949, when the Soviet Union became the second nuclear weapons power, at which point the UNAEC ceased to function until it was formally dissolved in 1952.[6]

The Foundations of Non-Proliferation Verification

In 1953, the U.S. President Dwight D. Eisenhower delivered his famous “Atoms for Peace” speech to the UNGA, in which he called for the founding of an organisation that would become the International Atomic Energy Agency (IAEA), established in 1957.[7] The IAEA and its Member States developed a system of nuclear safeguards for non-proliferation purposes (rather than for arms control or disarmament) that relied on inspections conducted to verify State declarations of nuclear material and facilities subject to nuclear safeguards agreements and was supported by sampling and measurements of material subject to safeguards.[8]

The developments described thus far formed the foundations of non-proliferation verification as it is understood today. At the same time, in the late 1950s and early 1960s, the United States and the Soviet Union were already considering the challenges that bilateral nuclear negotiations would come to address.[9] The first such agreement was the Limited Nuclear Test Ban Treaty (LTBT), also called the Partial Nuclear Test Ban Treaty, which entered into force in 1963. Initially, the United States and the Soviet Union discussed a comprehensive ban on nuclear testing, but could not agree on the number of on-site inspections.[10] Thus, the LTBT banned nuclear testing in the atmosphere, outer space and underwater, and was verified only through so-called national technical means (NTMs), i.e. derived from intelligence activities, such as radionuclide sensors and satellite imagery analysis to detect prohibited nuclear tests.[11]

3 United States Department of State, Report on the International Control of Atomic Energy (Acheson-Lilienthal Report), 16 March 1946. Available at: https://fissilematerials.org/library/ach46.pdf.

4 Ibid.

5 The Baruch Plan, 1946. Available at: https://www.atomicarchive.com/resources/documents/postwar/baruch-plan.html.

6 United Nations General Assembly, Regulation, Limitation and Balanced Reduction of All Armed Forces and All Armaments; International Control of Atomic Energy, A/RES/502 (VI), 11 January 1952. Available at: https://docs.un.org/en/A/RES/502%28vi%29.

7 Dwight D. Eisenhower, Atoms for Peace Address to the United Nations General Assembly, 8 December 1953. Available at: https://www.iaea.org/about/history/atoms-for-peace-speech.

8 International Atomic Energy Agency, The Agency’s Safeguards System (1961), INFCIRC/26; The Agency's Safeguards System (1965), INFCIRC/66 and revisions. Available at: https://www.iaea.org/publications/documents/infcircs/agencys-safeguards;%20https://www.iaea.org/publications/documents/infcircs/agencys-safeguards-system-1965.

9 Dr. Siegfried Hecker, “Doomed to Cooperate: How American and Russian Scientists Joined Forces to Avert Some of the Greatest Post-Cold War Nuclear Dangers”, Bathtub Row Press, 29 June 2016.

10 Arms Control Association, Nuclear Testing and Comprehensive Test Ban Treaty (CTBT) Timeline. Available at: https://www.armscontrol.org/factsheets/nuclear-testing-and-comprehensive-test-ban-treaty-ctbt-timeline.

11 United States Department of State, Limited Test Ban Treaty. Available at: https://2009-2017.state.gov/t/avc/trty/199116.htm.

In 1968, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was opened for signature. Upon its entry into force in 1970, the NPT required all non-nuclear-weapon States Parties to the Treaty to conclude safeguards agreements with the IAEA on all source or special fissionable material in all peaceful nuclear activities with the State's territory, under its jurisdiction or carried out under its control anywhere – what today are known as comprehensive safeguards agreements (CSAs).[12] Following the entry into force of the NPT, the IAEA's Board of Governors established a special open-ended committee of the Board of Governors to negotiate the structure and content of the requisite safeguards agreements, resulting in the document INFCIRC/153. In addition to inspections and sampling to check against States' declarations, CSAs also included explicit provisions for containment and surveillance measures such as seals and cameras.[13]

The Dawn of Nuclear Arms Control

In 1969, the United States and the Soviet Union began the Strategic Arms Limitation Talks (SALT), which produced two agreements by May 1972.[14] One was the Anti-Ballistic Missile (ABM) Treaty.[15] Under the ABM Treaty, the United States and the Soviet Union agreed, inter alia, to limit themselves to two ground-based missile defence sites of up to 100 missile interceptors each. Later, the two sides signed a protocol to the Treaty that limited each side to one such site. Verification of the ABM Treaty was conducted purely through NTMs. The second agreement resulting from the talks was an interim agreement referred to as SALT I, by which the two sides agreed, inter alia, not to begin construction of new land-based intercontinental ballistic missile (ICBM) launchers following entry into force of the agreement.[16] SALT I was also verified exclusively through NTMs. Each agreement had a consultative mechanism to discuss questions of compliance.

As SALT I was merely an interim agreement, the United States and the Soviet Union began already in 1972 negotiating what became known as SALT II, which entered into force in 1979.[17] Under the terms of the agreement, each side committed, inter alia, to: an aggregate limit of 1,320 total launchers of ballistic missiles with multiple independently targetable re-entry vehicles (MIRVs) and heavy bombers with long-range cruise missiles; an aggregate limit of 1,200 total launchers for "MIRVed" ballistic missiles; an aggregate limit of 820 launchers for "MIRVed" ICBMs; and an initial aggregate limit of 2,400 "strategic nuclear delivery vehicles", to be lowered to 2,250 by the end of 1981. Though the treaty was never ratified due to the United States' political objections to the Soviet invasion of Afghanistan, both sides agreed to abide by the terms of the agreement as long as the other did also.[18] As with previous nuclear arms control agreements, SALT II was to be verified exclusively through NTMs. This was, however, not to be; the agreement fell apart in the mid-1980s as relations between the two sides soured.

On the heels of SALT II's demise, United States and Soviet Union leadership met in Reykjavik, Iceland.[19] President Reagan and General Secretary Gorbachev sought to limit the nuclear arms race between the two sides and agreed on principles for the Intermediate-Range Nuclear Forces Treaty or INF Treaty.[20] The INF Treaty entered into force in 1987 and committed each side to destroying all ground-launched ballistic missiles and cruise missile with a range between 500 and 5,500 kilometres along with their launchers.

12 International Atomic Energy Agency, 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, 1972. Available at: https://www.iaea.org/sites/default/files/publications/documents/infcircs/1972/infcirc153.pdf.

13 Ibid.

14 Arms Control Association, Strategic Arms Limitation Talks (SALT). Available at: https://www.armscontrol.org/treaties/strategic-arms-limitation-talks.

15 United States Department of State, Anti-Ballistic Missile Treaty. Available at: https://2009-2017.state.gov/t/avc/trty/101888.htm.

16 Interim Agreement on Offensive Arms (SALT I), 1972. Available at: https://treaties.un.org/doc/Publication/UNTS/Volume%20944/volume-944-I-13445-English.pdf.

17 United States Department of State, SALT II Treaty. Available at: https://2009-2017.state.gov/t/isn/5195.htm.

18 Arms Control Association, SALT II. Available at: https://www.armscontrol.org/treaties/strategic-arms-limitation-talks-ii.

19 Atomic Heritage Foundation, Reykjavik Summit. Available at: https://ahf.nuclearmuseum.org/ahf/history/reagan-and-gorbachev-reykjavik-summit/

20 United States Department of State, Intermediate-Range Nuclear Forces Treaty. Available at: https://2009-2017.state.gov/t/avc/trty/102360.htm.

Unlike previous agreements, the INF Treaty included a complex verification system which included on-site inspections of eliminated treaty-limited items (TLIs). This included managed access to all missile operating bases and missile support facilities named in a memorandum of understanding associated with the Treaty, as well as all elimination facilities. The INF Treaty also provided for the use of NTMs. As with previous treaties, there was a bilateral commission established to discuss compliance issues.

