VCDNP Vienna Center for Disarmament and Non-Proliferation

May 2025

The Balance of Confidence and Feasibility in Irreversible Nuclear Disarmament

Noah Mayhew
Dr. Nikolai Sokov
Dr. Adam Bernstein

Authors

Noah Mayhew is a Senior Research Associate at the VCDNP, working on nuclear safeguards, non-proliferation, and other IAEA matters. He has also worked on US-Russian arms control, including verification and monitoring. He leads the VCDNP's courses for diplomats and practitioners.

Dr. Nikolai Sokov is a Senior Fellow at the VCDNP. As a Soviet/Russian diplomat, he participated in numerous arms control negotiations, including on the INF Treaty, START I, and START II. He has published extensively on arms control, nuclear deterrence, risk reduction, and verification issues.

Dr. Adam Bernstein is a consultant to the VCDNP. In 2023, he retired from a long career at Sandia National Laboratory and Lawrence Livermore National Laboratory in the United States, where he worked to adapt technologies to address needs in nuclear treaty verification and nuclear security.

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.

Acknowledgements

This paper was produced with the generous support of the **United States Key Verification Assets Fund (V Fund)**.

The authors thank VCDNP experts Elena K. Sokova, Gaukhar Mukhatzhanova, Laura Rockwood, and Louis Reitmann for their extensive contributions to the project and this report.

VCDNP
Vienna Center for Disarmament and Non-Proliferation

Andromeda Tower, 13/1
Donau-City-Strasse 6
1220 Vienna
Austria

vcdnp.org
info@vcdnp.org
@VCDNP
VCDNP

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The principle of irreversibility has become an increasingly prominent topic in the NPT review process. 2022 NPT Review Conference in the UN General Assembly Hall. Credit: Cristian de Francia/IAEA.

Introduction

Recent years have seen a marked increase in interest in the principle of irreversibility in nuclear disarmament. The beginnings of the concept can be found in bilateral US-Soviet, and subsequently, US-Russian arms control negotiations in the last years of the Cold War as the two parties were developing procedures for the reduction of nuclear-capable delivery vehicles. The two States subsequently applied this principle to bilateral fissile material reductions from nuclear weapons. Soon thereafter, the term “irreversibility” became a common feature in non-proliferation discourse and was mentioned in the arms control context at the 1995 Review and Extension Conference of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). The principle of irreversibility has since been integral to how many NPT States Parties view nuclear disarmament.

The 13 practical steps for the implementation of the NPT's Article VI on nuclear disarmament adopted at the 2000 NPT Review Conference stated that the principle of irreversibility should "apply to nuclear disarmament, nuclear and other related arms control and reduction measures".[2] In 2010, NPT States Parties agreed to a 64-point action plan, the second item of which stated that States Parties should "commit to apply the principle of irreversibility, verifiability, and transparency in relation to the implementation of their treaty obligations."[3] The 2005, 2015, and 2022 NPT Review Conferences also discussed irreversibility, although the meetings concluded without consensus outcomes.[4]

Intuitively, the notion of irreversibility is clear. When a State eliminates nuclear weapons or weapons-grade fissile material from military use under an international agreement or other regime, all parties to that regime have an interest in ensuring that the weapons cannot be reconstituted, whether openly or clandestinely. Otherwise, the agreement's impact is weakened or even nullified. Accordingly, US-Soviet and US-Russian arms control treaties, which pioneered practical implementation of the irreversibility concept, contained specific procedures governing the dismantlement of weapons systems. These procedures provided credible assurance that eliminated weapons could not be used for the original purposes and provided for intrusive verification capable of detecting work on reconstituting reduced capabilities.

Irreversibility of *complete* nuclear disarmament, without doubt, presents a bigger challenge than dismantlement of a limited number of nuclear-capable delivery vehicles. It needs to guarantee with a reasonable degree of reliability that nuclear weapons are not rebuilt once they have been dismantled. In other words, it requires dismantlement not only of weapons, but also the infrastructure that supports the production of such weapons.

A nuclear weapons capability can be thought of as comprising three main components: fissile material, delivery vehicles, and the infrastructure and personnel associated with the nuclear weapons complex. These three elements require different approaches to verification in the context of disarmament:

- The possession or capability to produce weapons-grade fissile material is commonly recognised to be the key element of the fabrication of nuclear weapons. The safeguards system of the International Atomic Energy Agency (IAEA) is concentrated on the production and inventories of nuclear material – defined in the IAEA Statute as special fissionable material and source material – to ensure that the material is not being diverted toward nuclear weapons development.[5] The verification of nuclear material in a large-scale disarmament scenario would additionally include a series of activities to verify the origin and disposition of fissile material from weapons programmes.

2 Final Report of the 2000 Review Conference (NPT/CONF.2000/28 (Parts I and II)), pg. 14. Available at: https://disarmament.unoda.org/wmd/nuclear/npt-review-conferences/.

3 Final Document of the 2010 Review Conference (NPT/CONF.2010/50 (Vol. I)), pg. 20. Available at: John Carlson, "Prohibition of military attacks on nuclear facilities", VCDNP, 12 September 2022, https://vcdnp.org/prohibition-military-attacks-on-nuclear-facilities/. .

4 For example:
A 2005 working paper submitted by Cuba grouped transparency, verification and irreversibility as essential principles in the process of nuclear disarmament. See: "Transparency, verification and irreversibility: essential principles in the process of nuclear disarmament" (NPT.CONF.2005/WP.24), 4 May 2005. Available at: https://documents.un.org/doc/undoc/gen/n05/333/41/pdf/n0533341.pdf?token=Z30jiccZ9EVyBOVJBj&fe=true.

The draft final document from the 2015 Review Conference reaffirmed "the importance of all States applying the principles of transparency, verifiability and irreversibility in relation to the implementation of their treaty obligations". See Draft Final Document of the 2015 Review Conference (NPT/CONF.2014/R.3), pg. 15, 21 May 2015. Available at: https://www.reachingcriticalwill.org/images/documents/Disarmament-fora/npt/revcon2015/documents/DraftFinalDocument.pdf.

The Review Conference in 2022 also reaffirmed these principles. See: Draft Final Document of the 2020 Review Conference (NPT/CONF.2020/CRP.1/Rev.2), pg. 16, 25 August 2022. Available at: https://reachingcriticalwill.org/images/documents/Disarmament-fora/npt/revcon2022/documents/CRP1_Rev2.pdf.

5 In this report, the terms "fissile material" and "nuclear material" are used interchangeably. In both cases, the authors are referring to special fissionable material as defined in Article XX.1 of the IAEA Statute, e.g. "plutonium-239; uranium- 233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing". When it is necessary for context to specify that the material in question is weapons-usable, the authors have done so.

- Delivery vehicles are both easier and more challenging to address. On the one hand, the United States and Russia possess considerable expertise in the elimination of nuclear-capable delivery vehicles and verifying that their production is not resumed. That expertise can be usefully applied in other nuclear-armed States. On the other hand, almost every delivery vehicle today is dual-capable, i.e., can carry either nuclear or conventional weapons.[6] Accordingly, it may be difficult to expect complete dismantlement of this aspect of a nuclear weapons programme.

- Finally, knowledge about nuclear weapons and their design as well as the institutions and infrastructure supporting nuclear weapons design, production, and maintenance are perhaps an even greater challenge. This element can be thought of as the "echoes" of a nuclear weapons programme post-disarmament. While dismantling institutions may be easy, it is virtually impossible to eliminate knowledge underlying a nuclear weapons programme – all the more so since the science of nuclear weapons is a relatively old area of knowledge and can be reconstituted as long as there is sufficient determination and support.

Following the 2010 NPT Review Conference, several NPT States Parties expressed interest in developing a better understanding of the principle of irreversibility. The government of Switzerland commissioned two reports, both of which were published in 2011. The Verification Research, Training and Information Centre (VERTIC) published a report focusing on the conceptual, technical, and operational aspects of irreversibility.[7] The VERTIC report included a high-level conceptual description of five potential end states in disarmament along a spectrum. The second report was published by the Stockholm International Peace Research Institute (SIPRI) and addressed political, societal, legal, and military-technical aspects of irreversibility.[8]

Further research on irreversibility has since been commissioned, including by the governments of Norway, the United Kingdom, and the United States. Wilton Park has held a series of four meetings between 2022 and 2025, bringing together the non-governmental expert community and government officials to discuss the concept of irreversibility.[9] In 2023, the Center for Strategic and International Studies' (CSIS) Project on Nuclear Issues (PONI) published a series of essays that represent a range of views on the importance of a shared vision for irreversibility in nuclear disarmament.[10] Most recently, the *Journal for Peace and Nuclear Disarmament* published three special editions that explored various issues in connection with irreversibility.[11] Irreversibility in the context of nuclear disarmament has become an increasingly active area of dedicated research.