The INF Treaty collapsed in 2019 following accusations by each side of non-compliance that the commission was unable to resolve. One lesson from this experience is that States should prioritise the use of these consultative mechanisms to address compliance concerns at an early stage and, where possible, in a confidential setting. Experience suggests that once compliance disputes become public and politicised, they can harden into fixed policy positions, making resolution significantly more difficult. Effective use of technical and diplomatic channels to manage such concerns quietly can help preserve agreements and prevent escalation.

In 1991, as the Soviet Union was facing dissolution, the two sides signed the Strategic Arms Reduction Treaty or START I. In 1994, the Treaty entered into force.[21] START I limited each side, inter alia, to: 1,600 deployed ICBMs and associated launchers, submarine-launched ballistic missiles (SLBMs) and associated launchers, heavy bombers, and associated warheads and armaments; and 6,000 warheads in the aggregate for ICBMS, SLBMs and heavy bombers (with specified limits for each category).[22] Verification provisions included NTMs and on-site inspections, continuous monitoring activities and exhibitions as provided for in the detailed 74-page Inspection Protocol, which determined procedures, counting rules, initial declarations, perimeter monitoring for ICBM plants and other aspects.[23] START I entailed by far the most detailed verification regime to date.

In 1993, shortly after the Soviet Union was dissolved, the United States and the new Russian Federation signed START II as START I was still being implemented.[24] However, the implementation of START II was delayed due to issues with ratification in the United States and was finally abandoned in 2002.[25] Had START II entered into force, it would have further reduced the limits for deployed warheads on ICBMs, SLBMs and heavy bombers under START I. START II included verification provisions, including NTMs and on-site inspections, as codified in Protocols related to ICBMs, SLBMs and heavy bombers respectively.[26] Almost immediately following the 2002 withdrawal of the United States from the ABM Treaty and Russia's announcement that it would no longer be bound by START II commitments, the two sides concluded the Strategic Offensive Reductions Treaty (SORT).[27] In contrast to the very specific limitations on individual classes of weapons under START I and START II, SORT left up to the parties the composition of arsenals under the agreed limits of 1,700-2,200 aggregate strategic nuclear warheads and did not contain explicit verification provisions, though it was understood that SORT would use the measures available under START I.[28]

21 START I Treaty Text. Available at: https://media.nti.org/documents/start_1_treaty.pdf.

22 Arms Control Association, START I at a Glance. Available at: https://www.armscontrol.org/factsheets/start-i-glance.

23 United States Department of State, START I Inspection Protocol. Available at: https://2009-2017.state.gov/documents/organization/27364.pdf.

24 Arms Control Association, START II at a Glance. Available at: https://www.armscontrol.org/factsheets/start-ii-and-its-extension-protocol-glance.

25 Ibid.

26 United States Department of State, START II Treaty Text. Available at: https://2009-2017.state.gov/t/avc/trty/102887.htm.

27 Dr. Nikolai Sokov, "The Russian Nuclear Arms Control Agenda After SORT", Arms Control Association, 1 April 2003. Available at: https://www.armscontrol.org/act/2003-04/features/russian-nuclear-arms-control-agenda-after-sort.

28 United States Department of State, SORT Treaty. Available at: https://2009-2017.state.gov/t/isn/10527.htm.

Novel Challenges to and Opportunities for Nuclear Verification

As the United States and the newly formed Russian Federation continued negotiating on further arms reductions in the 1990s and early 2000s, non-proliferation verification faced novel verification challenges. The discovery of Iraq's clandestine nuclear weapons programme in 1991 demonstrated that the existing NPT safeguards system, which had been, as a practical matter, focussed principally on declared material in declared facilities, would benefit from additional tools to enhance the IAEA's legal authority to verify the absence of undeclared nuclear activities.[29] This prompted a concerted effort to strengthen safeguards, focussing in particular on expanding the Agency's access to information and its ability to build a more complete picture of a State's nuclear fuel cycle. The resulting strengthening process led to the approval by the IAEA's Board of Governors of the Model Additional Protocol in 1997.[30] The Model Additional Protocol included expanded reporting obligations covering nuclear fuel cycle activities more broadly, codified procedures for broader access to locations beyond declared facilities and simplified administrative procedures, such as multi-entry visas for inspectors.[31]

A different set of challenges emerged in the case of South Africa's voluntary dismantlement of its nuclear weapons programme, also in the 1990s. Here, the issue was not the identification of undeclared activities in an ongoing programme, but rather the need to establish confidence in the completeness of a State's declarations following disarmament.[32] In this context, the IAEA was granted extensive "any time, anywhere" access, enabling it to reconstruct past nuclear activities and verify that all weapons-related activities had been identified and discontinued. This experience underscored the importance of access to information and locations in enabling verification of completeness and highlighted how different verification objectives—verifying the correctness of States' declarations versus verifying the completeness of such declarations (i.e. the absence of undeclared activities) can require tailored approaches and levels of intrusiveness.

Around the same time, a series of United States-Russian initiatives in the 1990s and early 2000s sought to develop practical approaches to the verification of fissile material disposition.

The Megatons to Megawatts programme (1993-2003) established a bilateral transparency regime combining on-site monitoring, non-destructive measurements, documentation review and continuous monitoring systems to provide confidence that Russian weapons-grade highly enriched uranium was downblended and used as civil reactor fuel in the United States.[33] Verification relied on the aggregation of multiple data streams—ranging from chain-of-custody documentation to process monitoring—to establish continuity from weapons-grade material to final disposition.[34]

With this experience in the background, the Trilateral Initiative (1996-2002) between the United States, the Russian Federation and the IAEA developed legal and technical frameworks for placing excess weapons-grade fissile material under international verification by the IAEA.[35]

29 VCDNP, A Lexical History of the State-Level Concept and Issues for Today. Available at: https://vcdnp.org/a-lexical-history-of-the-state-level-concept-and-issues-for-today/

30 Noah Mayhew, "Reflecting on the Annexes to the Model Additional Protocol", VCDNP, 14 December 2020. Available at: https://vcdnp.org/reflecting-on-the-annexes-to-the-map/

31 International Atomic Energy Agency, Model Additional Protocol, INFCIRC/540 (Corrected), 1997. Available at: https://www.iaea.org/sites/default/files/infcirc540.pdf.

32 Noah Mayhew, Dr. Nikolai Sokov and Dr. Adam Bernstein, "The Balance of Confidence and Feasibility in Irreversible Nuclear Disarmament", VCDNP, 19 May 2025. Available at: https://vcdnp.org/confidence-feasibility-irreversible-disarmament/

33 Edward Mastal, Janie Benton, Joseph Glaser and Ed Rutkowski , "Implementation of the United States/Russian HEU Agreement: Current Status and Prospects ", Lawrence Livermore National Laboratory, 25 November 2003. Available at: https://www.osti.gov/servlets/purl/1393321.

34 Janie Benton, David Thomas, Joseph Glaser and David Dougherty, "U.S. Transparency Monitoring under the U.S./Russian HEU Purchase Agreement", Lawrence Livermore National Laboratory, 27 July 1999. Available at: https://www.osti.gov/servlets/purl/14539.

35 Laura Rockwood and Thomas Shea, "IAEA Verification of Fissile Material in Support of Nuclear Disarmament", Belfer Center for Science and International Affairs, 27 April 2015. Available at: https://www.belfercenter.org/publication/iaea-verification-fissile-material-support-nuclear-disarmament.

Its most notable contribution was the development of an attribute verification system with information barriers, enabling inspectors to confirm key characteristics of weapons-grade fissile material without accessing sensitive data.[36] Before the end of the Trilateral Initiative, however, the parties were only able to address potential approaches for plutonium.

The Plutonium Management and Disposition Agreement (PMDA) (2000-2016), another U.S.-Russian initiative, also envisaged a role for the IAEA in verifying the irreversible disposition of 34 metric tonnes of plutonium, including through material accountancy and inspection-based approaches, although detailed procedures were left to be developed.[37]

In practice, both the Trilateral Initiative and the PMDA encountered challenges. The Trilateral Initiative was ultimately constrained by a loss of political momentum, alongside unresolved questions relating to equipment authentication and what constituted irreversibility, while the PMDA faced persistent difficulties related to costs and disagreements over disposition methods.[38] Taken together, these efforts illustrate both the potential for increasingly sophisticated verification approaches and the extent to which their implementation depends on sustained political and technical alignment, as well as sustainable funding.

Alongside these developments, efforts to prohibit nuclear testing, first partially realised by the LTBT, culminated in the negotiation of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in 1996.[39] Where the LTBT had relied on the inherent detectability of atmospheric testing, the CTBT required a far more ambitious approach to verification in order to support a comprehensive prohibition. The Treaty established a globally distributed and continuously operating verification system, centred on an international network of seismic, hydroacoustic, infrasound and radionuclide monitoring stations, with data transmitted to an international data centre for analysis and dissemination to State Signatories.[40] This system was complemented by the provision for on-site inspections to clarify ambiguous events. Though much of the treaty's verification system operates today, the CTBT itself has yet to enter into force, thereby preventing on-site inspections from being implemented.

Nuclear Arms Control in the 21st Century

As non-proliferation verification continued to develop, so did bilateral nuclear arms control. In 2010, the United States and the Russian Federation signed the New Strategic Arms Reduction Treaty, or New START.[41] New START superseded SORT and re-established an explicit legally binding verification framework, following the more limited arrangements under SORT. Building on the verification provisions developed under START I, New START combined data exchanges, notifications and on-site inspections to provide transparency and confidence in compliance with agreed limits on deployed strategic offensive arms. These limits capped deployed strategic warheads at 1,550, while also placing constraints on deployed and non-deployed delivery systems. The Treaty introduced a streamlined inspection regime, simplified from START I, to support tracking and accountability over time. As with previous arms control treaties, New START established a bilateral commission to address implementation issues and clarify ambiguities.

36 Noah Mayhew, "Verification is Possible: Lessons From the Trilateral Initiative For Today", Institute of Nuclear Materials Management, 2021. Available at: https://resources.inmm.org/sites/default/files/2021-09/a115.pdf

37 United States Department of State, Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation. Available at: https://2009-2017.state.gov/documents/organization/213493.pdf.

38 Mark Holt and Mary Beth D. Nikitin, "Mixed-Oxide Fuel Fabrication Plant and Plutonium Disposition: Management and Policy Issues", Congressional Research Service, 14 December 2017. Available at: https://fas.org/sgp/crs/nuke/R43125.pdf.

39 Comprehensive Nuclear-Test-Ban Treaty Organization, The Treaty. Available at: https://www.ctbto.org/our-mission/the-treaty.

40 Noah Mayhew and Benedict Höfter, "Navigating the CTBTO: The Policy-Making Organs, Programmes, and Contributions to Science Diplomacy", VCDNP, 12 November 2024. Available at: https://vcdnp.org/navigating-the-ctbto/

41 United States Department of State, New START Treaty. Available at: https://2009-2017.state.gov/t/avc/newstart/c44126.htm.

The Drive Towards Nuclear Disarmament Verification

In parallel to these arms control and non-proliferation developments, efforts to advance nuclear disarmament verification gained momentum through a series of international initiatives aimed at addressing the technical and political challenges of verifying the dismantlement of nuclear weapons. The United Kingdom-Norway Initiative (2007–2015) represented one of the first efforts to explore how a nuclear-weapon State and a non-nuclear-weapon State could cooperate on such verification, focussing on practical procedures for warhead dismantlement while protecting sensitive information.[42]

At the same time, the International Partnership for Nuclear Disarmament Verification (IPNDV) was launched in 2014. The IPNDV brought together a broader group of nuclear weapon and non-nuclear weapon States to examine the technical and procedural challenges of verifying different stages of the nuclear weapons lifecycle, with particular attention to monitoring and inspection approaches.[43]

This work was followed by the Quad Nuclear Verification Partnership (2015–2019), involving the United Kingdom, the United States, Norway and Sweden, which further developed concepts and exercises related to verification of nuclear warhead dismantlement. This included challenges related to managed access and information barrier approaches.[44]

The Treaty on the Prohibition of Nuclear Weapons (TPNW), which was adopted in 2017 and entered into force in 2021, has introduced new considerations for nuclear disarmament verification, albeit without establishing a fully developed verification regime of its own.[45] The Treaty prohibits, inter alia, the development, possession and use of nuclear weapons, and envisages pathways for nuclear-armed States to join and eliminate their arsenals under international verification. Rather than prescribing detailed verification measures, the TPNW defers key questions, such as the designation of a competent international verification authority, to future negotiation and agreement among States Parties. While it is often assumed that the IAEA could fulfil such a role, this has not been formally determined. At the same time, the Treaty reinforces core verification principles, including irreversibility, transparency and verifiability, and reflects an expectation that existing safeguards and emerging disarmament verification practices could serve as a foundation for future arrangements. In this respect, the TPNW highlights both the continued importance of verification in disarmament and the extent to which its practical implementation remains contingent on further technical development and political agreement.

Most recently, in 2024, the United Nations General Assembly adopted a resolution initiating a process to establish a Group of Scientific and Technical Experts (GSTE) on nuclear disarmament verification, tasking the Secretary-General with seeking Member State views and outlining possible modalities for such a group.[46] The GSTE is expected to begin its work in 2027.

Taken together, these initiatives reflect a gradual shift toward collaborative, multilateral approaches to disarmament verification, with an emphasis on developing practical tools and procedures that can reconcile the need for confidence with the protection of sensitive information.

42 UK Government, UK-Norway Initiative. Available at: https://www.gov.uk/government/publications/uk-norway-initiative-on-nuclear-warhead-dismantlement-verification--2.

43 International Partnership for Nuclear Disarmament Verification. Available at: https://www.ipndv.org/

44 Quad Nuclear Verification Partnership. Available at: https://quad-nvp.info/.

45 Treaty on the Prohibition of Nuclear Weapons, 2017. Available at: https://ihl-databases.icrc.org/assets/treaties/640-TPNW-EN.pdf.

46 United Nations General Assembly, Group of Scientific and Technical Experts on Nuclear Disarmament Verification, A/RES/79/240, 2024. Available at: https://docs.un.org/en/A/RES/79/240.

Where Are We Today?

This evolution of verification across non-proliferation, arms control and disarmament highlights several enduring lessons for negotiators.

First, verification measures have become progressively more intrusive and sophisticated over time, evolving from reliance on NTMs to complex, layered systems combining on-site inspections, measurements, continuous monitoring, data exchanges and advanced analytical techniques. This progression has not been linear, but has been driven by practical experience, technological developments and, at times, the exposure of gaps in existing verification approaches.

Second, verification has developed not as a fixed set of tools, but as an adaptive practice, with mechanisms and procedures continually refined—or, in some cases, left deliberately ambiguous—to address new challenges, from verifying declared material, to detecting undeclared activities, to establishing the completeness and irreversibility of disarmament.

Third, across all domains, a persistent tension remains between the need for transparency to build confidence and the imperative to protect sensitive information and national security interests. As the historical record demonstrates, much of verification design—and negotiation—has centred on managing this tension through approaches such as managed access, information barriers and carefully calibrated levels of intrusiveness, underscoring that verification is as much a political and negotiated construct as it is a technical one.

IAEA inspector Georges Rubenstein fixes an IAEA seal on a valve at the Nuclear Fuel Services Inc. plant in West Valley, New York, 1967. Credit: IAEA

Verification Approaches and Technologies

This section contains an overview of current and potential future verification approaches used in nuclear arms control, disarmament and non-proliferation agreements. While there are many points in common, the need to protect sensitive weapons-related information is a key differentiator between civil non-proliferation and arms control and protocols developed and implemented for nuclear weapons, with the latter significantly more complex. This section concludes with a summary of general points to consider when evaluating verification options.

Given the stasis in the nuclear agreement landscape over the last decade, it is possible to define a “legacy”, meaning well known and used in past agreements, set of verification tools. NPT commitments to disarmament notwithstanding, global-scale verifiable nuclear disarmament per se remains a hypothetical construct, a subject of multiple studies, but never consistently implemented in international agreements. However, many disarmament verification techniques can and should be adapted from the classic verification toolkit we describe here.