Though the report from the 2023 Wilton Park meeting noted that irreversibility "remains an unexplored concept", the expert community largely agrees on a few key points.

First, irreversibility should be viewed as a spectrum of options rather than as one predetermined end state. The ultimate choice will be made by the international community, depending on multiple factors. The five end states described in the 2011 VERTIC study are instructive in this respect and will be considered in detail in this study.

6 The only exception in the United States and Russia so far are strategic delivery vehicles, but one cannot rule out that in the future some of them will be equipped with conventional.

7 David Cliff, Hassan Elbahtimy, and Andreas Persbo, "Irreversibility in Nuclear Disarmament: Practical steps against nuclear rearmament", VERTIC, September 2011. Available at: https://www.vertic.org/media/assets/Publications/Irreversibility_Report_Sept_2011.pdf.

8 Ian Anthony, "Irreversibility in Nuclear Disarmament: Political, Societal, Legal and Military-Technical Aspects", SIPRI, September 2011. Available at: https://ext.d-nsbp-p.admin.ch/NSBExterneStudien/externestudien/590/it/2398.pdf.

9 Report: Irreversibility in Nuclear Disarmament (2022), Wilton Park. Available at: https://www.wiltonpark.org.uk/app/uploads/2021/12/WP2019-Report.pdf.

Report: Irreversibility in Nuclear Disarmament (2023), Wilton Park. Available at: https://www.wiltonpark.org.uk/event/moving-forward-on-irreversibility-in-nuclear-disarmament-2023/.

Report: Irreversibility in Nuclear Disarmament (2024), Wilton Park. Available at: https://www.wiltonpark.org.uk/event/irreversibility-in-nuclear-disarmament-2024/.

Report: Irreversibility in Nuclear Disarmament (2025), Wilton Park. Available at: https://www.wiltonpark.org.uk/event/irreversibility-in-nuclear-disarmament-2025-3/.

10 Heather Williams, Jessica Link and Joseph Rodgers (editors), "Irreversibility in Nuclear Disarmament", CSIS PONI, February 2023. Available at: https://www.csis.org/analysis/irreversibility-nuclear-disarmament.

11 Journal for Peace and Nuclear Disarmament, Volume 6, Issue 2, 30 December 2023. Available at: https://www.tandfonline.com/toc/rpnd20/6/2.

Second, on a purely technical basis, there is no such thing as truly irreversible nuclear disarmament. As long as a State or a group of States is prepared to weather political, economic, security, and other costs associated with the resumption of a nuclear weapons programme, a nuclear weapons capability can be reconstituted. In this sense, nuclear disarmament itself is hardly an end state – it is a process, which has to be maintained long after nuclear weapons and the underlying industrial and scientific infrastructure have been eliminated. This process requires not only effective verification but also the political will on the part of the international community to act if an attempt to reconstitute nuclear capability is detected and – perhaps the most difficult part – ensuring the absence of the stimulus to acquire or reacquire nuclear weapons, i.e., a stable international environment.

Third, bearing this in mind, consideration should be given to the added value of trying to establish a shared understanding of irreversibility, including actions that can ensure a sufficient degree of irreversibility (and a shared understanding of what "sufficient" means), measures to ensure verification, and enough transparency to permit timely detection of attempts at rearmament.

Fourth, there are unavoidable trade-offs regarding confidence in irreversibility and feasibility. As prior work has demonstrated, measures capable of ensuring the highest degree of irreversibility also carry with them highly intrusive verification and considerable financial costs. This study explores these trade-offs and how they might affect positions on future treaties and agreements.

Fifth and finally, discourse on irreversibility has lacked a focused, systematic effort to understand the view of NPT States Parties on what constitutes nuclear disarmament, on what is needed to ensure its irreversibility, on the degree of feasibility of these measures, and on appropriate legal, institutional and political instruments. As noted above, the arrangements for irreversible nuclear disarmament will ultimately reflect a political decision by NPT States Parties, to which experts may provide valuable input. Consequently, practice-oriented work in this area requires better understanding of the views of NPT States Parties themselves.

This project seeks to contribute to the ongoing international effort in this area by assessing confidence in irreversibility and feasibility. The disarmament end states outlined in the VERTIC study were used for an assessment of political, legal, and technical requirements and, accordingly, their feasibility, which informs a confidence-feasibility framework. Such a framework should help improve the understanding of potential trade-offs associated with different degrees of irreversibility of nuclear disarmament, facilitate discussions in the international governmental and non-governmental community, and help inform diplomats and experts working on nuclear disarmament and non-proliferation issues.

An integral part of the project has been consultations with a representative group of NPT States Parties to gauge their views on these issues. Better understanding of the views of NPT States Parties on various aspects of irreversibility should help identify areas where debates among the expert community overlap with governmental views and develop better knowledge of pathways that may be practical to pursue. This will inform ongoing interaction between the expert community and NPT States Parties and facilitate the further development of dialogue – including between government representatives (Track 1) and between governments and non-governmental experts (Track 1.5) – in this area.

A gift of Luxembourg to the United Nations, the statue “Non-Violence” has become an internationally recognisable symbol for the struggle for peace and disarmament. Credit: United Nations.

Review of Literature and Practice

This section contains a thematic review of how the subject of irreversibility in nuclear disarmament has been approached in previous studies and in practice. The review begins with an overview of definitional issues: first and foremost, it addresses whether it is even necessary to develop a shared definition or understanding of irreversibility. The review then addresses the nexus between the concepts of transparency, verification, and irreversibility. The following two sections explore practical experience obtained in the implementation of international safeguards and fissile material disposition and arms control verification, and the lessons learned from these activities for creating a reliable irreversibility regime. The final two sections in the review are focused on issues related to infrastructure associated with nuclear weapons programmes and considerations that may incentivise or disincentivise States to accept certain end states of nuclear disarmament.

A review of the existing literature is complemented by a summary of practical activities (primarily by the United States and Russia) relevant for establishing irreversibility of nuclear disarmament in several aspects, including, inter alia, fissile material, nuclear weapons accounting, and the elimination of nuclear-capable delivery vehicles. The review also draws lessons from this experience that could contribute to practice-oriented work and negotiations on nuclear disarmament.

A Shared Definitional Understanding or Vision of Irreversibility

While the importance of the principle of irreversibility itself remains uncontroversial among NPT States Parties, neither the States Parties nor the non-governmental expert community has agreed on a shared definition of irreversible nuclear disarmament. During the establishment of the US-Russian Joint Working Group on Safeguards, Transparency, and Irreversibility (STI) in 1994, parties interpreted irreversibility as a condition when fissile material "declared excess to military needs (including civilian weapons-usable materials) are not being used to build new nuclear weapons."[12] The goal of the STI's work was to ensure that fissile material withdrawn from military use, including that which has been removed from nuclear weapons during dismantlement, would not be cycled back into a nuclear weapons programme. The parties agreed to achieve that through a variety of ways, including conversion of highly enriched uranium (HEU) into low-enriched uranium (LEU) for use as reactor fuel and monitored storage of plutonium pits. By and large, a similar understanding of irreversibility has been shared by NPT States Parties since 2000 because the principle of irreversible withdrawal of fissile material from a nuclear weapons programme can apply to both arms control and disarmament.

Although the STI definition is straightforward and seems intuitively sufficient, there have been other, perhaps more refined, approaches to the understanding of irreversibility. These definitions largely acknowledge the fact that, at least on technical grounds, complete irreversibility is not possible and that a nuclear weapons programme can be reconstituted given sufficient time, investment, and level of secrecy. Even in 1964, in the context of a discussion of the future safeguards regime, IAEA Member States noted that "some operations might be technically feasible but economically unacceptable".[13] They argued that economic as well as technological criteria should apply in determining whether nuclear material was "practically irrecoverable" for nuclear use.