Foundations and Principles of Verification in Earlier Arms Control Treaties

As a general rule, arms control agreements are constructed to achieve specific goals. In the past, the primary goal of such agreements was strategic stability or, more broadly, military balance. This can be thought of as: (1) assured retaliatory capability (the absence of ability of any party to carry out a surprise large-scale disarming strike); and (2) limitations on quantitative and qualitative arms racing to ensure the stability of balance for the duration of the agreement and beyond. Accordingly, past treaties were primarily concerned with deployed and deliverable nuclear weapons; thus the main accounting unit (e.g. TLIs) were delivery vehicles – missiles, submarine, bombers. The nuclear weapons themselves (e.g. warheads) were addressed only indirectly via agreed accounting rules. The actual nuclear weapons were not the subject of these treaties to the extent that non-deployed (stored) weapons could not be used in a surprise first strike.

Arms control negotiations held in the 1980s produced a verification system based on a synergy of multiple verification methods. That system was used in both bilateral US-Soviet/Russian and multilateral treaties. It is built around the lifecycle principle, according to which each TLI is tracked throughout the entire time from its entry into the accounting system until it is removed from accounting as a result of elimination or conversion.[47] The foundation of the system is periodic regular exchange of data about all TLIs. That data is selectively verified using a range of measures, which ensures an acceptable level of probability that inaccuracies will be detected.

As described above, verification methods in bilateral arms control treaties included:

- NTMs, such as satellite surveillance and any other measures that allowed unilateral verification – in most cases, parties also agreed not to hinder the use of NTMs, for example by intentionally concealing objects or activities;
- Short-notice on-site inspections designed to ensure unanticipated visits of an inspection team to one of many declared facilities to verify that the number and types of TLIs there matched the data provided in an exchange, or other data (e.g. the number of warheads on strategic missiles);
- Planned inspections to verify implementation of activities, such as elimination of TLIs or facilities;
- Permanent monitoring of facilities (for legacy treaties this meant missile production facilities, but the same measure could be theoretically applied to any type of facility) to verify the number and types of items leaving (or, potentially and in other circumstances, entering) it;
- Challenge or suspect-site inspections at locations where TLIs are not supposed to be present – such inspections may be conducted at agreed facilities (or categories of facilities) or anywhere;
- Other treaty-specific measures, such as provision of telemetry from ballistic missile launches, which may be agreed by parties.

These mechanisms and methods may be operationalised differently in different treaties. For example, the Chemical Weapons Convention (CWC) provides for data exchange, verification of elimination of chemical weapons stockpiles and several types of inspections.[48] States party to the CWC submit reports on facilities associated with chemical weapons and agree to routine inspections at those facilities to confirm they are not being used to produce weapons. They also submit to investigative inspections in case chemical weapons use is reported and challenge inspections at facilities not subject to regular inspections where production of chemical weapons is suspected. The CTBT, for its part, relies primarily on (inter)national technical means (the International Monitoring System) and inspections at sites where a nuclear explosion may have taken place.

47 Miles Pomper, William Moon, Marshall Brown, Ferenc Dalnoki Veress, Dan Zhukov, Dick Gullickson, and Yanliang Pan, "Nuclear Verification's Holy Grail: Verifying Nuclear Warheads – a new approach", James Martin Center for Non-Proliferation Studies, December 2024. Available at: https://nonproliferation.org/wp-content/uploads/2024/12/nuclear_verifications_holy_grail_12162024b.pdf.

48 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 (Chemical Weapons Convention), 1993. Available at: https://www.opcw.org/chemical-weapons-convention/download-convention.

The IAEA safeguards system is based on the same principles and, in fact, its conceptual foundations precede the verification systems of arms control treaties. This is likely because safeguards address the civilian nuclear sector, which is less sensitive than matters that directly affect national security of States. Specifically, it is based on data exchanges (declarations) and inspections. The subsequent strengthening of the safeguards system through the Model Additional Protocol added the principle of lifecycle verification, which tracks nuclear material throughout the lifecycle and expands the range of facilities and locations subject to inspections. Safeguards were also the first type of verification regime that featured the use of technical tools to support verification; arms control regimes introduced a variety of tools much later, in the end of the 1980s.

None of these measures represents a “golden key” to reliable verification. They need to complement each other. Together they create synergy, which is the foundation of reasonably efficient implementation. Even then, implementation is never smooth. Parties always have questions, concerns or suspicions, which may hinder implementation and occasionally generate serious crises. To address these, legacy arms control treaties provided for special mechanisms – implementation commissions under bilateral US-Soviet/Russian treaties or international organisations for multilateral treaties. The collapse of the INF Treaty in 2019 was caused, in no small part, by the failure of the parties to fully utilise such a mechanism for development of measures to resolve the conflict over suspected violations.

International organisations created in support of recent treaties (including the CWC and the CTBT) feature certain differences from the IAEA, which dates back to the 1950s and was later given responsibility for verification under the NPT, and reflect a different understanding of the roles and the missions of such institutions. New organisations like the OPCW and the CTBTO have authority over entire treaties and thus both Member States and staff can address the entire range of issues related to their implementation, whereas many aspects of the NPT can only be addressed by its States Parties within the NPT review process. This helps enhance the effectiveness of international organizations as facilitators of implementation.

Verification Tools in Legacy Arms Control and Non-proliferation

The classic verification toolkit includes:

1. Sensors: gamma-ray and neutron radiation detectors to characterise nuclear material in warheads, pits and other forms; detectors to identify high explosives; size and weight measurements. Others largely include non-destructive tools to identify and quantify nuclear items.
2. Item and Facility Monitoring: Tags, seals and other means of tracking and maintaining continuity of knowledge for weapons and material in transit and for facility operations.
3. Data Sharing, Protection and Authentication: data sharing, such as the data exchanges in START and New START, provides basic information about declared items, such as type, location and number of TLIs. Data protection and authentication hardware and software securely store or transmit sensitive information, while authentication hardware and software confirm the integrity of data collected by a sensor.
4. NTMs: This category includes a wide variety of standoff systems and other methods to verify the absence of prohibited activities, such as satellite imagery, aircraft overflights and environmental monitoring for traces of prohibited material/activities. In some treaties, verification procedures are deliberately designed to facilitate collection of information via NTMs.

Most non-proliferation-related verification activities proceed under the aegis of the IAEA safeguards framework. Verification methods are implemented at various stages of in the civil nuclear fuel cycle, with declarations of relevant nuclear materials and facilities used as a reference point. For the most part, verification tools from categories 1-3 defined above are employed. NTMs are used relatively infrequently for IAEA safeguards, due to the necessity to corroborate intelligence collections made through NTMs.

Within the IAEA safeguards regime, protection of sensitive information (item 3 above) is for the most part done to minimise the risk of theft of intellectual property, such as facility process design, rather than to protect national security information.

Application of Legacy Approaches to Nuclear Disarmament: Possible Methods and Tools

The legacy verification system provided reasonably reliable support for implementation of multiple arms control treaties but is far from perfect, as it resulted from a compromise between two pairs of mutually contradicting variables:

- Intrusiveness versus sensitivity. In theory, treaties must feature as reliable and intrusive verification systems as possible, but in reality verification is never one-sided. It applies more or less equally to all parties and each of them is interested in protecting sensitive information related to national security. For example, detailed and current data about TLIs can not only serve as the foundation for efficient verification but can also facilitate the targeting of these TLIs. As a result, verification measures always have limited intrusiveness, and inspection protocols especially are built on principles generally apposite to those of other treaties ("everything not explicitly allowed is banned" as opposed to "everything that is not explicitly banned is allowed").
- Comprehensiveness versus costs. Generally speaking, the more data that is exchanged and the broader and more frequent the inspections, the more complete and exhaustive verification measures are. These activities have costs, both financially and in terms of disruption of facility operation, whether military or civilian (especially the latter). It is not by chance that regular inspections under the CWC are held, as a rule, no more than three times in 10 years. Costs were also the main reason why the United States and Russia chose not to extend START I in 2009 and instead negotiated New START, which has less taxing verification procedures.