The 2011 VERTIC study later referred to irreversibility in terms of cost and difficulty of reversal of nuclear disarmament and identified end states on a spectrum of disarmament. These end states utilised and built on the STI group definition of re-use of fissile materials for rearmament, such as the dismantlement of nuclear delivery vehicles and warheads.[14] This definition was further developed in a 2018 food-for-thought paper published by the International Partnership for Nuclear Disarmament Verification (IPNDV), which posited as criteria for irreversibility the costs, the difficulty, and the time required for reconstitution of nuclear capability, as well as the likelihood that such activity would be detected.[15]

Acknowledging that irreversibility on a purely technical level would be impossible, the expert community has begun to qualify the term. The 2018 IPNDV food-for-thought paper used the term "adequate irreversibility".[16] Participants in the 2022 Wilton Park meeting identified "sustainable confidence" as a necessary political aspect of irreversibility.[17] Mark Hibbs has referred to irreversibility as "a quality and aspiration". Noting the commonly accepted idea that irreversibility should be thought of as a spectrum rather than a binary state of disarmament, the 2023 Wilton Park meeting described irreversibility as "a gradual procedure to build trust and consequences in a spectrum on which states can more or less easily reverse a disarmament process".[18] In this same vein, Hassan Elbahtimy argues that it is more useful to think about *enhancing* irreversibility rather than achieving *total* irreversibility.[19]

12 "Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement", pg. 22, Office of Arms Control and Nonproliferation, United States Department of Energy, 19 May 1997.

13 International Atomic Energy Agency, Official Record of the Twentieth Meeting (GOV/COM. 14/OR.20), paras. 25-30, 15 January 1965.

14 David Cliff, Hassan Elbahtimy, and Andreas Persbo, "Irreversibility in Nuclear Disarmament: Practical steps against nuclear rearmament", pg. 8, VERTIC, September 2011.

15 Food-for-Thought Paper: Achieving Irreversibility in Nuclear Disarmament, Working Group 1: Monitoring and Verification Objectives, IPNDV, January 2018. Available at: https://www.ipndv.org/wp-content/uploads/2018/01/IPNDV-WG1-FFT-Irreversibility-Final.pdf.

16 Food-for-Thought Paper: Achieving Irreversibility in Nuclear Disarmament, Working Group 1: Monitoring and Verification Objectives, IPNDV, January 2018.

17 Report: Irreversibility in Nuclear Disarmament (2022), Wilton Park.

18 Report: Irreversibility in Nuclear Disarmament (2023), Wilton Park.

19 Hassan Elbahtimy, "Approaching Irreversibility in Global Nuclear Politics", pg. 211, Journal for Peace and Nuclear Disarmament, 20 December 2023. Available at: https://www.tandfonline.com/doi/full/10.1080/25751654.2023.2295595.

Participants in the 2023 Wilton Park meeting acknowledged that the diversity of approaches to irreversible nuclear disarmament "would make it difficult to agree on one definition", but that a shared vision would still be positive for advancing the disarmament agenda. Authors of the CSIS essay series have interrogated this question in some detail. Rebecca Davis Gibbons argues that developing "an agreed-upon vision or definition of [irreversible nuclear disarmament] is important for the irreversibility initiative to make progress."[20] Similarly, Irma Arguello argues that irreversible disarmament is impossible without a clear and shared definition of irreversibility.[21]

David Santoro posits that a shared vision for irreversibility is necessary, but that that vision "need not be comprehensive or set in stone".[22] More sceptically, Alice Spilman argues that "a singular and detailed vision of an irreversibly disarmed world is neither necessary nor possible" and suggests that the absence of a shared definition would add flexibility to operationalisation of the concept.[23] Tanya Ogilvie-White has argued that "the principle of [irreversible nuclear disarmament] is neither complicated nor ambiguous" and that, today, the idea of irreversibility has been reduced to a "distant and abstract goal."[24]

There is also a group of experts who, as Elbahtimy pointed out, have rejected the concept of irreversibility for being counterproductive.[25] Johann Kellerman, in preparation for the 2023 Wilton Park meeting, joined those who questioned whether the search for a shared definition, understanding, or vision of irreversibility in nuclear disarmament could be productive and whether, instead, it diverted energy from concrete progress on disarmament itself. John Gower and Christine Parthemore argued that the principle of irreversibility "restricts progress to what can be agreed by the P5".[26]

Given the general understanding that nuclear disarmament could be reversed in technical terms, measures are needed to ensure that the costs of a decision to rearm, broadly defined (funding, equipment and material, time, risk of detection, and sanction by the international community) are too high to seriously contemplate reversal or acquisition of nuclear weapons by a potential violator. This concept also implies that nuclear disarmament cannot be limited to elimination of the nuclear weapons themselves and should, instead, proceed further and deeper to the dismantlement of associated infrastructure as well as the development of measures (including verification) that would allow a reasonable level of assurances that an attempt to reverse nuclear disarmament would not only be difficult but also detectable.

Whether a detailed definition of the notion of irreversibility is needed remains an open question. It is possible to conclude that this state of affairs may continue for an extended period of time because, in the end, a common operational definition will be the product of negotiations among States working on relevant legal tools. While the input of the expert community will be valuable, other factors may well influence States' approaches during negotiations to arrive at a mutually acceptable compromise.

The irreversibility concept will likely continue to evolve, and even a major agreement on nuclear disarmament and irreversibility will perhaps not be the last stop in this evolution. One can recall as an illustration the evolution of nuclear safeguards from the late 1950s until today. The definition of irreversibility may well follow a similar path.

20 Rebecca Davis Gibbons, "Norms versus Security Approaches to Irreversible Nuclear Disarmament", contained in "Irreversibility in Nuclear Disarmament", CSIS PONI, February 2023.

21 Irma Arguello, "Politics and Irreversible Nuclear Disarmament", contained in "Irreversibility in Nuclear Disarmament", CSIS PONI, February 2023.

22 David Santoro, "A Shared Vision for Irreversible Nuclear Disarmament", contained in "Irreversibility in Nuclear Disarmament", CSIS PONI, February 2023.

23 Alice Spilman, "Necessary but Not Sufficient: Political, Legal, and Technical Factors for Irreversible Nuclear Disarmament", contained in "Irreversibility in Nuclear Disarmament", CSIS PONI, February 2023.

24 Tanya Ogilvie-White, "A Historical Approach to Irreversible Nuclear Disarmament", contained in "Irreversibility in Nuclear Disarmament", CSIS PONI, February 2023.

25 Hassan Elbahtimy, "Approaching Irreversibility in Global Nuclear Politics", pg. 203, Journal for Peace and Nuclear Disarmament, 20 December 2023.

26 John Gower and Christine Parthemore, "A Practical Strategy for Nuclear Risk Reduction and Disarmament: Fulfilling the Code of Nuclear Responsibility", Council on Strategic Risks, 19 April 2021. Available at: https://councilonstrategicrisks.org/wp-content/uploads/2021/04/A-Practical-Strategy-for-Nuclear-Risk-Reduction-and-Disarmament_Fulfilling-the-Code-of-Nuclear-Responsibility_Briefer-17_2021_4_19.pdf.

The Nexus Between Irreversibility, Transparency, and Verification

Since the principle of irreversibility entered the discourse on non-proliferation, arms control, and disarmament in the 1990s, it has been intertwined with the principles of transparency and verification. These three elements were considered part and parcel of the envisioned 1994 US-Russian STI group, referred to above.[27] The 2011 SIPRI report argued that full transparency and intrusive verification were needed to support irreversibility, citing as examples the destruction of hundreds of thousands of heavy weapons under the Treaty on the Conventional Armed Forces in Europe (CFE Treaty) and the destruction of chemical weapons under the Chemical Weapons Convention (CWC).[28] The 2011 VERTIC study acknowledged the relationship between irreversibility, verifiability, and transparency, but argued that there was also a need to disentangle verification from irreversibility as one does not necessarily guarantee the other.[29]

The 2018 IPNDV paper argues that a combination of "transparency measures and credible verification" could help obtain assurances that weapons are irreversibly destroyed. It further describes transparency and verification as prerequisites for "adequate irreversibility", as noted above.[30] Johann Kellerman notes that the link between the three principles is logical because the combination of the three can be expected to result in confidence that a nuclear disarmament regime is robust, goal-oriented, and effective. He further elaborates on this argument:

"Depending on one's point of view, it may be said that the notion of irreversibility in a nuclear disarmament context very broadly relates to the fissile material required to produce nuclear weapons, as well as the dismantlement of the weapons themselves. While transparency would contribute towards confidence in the process, a system of verification would then ensure that States do not cheat, or roll back on their nuclear disarmament commitments."[31]

There is broad agreement among experts that transparency and verification are an integral part of the concept of irreversibility. The process of disarmament, and perhaps more importantly, the maintenance of a world without nuclear weapons requires additional effort, namely, maintenance of sufficiently robust transparency and verification during and after the disarmament process. More specific details of operationalisation of these two requirements can be addressed in a variety of ways.