This balance is always ad hoc because it depends on the provisions of the treaty. For example, it may be easier to verify the complete elimination of TLIs than limitations simply because national security restrictions will be less severe. Similarly, the verification system designed for large TLIs in legacy agreements (first stages of strategic missiles) may be easier to verify than much smaller ones, such as nuclear warheads.

The next stage of arms control – and, at the same time, the first stage of nuclear disarmament – will likely be accounting for and possibly limiting/reducing the number of nuclear warheads. It will be necessary to negotiate a new balance between the aforementioned variables. By definition, NTMs will be less effective than with respect to delivery vehicles. On-site inspections will have to be more intrusive because of the smaller size of TLIs and, consequently, affect the operation of facilities and infringe on national security interests much more than was the case in the past.

These challenges can be resolved, but it is clear that the transfer legacy verification provisions from old to future treaties will require adjustment. One possible solution is development of new technical tools and procedures, which could at least partially replace human presence and visual observation as the central monitoring concept. Similarly, it may be necessary to pay closer attention to the non-proliferation implications of such a treaty in case non-nuclear-weapon States are involved to prevent the leakage of sensitive information in contravention of the NPT.

Moreover, the balance is dynamic: as nuclear warhead stockpiles dwindle, verification may have to become more intrusive because the consequences of violation increase. One of the underlying principles of verification is the ability to detect, with acceptable probability, a *significant violation*; the definitions of "acceptable" and "significant" are developed by each State individually and then de facto agreed in the course of negotiations.

As arsenals decline, however, the consequences of undetected violations increase. For example, 10 percent of 4,000 warheads has much less consequence than 10 percent of 100 warheads and even one or two undetected warheads may have strategic consequences when all nuclear weapons are eliminated. Accordingly, as nuclear-armed States and possibly also States without nuclear weapons embark on the path toward nuclear disarmament, it might be necessary to factor in the dynamic, evolving nature of verification or at least provide for a sequence of new treaties and verification regimes.

Possible Verification Tools for Future Treaties

A wider, possibly more intrusive set of tools has been contemplated by the non-governmental expert community for the verification of future arms control treaties, as well as for disarmament treaties. Because complete disarmament may also include decommissioning of military (and possibly civil) nuclear infrastructure, tools may also be needed for verification of the shutdown or disablement of nuclear warhead manufacturing facilities, military reprocessing or enrichment facilities and other elements of a State's nuclear facilities that may be relevant for weapons or nuclear material production. When considering verification of future agreements, we consider two broad types of verification tools: warhead-focused and facility-focused.

Warhead-focused Verification

As discussed above, the deployment platforms for nuclear warheads have been the main focus of past arms control agreements. The next frontier in arms control and disarmament will likely involve verification of their retirement from military service, and the dismantlement of nuclear warheads themselves.

While not yet implemented in nuclear treaties, there have been decades of research into warhead-based verification. The topic is further subdivided into concepts that involve containment and tracking of warheads and launchers at operational, storage or maintenance sites, but not necessarily intrusive inspections of the warheads themselves, and a somewhat more widely studied suite of concepts that aim to verify the physical properties of either the intact warhead or its dismantled components.

Warhead Tracking and Containment Concepts

Concepts such as New Court, and more recently the Warhead Passport system elaborated by the James Martin Center for Nonproliferation Studies (CNS), focus on tracking the deployment, transit, storage and maintenance of nuclear warheads, in order to verify that declared TLIs remain within designated locations as might be defined in a future treaty.[49] In these approaches, the warhead's identity is not directly verified using sensors or other physical properties. Instead, the locations and types of warheads are declared by treaty signatories, sensors and containment and surveillance techniques are used to ensure that the warheads are not removed from the sites (typically defined as use, storage and work sites) designated under the treaty and secure means are used to share select information about the status of individual warheads. These concepts do not directly verify warhead dismantlement or even their presence, but instead aim to ensure that a set of items declared to be warheads, once placed in this monitoring ecosystem, verifiably never leave the system. The warheads may or may not be slated for retirement from military service – the heart of the concept is (presumed) knowledge of the locations and number of treaty-accountable nuclear warheads. The fact that an enormous effort would be required to completely spoof and defeat already-known information (shared or collected by NTMs) about the locations of warheads is presumed to be a key deterrent to cheating.

Both the New Court and the CNS Passport concepts are proposed as non-intrusive but still meaningful first steps towards more comprehensive agreements that would verify the actual disablement or dismantlement of nuclear warheads, and ultimately their constituent materials. These warhead tracking approaches are anticipated to be more readily accepted by nuclear-weapon States and their allies, since they do not involve solving the problem of directly verifying warhead properties, which would increase the risk that a counterparty might gain access to secret and highly sensitive weapons design or operational data.

49 The New Court concept is described in Robert L. Rinne, "An Alternative Framework for the Control of Nuclear Materials", Center for International Security and Cooperation (CISAC), Stanford University, May 1999. Available at: https://www.files.ethz.ch/isn/20024/Alternative_Framework_Control_Nuclear_Materials.pdf.
The Warhead Passport system is described in Marshall Brown Jr., "Demonstrating a Warhead Tracking System", CNS, March 2023. Available at: https://nonproliferation.org/wp-content/uploads/2023/03/web_warhead_verification_demonstration030823.pdf.

Direct Verification of the Properties of the Warhead and of Warhead Components

To satisfy concerns about potential cheating, there is a strong push by governments and in the expert community to develop means for direct verification of the properties of intact warheads and warhead components upon dismantlement. The principle distinguishing feature of modern arsenals is the presence of some number of kilogrammes of highly enriched uranium (HEU) or plutonium in a nuclear "pit" which provides (or in fusion weapons facilitates) nuclear explosive yield. Other identifying features are of course present, such as insensitive high explosives, fusion-related components like tritium or even the characteristic size and weight of the warhead or component, but are not themselves considered sufficient to positively identify a warhead. The presence of nuclear material is also required when dismantlement protocols are defined in arms control and disarmament treaties.

Unfettered access to a warhead or its components would make the verification process straightforward technically, though still not trivial operationally. However, due to the high sensitivity of States regarding the design and security features of nuclear weapons, such access will not be available in foreseeable nuclear arms control or disarmament treaty contexts. Instead, verification tools must be carefully designed to reveal features unique to nuclear warheads—perhaps even specific warhead types—without compromising sensitive national security information as defined by the possessor of the weapon. This balance between the non-proliferation goal of avoiding revelation of design information and the arms control goal of ensuring that TLIs are what they are declared to be is a central tension specific to arms control and disarmament verification.

Due to the high specificity of the isotopic signatures, verification focuses largely on radiation-based measurements. This is because both plutonium and HEU emit penetrating radiation—neutrons and gamma-rays —which can be collected at a few metres standoff by radiation detectors, and used to reliably confirm the identity, or at least key characteristics of, the warhead or nuclear material-bearing component being verified. A more complete survey would include alternative approaches, such as the use of acoustic or other approaches, but these have typically had less success in research contexts.

In intact warheads, the nuclear material is surrounded by materials that can attenuate or distort the energy, number and direction of emitted particles. This poses additional challenges for both the inspecting and the inspected parties. For inspectors, these distortions may mask the true nature of the nuclear material and may allow the introduction of spoofing radioactive material whose emission patterns cannot easily be distinguished from those of a true warhead. Conversely, for the owner of the warhead, the distortions in the radiation pattern can also in principle reveal the interior structure of the warhead and its surroundings, and thus sensitive design information.

In spite of these concerns, systems have been developed to verify the identity of warhead types or classes, without revealing classified information. While somewhat mature, none of these systems has been used in actual treaty contexts to date.

Radiation detection systems for verifying warhead or component identity can be further classed into attribute-based or template-based approaches.