Nuclear Material Verification: Safeguards and Disposition Programmes

A key element of any nuclear weapons programme is weapons-grade fissile material, an essential component of such weapons. Accordingly, experts working on irreversibility largely agree that control of nuclear material is needed to ensure that disarmament is irreversible. There are different ways to achieve that control, with different degrees of consequence for irreversibility. The most widely used option is safeguards – technical measures implemented by the IAEA designed to ensure that nuclear material is not diverted or misused for weapons development. While the safeguards system today largely applies to non-nuclear-weapon States (NNWSs), the NPT nuclear-weapon States (NWSs) have volunteered, to varying degrees, to submit parts of their civilian nuclear programmes for IAEA verification. Bilateral US-Russian nuclear material disposition initiatives – discussed in the next section – are another type of control mechanism.

27 "Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement", pg. 22, Office of Arms Control and Nonproliferation, United States Department of Energy, 19 May 1997.

28 Ian Anthony, "Irreversibility in Nuclear Disarmament: Political, Societal, Legal and Military-Technical Aspects", pg. 10, SIPRI, September 2011.

29 David Cliff, Hassan Elbahtimy, and Andreas Persbo, "Irreversibility in Nuclear Disarmament: Practical steps against nuclear rearmament", pg. 14, VERTIC, September 2011.

30 Food-for-Thought Paper: Achieving Irreversibility in Nuclear Disarmament, Working Group 1: Monitoring and Verification Objectives, IPNDV, January 2018.

31 Johann Kellerman, "Towards an understanding of 'irreversibility' in the context of nuclear disarmament", paper prepared in advance of the 2023 Wilton Park meeting on irreversibility in nuclear disarmament, 2023.

In principle, it is possible to agree on other alternatives. The Treaty on the Prohibition of Nuclear Weapons (TPNW) talks about "credible assurance of the non-diversion of declared nuclear material from peaceful nuclear activities and of the absence of undeclared nuclear material or activities in the State as a whole" without an explicit link to the IAEA, though many assume that the IAEA would take this role. Given that assumption, and the IAEA's current dominant role in monitoring nuclear facilities and material, maintaining nuclear material verification under IAEA safeguards and disposition programmes is considered to be a key tenet of irreversibility in nuclear disarmament. However, the 2011 VERTIC study argues that the highest level of irreversibility would entail the State's complete abandonment of nuclear infrastructure, including the disposition of all fissile material.[32]

The majority opinion among the proponents of the TPNW seems to centre around a more modest goal – the "irreversible conversion of all nuclear-weapons-related facilities" or "irreversible elimination of nuclear-weapons programmes, including the elimination or irreversible conversion of all nuclear-weapons-related facilities".[33] The Treaty explicitly equates these criteria with "irreversible elimination of its nuclear-weapon programme".[34]

IAEA Safeguards and Irreversibility

Broadly speaking, IAEA safeguards represent a form of verification whereby the diversion of nuclear material from peaceful uses would be detected early to allow the international community to respond. This is achieved through a variety of means, including detailed accounting of all nuclear material in a given State. The same approach may be applicable to ensure irreversibility of nuclear disarmament, namely, the accounting and verification of nuclear material that could be diverted to military purposes.

Through a safeguards lens, one can think of irreversibility in fissile material disposition as "practically irrecoverable for nuclear use". This concept was developed as a prerequisite for the termination of safeguards on nuclear material under the safeguards system as defined in the IAEA document INFCIRC/66 and its revisions. The concept of "practically irrecoverable" was carried forward into the safeguards system as adapted for verification of the NPT obligations of NNWSs in INFCIRC/153 (Corr.).

The term "practically irrecoverable" was left without a specific, formal definition, which was likely intentional. Attempts to define specific, technical criteria for the termination of safeguards – as described in a report from a 1989 IAEA consultants' meeting for the development of technical criteria for termination of safeguards for material categorised as 'measured discards' – have been unsuccessful in defining what 'uneconomic to recover' would mean in practice or how to cope with the wide variation of plutonium concentration in waste streams from different types of nuclear fuel.[35] In 1991, Abdul Fattah and Nikolai Khlebnikov – then staff members of the IAEA Secretariat – proposed a set of technical criteria for the termination of safeguards. However, they acknowledged that "it would be unrealistic to establish universally applicable criteria governing a wide range of physical forms, quantities, concentrations and compositions of waste."[36]

This experience indicates that there may need to be some flexibility in making technical determinations as to whether fissile material is practically irrecoverable for nuclear use, or for the purposes of this study, has been irreversibly disposed.

32 David Cliff, Hassan Elbahtimy, and Andreas Persbo, "Irreversibility in Nuclear Disarmament: Practical steps against nuclear rearmament", pg. 27, VERTIC, September 2011.

33 Treaty on the Prohibition of Nuclear Weapons (hereafter "TPNW"), Articles 2.1(a) and 4.6

34 TPNW, Article 4.2

35 Consultants' Report on Meeting for Development of Technical Criteria for Termination of Safeguards for Material Categorized as Measured Discards (STR-251 (Rev. 2)), International Atomic Energy Agency, March 1990. Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/42/039/42039820.pdf?r=1.

36 Abdul Fattah and Nikolai Khlebnikov, "A Proposal for Technical Criteria for Termination of Safeguards for Materials Characterized as Measured Discards", Journal of Nuclear Materials Management, 1 May 1991. Available at: https://resources.inmm.org/jnmm/proposal-technical-criteria-termination-safeguards-materials-characterized-measured-discards.

The experience of safeguards also demonstrates that conclusions about material being 'practically irrecoverable', including the case of irreversibility, may be informed by factors other than purely technical ones. This is exemplified by the IAEA's use of so-called State-specific factors, which are used along with the practice of acquisition path analysis to determine the technical objectives to be met in individual State-level safeguards approaches (SLAs). The use of State-specific factors was an evolution from the use of the prescriptive Safeguards Criteria from the 1980s and 1990s and was developed with a view to conducting safeguards for the State as a whole as opposed to looking at individual facilities declared by the State. The factors range from consideration of the State's nuclear fuel cycle capabilities to the IAEA's experience in implementing safeguards in the State concerned.[37]

It remains an open question how State-specific factors may be applicable to large-scale nuclear disarmament verification, considering the potentially politicised environment in which disarmament may occur. This includes the possible insistence of all NWSs that disarmament verification be conducted in a prescriptive fashion. However, the precedent of the IAEA practice for the termination of safeguards may be useful. If and when such materials are classified as "practically irrecoverable" in accordance with agreed criteria, they may be exempted from verification procedures. This could help reduce the costs of what almost inevitably will be a complex and potentially expensive verification system.

There is some debate between IAEA Member States about whether the Agency has a role in nuclear disarmament verification, despite its experience in verifying the disarmament of Iraq and South Africa (in the latter case, ex post facto) and its experience in programmes pursued together with States, such as the Russia-US-IAEA Trilateral Initiative, as discussed below.[38] In 2024, the VCDNP and the research consortium VeSPoTec (Verification in a Complex and Unpredictable World: Social, Political and Technical Processes) held a workshop with eminent experts on IAEA safeguards and nuclear verification on the IAEA's role in the irreversible reduction and elimination of military nuclear stockpiles. Workshop participants concluded that, as long as the IAEA did not gain access to classified, weapon-sensitive information, it would certainly have a role to play.[39]

Fissile Material Disposition Programmes and Irreversibility

In the 1990s, as the United States and Russia embarked on deep reductions in nuclear weapons, they addressed, in addition to formal arms control treaties, issues related to the handling of fissile material removed from nuclear weapons. Arms control regimes did not tackle stockpiles of nuclear weapons themselves, but both sides began to reduce these stockpiles unilaterally in parallel and decided to introduce an element of transparency, ensuring that the fissile material from weapons is not recycled back into nuclear weapons production. These activities de facto operationalised the nexus between irreversibility, transparency, and verification for the purpose of disposing of weapons-grade fissile material, and as such, provided important practical insights into how the issue of irreversible nuclear disarmament could be addressed.