Attribute-based Measurements

Attribute-based radiation detection systems define ranges of values for measured quantities (attributes) such as the energy and emission rates of gamma-rays or neutrons, the time-intervals between successive emissions, and others. A TLI is considered verified if and only if measurements of these quantities fall within the designated range of values. If the range of acceptable values is too small, there may be too much specificity in the collected data, which may in turn reveal more information than that required to validate the nuclear nature of the object. If the range is too wide, the system will be easier to fool using spoofing configurations (made from other radioactive material).

Template-based Measurements

Template-based approaches make use of a master copy of the warhead or dismantled nuclear material-bearing component to be verified. The template, acquired by non-radiation-based means, such as random selection from a declared stockpile of weapons, is comprised of a set of radiation measurements that identify the warhead or component. The template set of measurements is used as a standard to which other warhead measurement sets are compared. In other words, values from a measured TLI match those of a master copy (the template) within agreed upon ranges. Because the comparison is a binary operation—match or no match—template-based approaches can be designed to minimise the risk of the compromise of sensitive weapons information.

Information Barriers

For both template and attribute-based approaches, some kind of information barrier may be needed, to prevent the release of sensitive information, while still permitting verification that the presented item is indeed a TLI. Such barriers could be built into the measuring device itself or engineered into algorithms and electronics that are used to process the raw sensor data. An example of an intrinsic barrier would be the use of a sensor whose sensitivity to the energy or direction of the emitted particle is deliberately kept low enough to prevent the transmission of design information, but still accurate enough to meet the verification purpose. A considerable body of research has been performed to design information barriers for nuclear arms control treaties.

Authentication

Information barriers are designed to protect the interests of the owners of the TLI, namely that sensitive design information not be revealed in the course of verification. A complementary process known as authentication refers to measures that aim to ensure that transmitted data, and the sensors and equipment used to process it, are indeed arising from the claimed measurement process. Authentication is designed to protect the interests of the inspecting party that the TLI is indeed being accurately verified, and that spoofing or masking of valid data has not taken place.

Zero-knowledge Protocols

A promising approach that neatly combines authentication and information barriers in a single methodology has evolved over the past decade, known as zero-knowledge protocols. Zero-knowledge protocols may be data transmission protocols or physically engineered systems. They are designed or engineered to rigorously demonstrate that a certain statement is true (e.g. this TLI is, in fact, a warhead) while revealing no other information about the object under examination. If this promise can be realised, this approach would go a long way towards addressing the central verification dilemma, namely protecting sensitive design information while confirming the identity of a TLI. Key considerations for these systems are their complexity, which can complicate practical deployment, and their relative unfamiliarity to the government negotiators and other stakeholders.

The Balance of Effectiveness and Feasibility in Achieving Confidence

The inspecting party's fundamental interest is to ensure that sufficient information is acquired to ensure that treaty obligations are fulfilled. In addition, the inspectorate needs to achieve high confidence that spoofing is unlikely through the use of robust authentication measures for the equipment used to make measurements, as well as protection of acquired data from tampering by the host or other parties.

The host's fundamental interest is to ensure that only information necessary to meet the verification goals is acquired, and specifically to ensure that no sensitive design information is acquired in the verification process. Relatedly, the host must be able to ensure itself that the verification tools can be operated safely, securely and practically in its facilities. A formal certification process will likely be imposed by the host in order to permit operation of any sensors near warheads or other TLIs.

Both the host and the inspecting party have a common interest in ensuring that the verification concept is as familiar and easily explained as practical to decision-makers, facility managers and the public.

Facility-focused Verification

As nuclear arms control and disarmament initiatives progress, many States and stakeholders have called for measures that would help ensure that dismantled warhead materials are not available for reuse in weapons. This push is embodied in the concept of irreversibility. Of course, since nuclear material and weapons can always be produced given political will, no arms reduction or disarmament program can ever be considered fully irreversible on a technical basis. However, important financial and temporal barriers to recovery of material and the use (or even the existence of) nuclear weapons material and weapons production infrastructure can be put in place.

Depending on political and policy stances, facility-focused verification may follow, or occur alongside the warhead-focused verification measures discussed above. Facility-focused verification would extend beyond the current IAEA safeguards system, in part simply because additional facilities, such as military enrichment and reprocessing facilities, nuclear weapon pit production facilities and others currently not under safeguards would be subject to monitoring for shutdown or elimination. Examples of treaties that may require such verification are a Fissile Material Cut-off Treaty and the TPNW.

Many elements of the verification toolkit discussed above would also likely be used under such treaties. In addition, nuclear-weapon States with highly sensitive facilities such as military plutonium reprocessing sites would likely demand additional security measures be applied to verification tools in these facilities. For uniquely military infrastructure, the disablement or destruction of facilities may be a condition of a treaty, which could require different methods for verification than found in the standard IAEA toolkit. As with warhead dismantlement verification, a balance would need to be struck between the risk of a potential proliferator sharing knowledge of plant operations, and the disarmament benefit of reducing a State's ability to manufacture nuclear materials or weapons.

Two employees of the Aircraft Maintenance and Regeneration Center cut up a BGM-109G Tomahawk ground launched cruise missile. Credit: The U.S. National Archives

Convergence and Divergence in Verification of Arms Control, Disarmament and Non-Proliferation

Nuclear disarmament verification is a vital element supporting effective implementation of agreements across arms control, non-proliferation and disarmament. Understanding where related verification mechanisms converge and where they differ is not merely an academic exercise. For practitioners engaged in the hard work of negotiating verification, clarity on these distinctions is foundational to crafting agreements that are effectively verifiable both technically and politically.

Shared Goals: Confidence, Transparency, Predictability and Stability

At the broadest level, verification across all arms control, disarmament and non-proliferation is oriented toward a common set of objectives. Whether the context is monitoring a state's civilian nuclear programme, counting deployed strategic nuclear warheads under a bilateral treaty or confirming the elimination of a weapons stockpile, the underlying ambition is the same: to generate sufficient confidence in compliance. This phrase—sufficient confidence—is important in that it does not imply certainty, and it does not demand omniscience. Indeed 100% confidence in verification is not achievable. Sufficient confidence requires a determination that the information gathered, and the methods used to gather it, are adequate to support the political judgments that parties must make about each other's behaviour.

Alongside this goal of confidence sits a broader strategic purpose: enhancing transparency, predictability and stability. Verification regimes do not merely catch cheaters — they build the conditions under which cooperation becomes the normal state. By making behaviour observable and accountable, effective verification mechanisms reduce the space for miscalculation and mistrust.

Key Divergences: Where the Verification Activities Part Ways

Despite this shared foundation, the three verification domains diverge markedly in their focus and operational demands. Non-proliferation verification is primarily concerned with correctness and completeness. Its central question is not whether a State is doing what it has declared, but whether the declaration itself is comprehensive and accurate. The identification of the misuse of declared facilities, undeclared facilities or diverted material sits at the heart of the safeguards enterprise. This orientation demands a posture of structured scepticism, and it places a premium on broad access, environmental sampling and the analytical capacity to identify anomalies against a baseline of expected behaviour.

Arms control verification, by contrast, operates in a different environment. Its primary concern is not with undeclared activities but with the declared ones: ensuring that the numbers, types, and locations of weapons systems are as declared, and that agreed limits are being observed. The emphasis here is less on suspicion than on stability and creating the predictability and mutual assurance that allows parties to rely on each other's compliance without constant crisis. Workshop discussions reflected this orientation clearly: participants engaged in detailed debate, including during the TTX, about how to verify chain of custody for fissile material, how to confirm weapons-grade status and how monitoring could be structured to be both technically adequate and politically acceptable.

Disarmament verification introduces a third and, in some respects, the most demanding set of requirements. Here, the central commitment is to sufficient irreversibility — the assurance not merely that weapons have been removed from deployment, but that their reconstitution is so costly, both in terms of time and money, that it is not a viable option. This requires verification methods capable of confirming not just current status but future constraints. The concept of irreversibility permeated workshop discussions on fissile material management: participants debated at length whether material should be downblended or merely stored, with those favouring downblending arguing that storage alone offered insufficient guarantees that material would not be repurposed.

These divergences in emphasis translate into real differences in the trade-offs that negotiators must navigate. Non-proliferation verification tolerates considerable intrusiveness in the name of completeness. Arms control verification is more circumspect about access, balancing the need for confidence against the protection of sensitive military information and unnecessary disruptions to day-to-day operations. Disarmament verification pushes intrusiveness furthest of all, demanding methods that can confirm not just current compliance but the elimination of future capability.

Handling Classified and Proliferation-Sensitive Information

Running through arms control, non-proliferation and disarmament is a persistent and structurally unresolvable tension: that between transparency and the protection of sensitive information. States that possess nuclear weapons guard their design parameters, deployment configurations and material quantities with extraordinary care, and for good reason. Detailed knowledge of these matters is not merely diplomatically sensitive — it is proliferation-relevant. The very information that provides the highest confidence in a verification regime is precisely the information that States are least willing and able to share.

Workshop participants discussed the verification of fissile material, with the group proposing that States owning such material should be permitted to alter its form prior to initial inspection, using a pre-agreed template procedure that would allow a counterpart to verify type and quantity without gaining access to design-sensitive parameters. This approach — essentially a managed access protocol — illustrates a broader class of techniques available to negotiators: information barriers that filter what information can be observed or collected by inspectors. These can include means that convey compliance-relevant data without exposing underlying configurations, and template-based procedures that allow verification to proceed against agreed benchmarks rather than requiring full disclosure of information.

The Warhead Passport system discussed extensively TTX and in this report represents another approach to this problem. By mathematically obscuring, or "hashing" warhead-specific data, the system was designed to enable verification of identity and status without revealing the underlying technical parameters that States wish to protect. Participants noted that the cybersecurity architecture of such a system would need to be carefully designed — isolated from open networks, resistant to spoofing and capable of detecting tampering — but that the fundamental insight was sound. It is possible to design verification architectures that generate meaningful confidence without requiring the full disclosure of information that states are unable to provide.

Sequencing Between Verification Activities

Workshop participants explicitly recognised the interdependence between arms control, disarmament and non-proliferation. Discussions on the scope of a potential verification treaty frequently returned to the question of sequencing: should a treaty begin with straightforward accounting verification and build toward full lifecycle monitoring, or should it attempt to encompass irreversibility from the outset? The emerging consensus favoured incrementalism — establishing a more general framework first and working toward specificity over time — on the pragmatic grounds that an achievable agreement with a narrower scope is more valuable than an unachievable agreement with a comprehensive one. This is itself a lesson drawn from the history of arms control: the INF Treaty, the START agreements and the CWC each built on prior frameworks and created political and technical precedents for what followed.

Multilateral Verification and the Role of Non-Nuclear-Weapon States

One question that generated sustained debate throughout the workshop concerns the appropriate role of multilateral institutions and non-nuclear-weapon States. Bilateral nuclear-weapon State verification arrangements offer certain advantages: they are more manageable, more reciprocal and less susceptible to the political complications that accompany broader participation. But participants from non-nuclear-weapon States raised a fundamental objection: bilateral verification between nuclear-weapon States requires non-nuclear-weapon States to accept the compliance of those States on trust. For States that have foregone nuclear weapons in reliance on the commitments of others, this is not a merely procedural concern — it goes to the heart of the bargain underlying the non-proliferation regime. The authors note useful precedents from the UK-Norway Initiative, the Quad Nuclear Verification Partnership and the IPNDV, which explored precisely how non-nuclear-weapon States might contribute to disarmament verification without gaining access to proliferation-sensitive information — a model that could inform future arrangements.

Defining Sufficient Confidence: A Negotiated Balance

The concept of sufficient confidence is ultimately not a technical standard but a political one. What counts as sufficient will depend on the specific context of a negotiation and resulting agreements. The relationship between the parties, the nature of the commitments being made, the historical record of compliance and the stakes associated with a potential violation all contribute to parties' level of confidence.

Intrusiveness, cost and the level of assurance required are all variables that must be calibrated against each other. On-site inspections provide high confidence but are expensive and operationally demanding. Remote monitoring and electronic tracking systems offer efficiency and continuity but depend on the integrity of data provided by, and in the custody of, host states and introduce cybersecurity vulnerabilities. The blended approach developed during the workshop's second breakout session — combining baseline declarations, on-site inspections and ongoing electronic tracking with triggered inspections for discrepancies — represents a practical attempt to optimize across these competing demands.

What Data Verification Should Provide

A final and underappreciated dimension of verification design concerns the information that verification is actually expected to generate. Not all data is created equal. Some information is essential to the compliance judgments that parties must make. Other information would be useful but is not necessary and some information, however technically accessible, represents a red line that States cannot cross. Negotiators must distinguish between these categories clearly and early, because misalignment on data requirements can result in deadlock.

Workshop discussions illustrated this dynamic in several ways. Participants debated whether a baseline declaration needed to cover all warheads or only those subject to treaty limits, and whether the electronic passport system should be understood as duplicating or supplementing the declaration. They considered whether non-nuclear-weapon States needed access to the full content of electronic passports or whether aggregated or hashed data would be sufficient for their purposes. They also struggled with the fundamental question of what information nuclear-weapon States would and would not share with a counterpart nuclear-weapon State versus with a non-nuclear-weapon States or an international organisation, recognising that the answer was likely to differ across negotiating partners and political contexts.

The lesson that emerges from these discussions is that verification is not a problem to be solved once and then set aside. It is a continuing negotiation — "it depends" — on what information matters, who has the right to obtain it and what level of confidence is sufficient to sustain the political commitments on which arms control and disarmament ultimately depend. The domains of arms control, non-proliferation and disarmament each bring their own logic and demands to this negotiation. Understanding both what they share and where they diverge is the prerequisite for any serious attempt to develop an effective verification regime.

The button Secretary of State Hilary Clinton presented to Foreign Minister Sergey Lavrov in 2009, before New START; it was intended to say "reset", but the Russian translation actually says "overload". Credit: Fabrice Coffrini / AFP/Getty Images

Getting to "Yes": Tips in Negotiations

Drawing on the experience of senior negotiators, the workshop participants discussed a number of tips for successful negotiation in the context of nuclear verification, whether in connection with arms control, disarmament or non-proliferation.

Technical and Substantive Issues

One of the key challenges associated with such negotiations is the highly technical nature of the subject matter, which impacts all aspects of the negotiation, from designing the verification approach to achieving an agreed solution.

As regards the design of such systems, the focus should be on ensuring that they are practically implementable and sustainable. The verification technologies involved in the system need to be translated into negotiable concepts, "boiling down" the descriptions of complex technical systems into clear, policy-relevant language. Analogies and simplified models (e.g. tracking systems) can build shared understanding.

While technology itself is neutral, negotiators should understand the choice of technology as a negotiated element of a verification system. That choice is both technical and political in nature. Among the issues that will need to be addressed is how to ensure authentication and trust in the verification tools and data, resolving concerns about tampering, hidden capabilities and equipment neutrality.

A key aspect of that issue will be the handling of information sensitivity and red lines, recognising that, as red lines will likely differ across the parties, they should be surfaced early. The legitimate interest of all sides in protecting sensitive information must be acknowledged by, for example, identifying and protecting classified or proliferation-sensitive information and using tools such as information barriers and managed access.

Core negotiation trade-offs must be managed. For example, the ultimate goal or objective of the system – e.g. whether completeness or correctness (full accounting versus accurate verification of declared items) – may depend on what is achievable. The required degree of confidence in the system will have to be balanced with its intrusiveness (e.g. inspections versus remote monitoring); efficiency will have to be balanced with the assurance the system provides (cost and scalability versus robustness).

In terms of the systems themselves, the negotiators offered some suggestions for designing workable verification systems:

- moving toward hybrid and layered approaches, rather than single solutions;
- using sequencing and phased implementation to build confidence over time; and
- incorporating redundancy and cross-checking to strengthen credibility.