37 For a discussion on State-specific factors, see Noah Mayhew, "A Lexical History of the State-Level Concept and Issues for Today", pp. 25-30, Vienna Center for Disarmament and Non-Proliferation, 14 December 2020. Available at: https://vcdnp.org/wp-content/uploads/2021/01/Lexical-History-of-the-State-level-Concept_Final.pdf.

38 Thomas E. Shea and Laura Rockwood, "IAEA Verification of Fissile Material in Support of Nuclear Disarmament," Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, May 2015. Available at: https://www.belfercenter.org/sites/default/files/pantheon_files/files/publication/iaeaverification.pdf.

39 Leonardo Bandarra, Noah Mayhew and Malte Gottsche, "The IAEA and Irreversibility: Addressing Political, Institutional and Technological Verification Challenges in Former Nuclear-Armed States," Journal for Peace and Nuclear Disarmament, 14 December 2024. Available at: https://vcdnp.org/the-iaea-and-irreversibility-addressing-political-institutional-and-technological-verification-challenges-in-former-nuclear-armed-states/.

In January 1994, US President Bill Clinton and Russian President Boris Yeltsin launched the Safeguards, Transparency, and Irreversibility (STI) programme noted above to ensure that nuclear material removed from dismantled warheads would not be recycled back into weapons production. An STI Joint Working Group was established to, inter alia, develop steps "to ensure the transparency and irreversibility of the process of reduction of nuclear weapons, including the possibility of putting a portion of fissionable material under IAEA safeguards."[40] Among other tasks, the group was directed to address data exchange on nuclear weapons stockpiles and fissile material, verification (including on-site) of fissile material declarations, development of procedures to verify dismantlement of nuclear weapons, and control of fissile material removed from weapons.

A December 1994 non-paper drafted by the United States identified irreversibility as one key objective of an STI regime, along with transparency, safeguards and security, and political benefits.[41] The mandate of the group included the development of measures to ensure confidence that "nuclear arms reductions being carried out are irreversible", and in particular that fissile material "declared excess to military needs (including civilian weapons-usable materials) are not being used to build new nuclear weapons."

At a May 1995 summit, the US and Russian presidents agreed on a more detailed agenda in the areas of transparency and irreversibility. In particular, they instructed their governments to negotiate an agreement that would include, inter alia, regular exchange of data on nuclear weapons stockpiles and fissile material, reciprocal monitoring at storage facilities for fissile material removed from nuclear weapons and declared to be excess, and other elements. The anticipated agreement on monitoring was also tied to nuclear material storage at the Mayak facility in Russia.

Although the STI Working Group achieved important initial progress, its work was terminated by the Russian Federation in the fall of 1995. Elements of the work, however, continued under the umbrella of the HEU Purchase Agreement and the Plutonium Management and Disposition Agreement (PMDA), described below.

The 1993 HEU Purchase Agreement provided for the conversion of 500 tonnes of weapons-grade HEU into LEU in Russia and the sale of the resultant LEU to the United States for use in civilian power generation. The agreement included monitoring and verification protocols and identified equipment needed for verifying conversion of material without revealing classified information.[42] Verification measures included the right to observe containers with HEU components of dismantled weapons and to conduct certain agreed measurements.

In 2000, the United States and Russia signed the PMDA, which provided for the elimination of 34 metric tonnes of plutonium declared excess to national security needs by each side.[43] The agreement explicitly provided for an irreversible method of disposition. It foresaw disposition through the production and irradiation of mixed-oxide (MOX) fuel for nuclear power generation or immobilisation with highly radioactive waste. Although the programme was later suspended due to political tensions, questions of how truly irreversible immobilisation with high-level waste, irradiation as MOX fuel, or the later US-preferred 'dilute and dispose' method were heavily debated. The programme ended inconclusively about decade and a half later with parties failing to reach an agreement on specific methods for disposition with the MOX fuel option strongly criticised in the United States and the 'dilute and dispose' method criticised by Russia.[44]

40 Joint Statement on Non-Proliferation of Weapons of Mass Destruction and the Means of Their Delivery, Administration of William J. Clinton, 14 January 1994. Available at: https://www.govinfo.gov/content/pkg/PPP-1994-book1/pdf/PPP-1994-book1-doc-pg71.pdf.

41 "Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement", Office of Arms Control and Nonproliferation, United States Department of Energy, 19 May 1997. Available at: https://www.nti.org/wp-content/uploads/2021/09/DOE_Office_of_Arms_Control_and_Nonproliferation_1997_Transparency_and_Verification_Options.pdf.

42 Ann Parker, "A Transparent Success: "Megatons to Megawatts" Program", Lawrence Livermore National Laboratory, April/May 2013. Available at: https://str.llnl.gov/content/pages/april-2013/pdf/4.13.3.pdf.

43 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, as amended by the 2010 Protocol, 2000. Available at http://fissilematerials.org/library/PMDA2010.pdf.

44 Ed Lyman, "Excess Plutonium Disposition: The Failure of MOX and the Promise of Its Alternatives", Union of Concerned Scientists, December 2014. Available at: https://www.ucsusa.org/sites/default/files/attach/2015/01/Excess%20Plutonium%20Disposition.pdf.

The methods of disposition foreseen in the PMDA were inspired by the earlier proposal of the US National Academy of Sciences in 1994, under which disposed plutonium should be made "roughly as inaccessible for weapons use as the much larger and growing stock of plutonium in civilian spent fuel".[45] This option was considered in the context the Trilateral Initiative.

The Trilateral Initiative (1996-2002), which included the United States, Russia, and the IAEA, intended to identify legal, technical, and financial means, through which the IAEA could verify that weapon-origin fissile material, including in classified forms, remained removed from US and Russian nuclear weapons programmes.[46] While the Initiative was never fully implemented, it succeeded in designing a technical approach for plutonium verification that was acceptable to both the US and Russian defence establishments.

US-Russian programmes pursued in the 1990s and some even into the 2000s, addressed head-on issues relevant to nuclear disarmament, even though the immediate purpose was more limited, specifically, making sure that weapons-grade fissile material withdrawn from nuclear weapons as both States were reducing their weapons stockpiles were not recycled back into weapons production. Similar approaches, however, could work on a larger scale and thus directly contribute to nuclear disarmament.

The US and Russia, in effect, tested the practical application of transparency of weapons-grade fissile material, verification of their removal from weapons programmes and storage, and arrangements needed to make them what under IAEA terms might be defined as 'practically irrecoverable' for nuclear use. They also proposed and partially tested practical methods, criteria, and procedures for verification of such activities. Specifically, the two countries de facto defined the dismantlement of nuclear weapons as removal of fissile material and worked on procedures to verify that that was the case (similar procedures were also developed and tested in the UK-Norway experiment later), accounting for and secure storage of plutonium pits removed from weapons, and disposition of the plutonium. Development of all of these methods and procedures was led by the United States, but was subsequently negotiated with Moscow and effectively represented agreement of the two leading nuclear-armed States about the practical definition of irreversibility (albeit in the context of more limited tasks, arms control rather than disarmament).

An important feature of all these procedures was strict limitation on access to classified information (including on the design of nuclear weapons and characteristics of the fissile material used in weapons). These limitations were motivated by a long-standing practice of secrecy in both the US and the Soviet Union/Russia regarding nuclear weapons design and production information. Release of nuclear weapons design information, even to another nuclear-armed State, was and is considered a grave danger to national security because weapons design information could give another State the ability to copy the design, design counter-measures, or come up with superior designs. In a broader disarmament context involving NNWSs, this approach will likely remain with even stronger justification since it would additionally help prevent unintentional proliferation of nuclear weapons design information, even as arsenals are being eliminated. In short, classified information and protocols for guarding it are likely to remain an essential – and difficult – part of the process, when a larger set of States and a more complete set of weapons are under consideration for disarmament.

An overview of practical measures implemented by the US and Russia suggests that accounting and verification of nuclear warhead stockpiles proved to be the most controversial and difficult-to-resolve issues – more difficult than similar measures for weapons-grade fissile material. The STI effectively collapsed over the former issue, whereas elements pertaining to fissile material were implemented in the context of other initiatives. Nuclear warhead stockpiles proved to be particularly controversial for Russia, especially after 1994.

45 Committee on International Security and Arms Control, "Management and Disposition of Excess Weapons Plutonium". National Academy of Sciences, March 1994. Available at: https://scholar.harvard.edu/files/matthew_bunn/files/bunn_management_and_disposition_of_excess_weapons_plutonium.pdf.

46 Thomas E. Shea and Laura Rockwood, "IAEA Verification of Fissile Material in Support of Nuclear Disarmament", Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard University, May 2015. Available at: https://www.belfercenter.org/sites/default/files/files/publication/iaeaverification.pdf.

The unilateral parallel steps on the reduction of non-strategic nuclear weapons in the 1991 Presidential Nuclear Initiatives (PNIs) did not contain any legally or politically binding obligations, nor did they include transparency or verification procedures.[47] Yet, the statement made by Soviet President Mikhail Gorbachev at the time contained an offer to launch formal negotiations on a legally binding treaty addressing these weapons. Unfortunately, the United States declined to pursue the matter in the fall of 1991 and, by 1994, the Russian position had already changed and the offer was off the table.

Addressing nuclear weapons stockpiles was key to the success of the PNIs because both sides had many thousands of non-strategic delivery vehicles that could carry nuclear weapons. Even if some of them were not equipped for a nuclear mission, they were often indistinguishable from systems of the same type that were intended for nuclear warheads. Hence, reductions had to concentrate on nuclear warhead stockpiles instead of the delivery vehicles, as had been customary for strategic arms treaties. For Russia, however, nuclear weapons storage remained the most sensitive category of sites, more sensitive than the storage of plutonium pits, and with the exception of a short period in 1991-1994, it resisted any transparency and verification measures with respect to nuclear warhead stockpiles. Although US representatives were allowed to visit some storage sites, such visits were characterised by stringent managed access procedures.

Nuclear Arms Control and Delivery Vehicles

The 2011 VERTIC paper identified elimination of delivery vehicles for nuclear weapons as one of the options for irreversible nuclear disarmament. Indeed, these vehicles are one of three components of a nuclear weapons programme. A 1999 study published by Princeton University argues that the elimination of delivery vehicles reinforces the elimination of the warheads themselves.[48] Nuclear weapons are only relevant when they can be delivered to the target. In this respect, a study of experiences in nuclear arms control is instructive, as arms control treaties in the past have focused on delivery vehicles rather than on nuclear material or nuclear weapons. This is because it was deemed easier to devise counting rules and verification for delivery vehicles, based on the premise that they are bigger (hence easier to verify) and usually more expensive than the warheads themselves.

Lessons Learned from the INF Treaty

The first treaty that provided for genuine reductions of delivery vehicles with strong elements of irreversibility was the Intermediate-Range Nuclear Forces (INF) Treaty. Joseph Rodgers and Heather Williams pointed out that the Treaty provided for the elimination of an entire class of US and Soviet nuclear-capable missiles (ground-launched missiles with ranges between 500 and 5,500 kilometres), robust data exchange and verification mechanisms, and the establishment of a Special Verification Commission to facilitate the implementation of the Treaty.[49] The irreversibility of reductions was ensured through a number of measures, including:

- Comprehensive, regular exchange of data pertaining to intermediate-range missiles encompassing the entire life-cycle from production to elimination;
- Detailed procedures for the dismantlement of missiles and associated launchers;
- Intrusive verification, including enhanced national technical means, on-site inspections, and monitoring of missile production facilities; and
- Confidence-building measures.

47 Nikolai Sokov and William Potter, “The Presidential Nuclear Initiatives, 1991-1992: An Assessment of Past Performance and Future Relevance”, Toda Peace Institute, October 2018. Available at: https://nonproliferation.org/the-presidential-nuclear-initiatives-1991-1992/.

48 Oleg Bukharin and Kenneth Luongo, “U.S.-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals”, pp. 20-21, Center for Energy and Environmental Studies, School of Engineering and Applied Science, Princeton University, April 1999

49 Joseph Rodgers and Heather Williams, “The Irreversibility Paradox: What Makes for Enduring Arms Control and Disarmament”, Journal for Peace and Nuclear Disarmament, 13 December 2023. Available at: https://www.tandfonline.com/doi/full/10.1080/25751654.2023.2292812.

The implementation of the verification regime continued in full for ten years after the completion of the elimination of INF-range missiles (which took three years). After that, the Treaty remained in force, but without verification. The INF Treaty also revealed certain challenges associated with that particular approach to the elimination of nuclear-capable delivery vehicles, the methods of implementation, and the legal framework chosen by the United States and the Soviet Union.

First, the Treaty provided for the elimination of all ground-launched nuclear-capable missiles with a range between 500 and 5,500 kilometres. This had two consequences.

It left untouched air and sea-launched missiles with similar ranges, which allowed for arms racing in these categories. That drawback can be addressed by a more comprehensive regime. More importantly, it also precluded the use of intermediate-range missiles for conventional payloads. This feature came to haunt the INF Treaty already in the late 1990s to early 2000s when Russia contemplated the development of a conventional long-range strike capability. In future, if the elimination of nuclear-capable delivery vehicles accompanies the elimination of nuclear weapons, parties will need to accept that this could also result in a ban on conventional delivery vehicles or require special intrusive verification provisions.

Second, while economic considerations were used to justify abandonment of verification after ten years, this created a vulnerability, which led to a major crisis a decade later and ultimately the demise of the Treaty. The absence of a verification regime created a window for suspicions about non-compliance. Furthermore, the parties failed to utilise the Special Verification Commission to properly address them. As a result, the Treaty collapsed in 2019 and both the United States and Russia now plan to deploy ground-launched intermediate-range missiles in Europe and the Asia-Pacific region. The lesson that could be drawn from that negative experience is that it can be risky to terminate a verification regime after a limited period of time. An accompanying lesson is that there is long-term value in using cooperative institutions and approaches to resolve conflicts, even (perhaps even especially) when political relations are unfavourable.

Lessons Learned from the START Treaty

The reduction of nuclear-capable delivery vehicles continued in the 1991 Strategic Arms Reduction Treaty (START I) and subsequent treaties on strategic weapons. They followed the principles first agreed upon in the INF Treaty, but START I provided for even more comprehensive data exchange and more intrusive inspections as well as additional verification measures. This included, in particular, the exchange of telemetry data from ballistic missile launches, which disclosed technical characteristics of missiles to the other side.

The experience of implementing these treaties has yielded the following lessons potentially relevant for irreversibility of nuclear disarmament.

First, while the verification mechanism for START I was comprehensive and intrusive, it also turned out to be cumbersome and expensive to implement. This was perhaps not surprising because negotiators had little practical background to build on when developing procedures; the INF Treaty could offer only limited guidelines for a much more complex document. Having successfully implemented START I for nearly two decades,[50] the United States and Russia negotiated a simpler, more streamlined, and cheaper verification system for the 2010 New START Treaty. This may point to an inverse relationship between effectiveness of verification and costs: a regime that provides a high level of assurance will likely be expensive to implement, and this phenomenon needs to be taken into account during negotiations, so that an acceptable balance between the two can be found. It also makes sense to test procedures prior to finalising them.

50 START I entered into force in December 1994 and expired in 2009, but multiple provisions entered into force upon signature in August 1991.

Second, the United States and Russia failed to fully agree on procedures for the conversion of strategic bombers from nuclear to conventional roles. The Treaty only required conversion "to the satisfaction" of the other party, but Russia remained concerned that procedures developed by the United States were insufficient because bombers could be converted to their original roles, although it would have taken time and effort. This issue demonstrated that irreversibility is a continuum rather than a fixed point and that preferences of players on what should be considered a sufficient degree of irreversibility might differ. It should be noted, however, that differences on the issue of conversion of strategic bombers did not hinder successful implementation of START I and subsequent treaties.

The challenges associated with the elimination of nuclear-capable delivery vehicles were particularly salient with respect to non-strategic weapons. As described above, there are thousands of non-strategic delivery vehicles (both missiles and aircraft), most of which are at least in theory nuclear-capable. It is difficult to differentiate a nuclear-capable delivery vehicle from one that is not equipped for nuclear warheads. Hence, the United States and Russia have always refrained from using delivery vehicles as the main accounting unit for this category of nuclear weapons. Addressing them within the context of nuclear disarmament may require agreement on differentiation and intrusive verification procedures to ensure that a missile or an aircraft has not been converted for a nuclear mission.