Language

The role of language is critical in any negotiation, but no more so than when working in multiple languages, especially when the negotiations are in a language that is not one's mother tongue.

Words carry different meanings across communities and countries; one needs to be careful about assuming your counterpart means what you mean, even if you are saying the same thing – the same word can mean different things to different people. And they might not have said exactly what you believe they meant.

Working across cultures and languages significantly elevates the importance of using precise terminology and keeping accurate records.

"Constructive ambiguity" is another particularly useful technique when trying to achieve agreement in a situation where positions are incompatible. It involves the use of vague or ambiguous language to bypass irreconcilable disagreements, allowing opposing parties to agree on a text while interpreting it differently. It's a risky technique, but if there is strong motivation to achieve agreement – and the point about which the ambiguity exists is a collateral issue – it can be very effective. However, while it frequently helps in the immediate negotiations, it might give rise to difficulties down the road.

Which leads to tips on how to best to communicate.

Communication

Effective communication can help create a bridge between technical, political and legal communities, framing proposals in ways that make them politically and technically acceptable. It begins with being clear about the ultimate objective(s). While being clear about the real objective(s), be flexible on how to achieve it/them.

Good communication is a two-way process involving the identification of common interests with the counterpart and understanding the divisions/tensions within the other side and, indeed, within one's own side, since frequently there are as many divisions within a given side internally as with external parties (the so-called two-level nature of negotiations). Focussing at the outset on shared objectives can facilitate progress by building trust and common goals, which can help pave the way for negotiations when they become more challenging because of a divergence of positions.

Another key to communication is active listening – listening to the counterpart with a view to understanding what is being said rather than to objecting to it: not only because it conveys an atmosphere of trust, but because you might actually learn something from the team across the table.

Process

Negotiation is an interactive and iterative process. It is important during this process to ask questions, probe assumptions and test proposals. Good preparation allows the parties to anticipate counterarguments and the other side's constraints (e.g. domestic decision-making processes).

Negotiations require a baseline level of trust to reach agreement, built on respect, patience, reciprocity and perceived fairness. This is best achieved by speaking to reason, rather than emotion. Paraphrasing a senior diplomat, the purpose of diplomacy and negotiation is not to say "no", but to get the other side to say "yes".

The Human Factor

Human beings share a common humanity, with egos and interests that need to be attended to for successful negotiations. That is true whether the negotiations are domestic or international. But there are aspects of negotiation peculiar to international negotiations, particularly in the context of sensitive issues that have national security dimensions. The importance of the individual cannot be overstated. Individuals can set a tone of trust and empathy without conceding negotiation points, or they can make agreement in even the most straightforward negotiations impossible.

Among the key contributors to successful negotiation are patience, persistence, respect and, critically, preparation and knowledge. While these won't necessarily ensure the negotiation of a treaty or arrangement, guarantee victory in the war against the proliferation of nuclear weapons or ultimately achieve disarmament or agreed arms control, they can increase the odds of winning – one battle at a time.

The U.S. and Russian Delegations sit at the negotiating table at the Russian Mission to the United Nations in Geneva, where many of the negotiating sessions for New START were held. Credit: U.S. Mission Photo: Eric Bridiers

Conclusions and Recommendations

The old Russian proverb often associated with nuclear verification reads “trust but verify”. While this was helpful political messaging when the United States President Ronald Reagan popularised it in the 1980s, the truth is that parties to a nuclear agreement—be it arms control, non-proliferation or disarmament—do not require trust in order to verify. Parties verify in the absence of trust and, eventually, verification can even help to build trust. This understanding is critical in today’s reality, where would-be parties to nuclear agreements claim that they cannot meet to discuss new treaties or further nuclear arms reductions due to a lack of trust.

As noted in the introduction, the VCDNP initiated this project against the backdrop of an unprecedented stall in nuclear negotiations. Given the expiration of New START, there is a danger that the capacity to conduct new negotiations will fade over time. In that light, this project aimed to provide diplomats, military experts and national policymakers an understanding of what can be done to sustain verification capacities into the future. Based on the inputs of former nuclear negotiators and workshop participants, the VCDNP generated the following recommendations for consideration by NPT States Parties, UN and IAEA Member States and the broader international community

Sustain and transfer negotiation expertise. States should take active steps to preserve and transfer institutional knowledge from past nuclear negotiations. With a growing generational gap and a prolonged absence of formal arms control processes, there is a risk that hard-earned experience in negotiating verification arrangements will be lost. Capturing lessons learned and ensuring their transmission to a new generation of diplomats, technical experts and policymakers should be treated as a priority.

Maintain and expand capacity-building initiatives. Workshops, simulations and other practitioner-focused engagements—such as those conducted under this project—should be continued and expanded. These formats provide a rare opportunity to develop practical negotiation skills, test verification concepts and foster mutual understanding across technical and policy communities. In periods when formal negotiations are not possible, non-governmental experts can play an important role in sustaining momentum, refining ideas and keeping verification issues "alive" in the international discourse. This work should be supported by a diverse set of stakeholders, reflecting the benefits that effective verification has for the entire international community.

Support and expand multilateral verification initiatives. States should provide sustained political, financial and technical support to ongoing multilateral initiatives, including the GSTE on nuclear disarmament verification. Ensuring that the GSTE is adequately resourced and broadly supported will be essential to maximising its practical contributions. At the same time, existing platforms such as the IPNDV and similar initiatives should be maintained and further developed, given their demonstrated value in bringing together nuclear- and non-nuclear-weapon States to address complex verification challenges. In this respect, efforts to bring on board States not currently participating in IPNDV would contribute to a stronger foundation for multilateral nuclear verification.

Revitalise and broaden technical cooperation. States—particularly nuclear-weapon States—should seek to revive and expand technical cooperation on nuclear verification, including lab-to-lab collaboration. Such cooperation not only advances the development of verification technologies and methodologies, but also plays a critical role in building trust, shared understanding and professional relationships that can facilitate future negotiations and effective verification of verification measures. Where possible, these efforts should be broadened to include additional partners, including non-nuclear-weapon States, in ways that protect sensitive information while enhancing inclusivity.

Better understand and communicate the cost and value of verification. A more systematic and transparent discussion is needed on the costs associated with verification, as well as its broader value to parties to an agreement and to the broader international community. Verification regimes can be resource-intensive, but their role in providing stability, reducing uncertainty and preventing conflict is often underappreciated. States should consider how best to articulate and justify these costs—both domestically and internationally—and explore ways to design verification systems that are both effective and economically sustainable.

Anticipate the implications of emerging technologies. The potential role of emerging technologies, including artificial intelligence (AI), quantum sensing, computing and communication, in nuclear verification should be examined more closely. These technologies may offer opportunities to enhance the effectiveness and efficiency of verification, including through improved data analysis, anomaly detection, and confidence is data authenticity. At the same time, asymmetries in technological capabilities could introduce new challenges in negotiations, including concerns about fairness, transparency and strategic advantage. These dynamics should be addressed proactively. This would be an area for further study.

Prepare for increasingly multilateral and data-rich verification environments. Future verification arrangements are likely to be more multilateral in nature and involve a broader range of actors, including non-nuclear-weapon States. States should continue to explore models for inclusive verification that balance transparency with the protection of sensitive information. In parallel, the growing accessibility of data—from commercial satellite imagery to open-source analysis—means that verification is no longer the exclusive domain of States. This evolving information environment presents both opportunities and challenges, and its implications for future verification regimes should be carefully considered.

Finally, what is clear from the implementation of this project is that, like negotiations themselves, advancing nuclear verification is an iterative process. Try and try again. Effective verification that is also feasible requires constant reflection on how related policies are conceived, what technology is available, which actors should be involved and how the benefits of verification are communicated. Ignoring the value of that iterative process—refusing to sit down at the negotiating table—will come at a cost.

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Vienna Center for Disarmament
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The VCDNP is an international non-governmental organisation that promotes peace and security by conducting research, facilitating dialogue, and building capacity on nuclear non-proliferation and disarmament.

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