Echoes of a Weapons Programme: Institutional Memory and Infrastructure

The third piece of a nuclear weapons programme consists of the infrastructure and personnel that make up the nuclear weapons complex, the web of institutions that design, assemble, and deliver the nuclear weapon for placement on delivery vehicles, using fissile material manufactured by the same complex. This includes both what the 2011 VERTIC study referred as issues associated with the "endurance of knowledge" as well as how to address remaining nuclear-related infrastructure, such as uranium enrichment and plutonium reprocessing capabilities. Or, according to Nick Ritchie, it "takes organisational effort, knowledge, money, and political will to bring a nuclear weapons complex together and sustain it."[51]

This "endurance of knowledge" question will create novel challenges that are likely specific to each disarmed country. In this respect, the example of South Africa's nuclear disarmament is instructive. The government of South Africa granted the IAEA unprecedented access to verify not just that all of its fissile material was under safeguards, but also that all non-nuclear weapon-specific components of the weapons had been destroyed, all facilities associated with the weapons programme had been fully decommissioned, and all weapon-specific equipment had either been destroyed or converted to peaceful use.[52] An IAEA report even notes the destruction of weapons-programme-related software, which would undoubtedly be much more challenging today.[53] While the IAEA does not "close the file" on any country's nuclear activities, the IAEA was able, owing to South Africa's transparency and cooperation, to conclude by 1995 (four years after South Africa's safeguards agreement had entered into force) that "there were no indications to suggest that the initial inventory is incomplete or that the nuclear weapon programme was not completely terminated and dismantled."[54]

How to ensure that the expertise supporting a weapons programme is not used to support other weaponisation activities remains challenging. Following the dissolution of the Soviet Union, the United States, together with other countries, launched several programmes intended to provide alternative employment for scientists and engineers who worked in the Soviet nuclear weapons complex to prevent the transfer of nuclear weapons-related knowledge and expertise to other countries.

51 Nick Ritchie, "Irreversibility and Nuclear Disarmament: Unmaking Nuclear Weapon Complexes", pg. 222, Journal for Peace and Nuclear Disarmament, 21 November 2023. Available at: https://www.tandfonline.com/doi/full/10.1080/25751654.2023.2282737.

52 IAEA, The Denuclearization of Africa (GC(XXXVII)/1075), 9 September 1993. Available at: https://www.iaea.org/sites/default/files/gc/gc37-1075_en.pdf.

53 IAEA, The IAEA Verification in South Africa (GOV/INF/698), 27 May 1993.

54 Adolf von Baeckmann, Garry Dillon and Demetrius Perricos, "Nuclear verification in South Africa", IAEA Bulletin, 1/1995, IAEA, March 1995. Available at: https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull37-1/37105394248.pdf.

In addition to technical verification measures, political steps contribute to confidence in the irreversible destruction of physical infrastructure. At the 2010 NPT Review Conference, France presented two working papers on the dismantlement of the Pacific Testing Centre and its plants for the production of fissile material for nuclear weapons, respectively.[60] In both cases, the French government declared that the dismantlement was irreversible, de facto taking a politically binding obligation not to reconstitute the capabilities. In the case of the Pacific Testing Centre, France invited an IAEA mission to visit the site. In the case of the fissile material production facilities, France organised visits for representatives of States that are members of the Conference on Disarmament, for non-governmental experts, and for foreign journalists. These steps, taken together with the political declaration, were meant to improve confidence in the irreversibility of dismantlement. As with the human component of a nuclear weapons programme, the monitoring of former facilities associated with nuclear weapons as well as other facilities that could be converted for that purpose will need to continue in a disarming world, even if only at a low level.

Without doubt, voluntary transparency and confidence-building measures can reduce the burden of verification. The experience of North Korea illustrates the value of these measures. When the North Korean government reported that it had destroyed the Punggye-ri Nuclear Test Site in 2018, it only hosted foreign journalists who saw a detailed topographical map of the site, which was based in a mountain.[61] There was no declaration that the destruction was irreversible nor were any technical observers permitted to inspect the site. North Korea is currently suspected of reconstructing the site.

The situation with human capital and industrial infrastructure serves as a reminder of the fact widely shared by experts that irreversibility is an ongoing process. Alice Spilman calls irreversible nuclear disarmament a "continuous and iterative process".[62] Irma Arguello similarly says that "disarmament is an inherently gradual process where irreversibility is an intrinsic part of the design for each action."[63]

Confidence versus Feasibility in Steps Along the Irreversibility Spectrum

There are a number of factors which will affect the feasibility of achieving a certain desired end state of nuclear disarmament and the likelihood of adopting measures assuring its irreversibility, including verification. The relationship between confidence and feasibility along the irreversibility spectrum is complex and often contradictory, certainly non-linear.

The Irreversibility Paradox

One of the core considerations defining the relationship between desirability versus feasibility of different disarmament end states is what Joseph Rodgers and Heather Williams call the "irreversibility paradox". In their words, this is "a parallel trade-off in between political, legal, and technical measures, including verification and transparency, which can strengthen and confirm irreversibility, and security concerns that will motivate states to build flexibility into agreements, making them *less* irreversible."[64] One example they offer is the existence of a withdrawal clause in nuclear-related agreements, which inherently makes the steps taken under an agreement reversible, but without which States are less likely to accede to the agreement.

60 "Dismantling of the Pacific Testing Centre" (NPT/CONF.2010/WP.36), 12 April 2010. Available at: https://digitallibrary.un.org/record/682367?ln=en.

"Dismantling of plants for the production of fissile material for nuclear weapons" (NPT/CONF.2010/WP.37), 12 April 2010. Available at: https://digitallibrary.un.org/record/682317?ln=en.

61 Frank Fabian, Joseph S. Bermudez Jr. and Jack Lui, "The Punggye-ri Nuclear Test Site Destroyed: A Good Start but New Questions Raised about Irreversibility", 38 North, Stimson Center, 31 May 2018. Availability: https://www.38north.org/2018/05/punggye053118/.

62 Alice (CSIS)

63 Irma (CSIS)

64 Joseph Rodgers and Heather Williams, "The Irreversibility Paradox: What Makes for Enduring Arms Control and Disarmament", Journal for Peace and Nuclear Disarmament, 13 December 2023.

The International Science and Technology Center (ISTC) and the Nuclear Cities Initiative are examples of efforts to address this challenge.[55]

South Africa, too, grappled with this issue. Following the closure of its weapons programme, it struggled to keep its nuclear scientists gainfully employed. This led to an episode, in which 16 former weapons experts threatened to sell weapon-sensitive information (although they later admitted the threat was a bluff in an attempt to negotiate a better retirement package).[56]

These examples provide important guidance for tackling this aspect of irreversibility, but much may depend on what happens to the civilian nuclear sector. If the civilian sector continues to exist after the elimination of nuclear weapons, alternative employment may be easier to find compared to options that include complete closure of the nuclear energy sector. The task may be even more challenging in a State with a large nuclear weapons programme.

However, expertise supporting a weapons programme would eventually fade. As the 2011 VERTIC study points out, "Artisanal skills such as these can only be learnt 'on the job'; reading an instruction manual will not suffice. Were a generation of machinists to die without training replacements, future generations would, in a sense, have to reinvent their skill."[57] Nick Ritchie refers to this process of decreasing States' weapons-related competencies, meanings, and institutions as "exnovation" as opposed to innovation.[58]

That said, knowledge and expertise related to nuclear weapons is hardly "cutting edge." The essential concepts were developed decades ago and can be restored or developed from scratch if a political decision were made and sufficient resources and time were committed. The loss of expertise caused by generational change will slow down the process and may result in a more primitive design, but nonetheless knowledge can be recreated. This means that an "end state" for verification and transparency can hardly be contemplated.

The physical infrastructure associated with a nuclear weapons programme, too, will be a challenge to irreversibility. Of the five potential end states of nuclear disarmament identified in the 2011 VERTIC study, two involve the elimination of certain elements of a nuclear programme and associated facilities, for example enrichment and reprocessing. The study argues that, if nuclear programmes and facilities are eliminated early, verification will be easier to implement, and can even be made more intrusive, compared to the case where numerous facilities shrouded in secrecy remain operational.

The logic behind this proposal is compelling. If a State loses the ability to produce fissile material, there is less to verify and an attempt to reverse disarmament would entail rebuilding of industrial facilities, which would be easier to detect. Hassan Elbahtimy later argued that this "irreversibility of the interim" – or steps taken towards disarmament – would "entail designing policies aimed at influencing the reversibility potential of those interim steps and neutralizing any backsliding. This would increase the chances that any partial progress achieved is locked-in to allow cumulative follow-on steps towards achieving disarmament."[59] In contrast, the other three end states of disarmament identified by VERTIC entail close monitoring of fissile material production to detect diversion, an activity analogous to IAEA safeguards.

55 "The Nunn-Lugar Cooperative Threat Reduction Program", Center for Arms Control and Non-Proliferation. Available at: https://armscontrolcenter.org/wp-content/uploads/2022/03/Nunn-Lugar-CTR.pdf.

56 David Albright and Andrea Sticker, "Revisiting South Africa's Nuclear Weapons Program", pg. 257, Institute for Science and International Security, 2016.. Available at: https://isis-online.org/uploads/isis-reports/documents/RevisitingSouthAfricasNuclearWeaponsProgram.pdf.

57 David Cliff, Hassan Elbahtimy, and Andreas Persbo, "Irreversibility in Nuclear Disarmament: Practical steps against nuclear rearmament", pg. 24, VERTIC, September 2011.

58 Nick Ritchie, "Irreversibility and Nuclear Disarmament: Unmaking Nuclear Weapon Complexes", pg. 227, Journal for Peace and Nuclear Disarmament, 21 November 2023

59 Hassan Elbahtimy, "Approaching Irreversibility in Global Nuclear Politics", pg. 211, Journal for Peace and Nuclear Disarmament, 20 December 2023.

The 2018 IPNDV food-for-thought paper also discusses this paradox and refers to the potential desire for disarmed States to maintain a hedging capability:

"It is even possible to consider that irreversibility could be viewed as a hindrance for disarmament: If a State perceives that there is no step back from a given disarmament measure, it may be unwilling to try it and open this path if it suspected that others were in non-compliance to their disarmament obligations. This is where verification and transparency come in as essential auxiliary measures that in a longer perspective can ensure that a State will not step back from disarmament commitments made."[65]

Similarly, Nick Ritchie argues that the "managed discontinuation" of nuclear weapons testing "shows how a commitment to an irreversible change through a prohibition and phase-out was conditioned on a plausible pathway to reversal."[66] He further argues that the longer an activity is discontinued – in this case, the longer a State goes without nuclear testing – the more difficult the prohibition becomes to reverse. Eventually, it would not be a matter of a State restarting nuclear testing, but rather reinventing the capability to do so. Indeed, in the long period since the practice of non-testing has become the norm in almost all nuclear-armed States, concern about losing this capability has been part of what motivates the robust conventional weapons test programmes that persist. Conventional testing activities are a way to preserve many aspects of nuclear weapons testing know-how, while remaining compliant with the CTBT (even prior to its entry into force).[67]

Verification Intrusiveness, Managed Access, and Weapon-Sensitive Information

Another issue that affects confidence versus feasibility of verification measures is the degree of intrusiveness, including requirements for managed access to sensitive nuclear facilities and classified or weapon-sensitive information. This issue was extensively contemplated in the context of the HEU Purchase Agreement: American monitors were excluded from more sensitive parts of the downblending process, such as the actual weapon dismantlement and the chipping of the uranium cores. However, they were permitted to conduct gamma measurements in between all steps and to observe the less sensitive parts of the process, including the oxidation, fluorination, and actual downblending of the material. This, paired with specific transparency measures identified in the agreement and the reciprocity in the monitoring activities (Russian monitors observed the fabrication of the downblended LEU into fuel for US reactors), provided an acceptable level of confidence in the irreversibility of the material disposition (defined for the purpose of that agreement as assurances that materials removed during the dismantlement would not be cycled back into weapons production).

Similarly, the Trilateral Initiative succeeded in overcoming sensitivities in the handling of classified and weapon-sensitive information by designing an attribute verification system with information barriers. This system provided yes/no indications based on gamma and neutron measurements that the material in question was plutonium, that it was weapons-grade, and that the mass of the material was greater than an agreed threshold. However, as noted previously, the subject of irreversibility remained outstanding at the end of the Trilateral Initiative. This was partially due to difficulties in agreeing on verification equipment authentication.[68]

65 Food-for-Thought Paper: Achieving Irreversibility in Nuclear Disarmament, Working Group 1: Monitoring and Verification Objectives, IPNDV, January 2018.

66 Nick Ritchie, "Irreversibility and Nuclear Disarmament: Unmaking Nuclear Weapon Complexes", pg. 233, Journal for Peace and Nuclear Disarmament, 21 November 2023.

67 Congressional Research Service, "US Nuclear Weapons Tests", December 2020. Available at: https://apps.dtic.mil/sti/trecms/pdf/AD1171932.pdf.

68 The issue of authentication remained outstanding after the Trilateral Initiative was concluded. It was anticipated that, if the IAEA were to provide equipment to the State and request the State to certify that that equipment could be used at a sensitive facility, the State concerned would carry out its investigations of the equipment using methods that it would not identify. If the equipment were found to be acceptable to the State, the Agency would then have to be able to assure itself that the equipment had not been tampered with, which could be very difficult to detect. If the equipment was not found to be acceptable, the State would not tell the Agency the reason why and the equipment might not be returned to the Agency at all. In either case, the equipment would have been dismantled to the point that any assurance the IAEA might have had that its use would have provided authentic results would have been lost. The certification tests might require months to complete with little assurance that the outcome would be positive. For more information, see Thomas E Shea, "The Trilateral Initiative: IAEA Verification of Weapon-Origin Plutonium in the Russian Federation and the United States" IAEA Symposium on International Safeguards, 2014.

As a general rule, the level of intrusiveness seems to be inversely related to the feasibility of reaching an agreement. In the HEU Purchase Agreement referenced above, the US had, for a time, insisted on more intrusive measures that could have made conclusion of the agreement impossible. The exact relationship between intrusiveness and feasibility in each specific agreement may be defined ad hoc during negotiations. The symmetry of obligations between parties is likely to play an important role; each party not only seeks to obtain more data about the other, but is also mindful that the other party will obtain similar data about its own programme and activities.

Cost of Verification

Cost will be an important consideration for determination of the feasibility of different end states in nuclear disarmament, especially in a world where countries with extensive nuclear weapons programmes and supporting infrastructure disarm. An early insight into the scale of relevant costs may be found in the 1997 warhead dismantlement study by the US Department of Energy, which offered four options for monitoring. These ranged from $2.5 to $12 million for a first inspection of the Pantex facility in the United States ($4.8 to $23.06 million if adjusted to 2024, according to US Consumer Price Index).[69] The high estimate of $12 million assumed a permanent presence of inspectors at a cost of $5.5 million per year.

These costs would obviously see significant increases in a world where multiple States had disarmed and would likely further increase, depending on which body were to be doing the monitoring and verification work. Should the IAEA be tasked with verification, the international community would have to consider its approach towards funding the Agency, which already faces resource constraints when implementing its existing mandate.[70] Additional complications for the IAEA to take this role include the likely necessity to establish an entirely new department or division for nuclear disarmament verification, likely staffed by weapons experts from the disarmed States themselves.[71]

Compared to current IAEA expenditures, the costs will be significant regardless of whether verification is entrusted to the IAEA (with attendant new departments) or whether, as Thomas Shea has argued, a dedicated new organisation (he called it the International Nuclear Disarmament Agency) is created.[72] While the latter option potentially avoids some of the political pitfalls associated with the IAEA conducting disarmament verification, the cost considerations remain. While the IAEA is generally kept to a zero-real-growth budget (meaning the budget increases to account for inflation but not otherwise), most of the rest of the UN system is kept to zero-nominal growth (meaning no budget increases at all). Should a new organisation be established to verify nuclear disarmament, it is unclear whether it would be able to follow the same principles.

Regardless of which body conducts verification, it will be bring additional costs beyond current IAEA expenditures and will likely be affected by other political and institutional considerations – just as the IAEA is. This raises questions as to how willing NNWSs would be to contribute financially to nuclear disarmament verification, and if that would look different from the existing UN system of assessed contributions. During the Trilateral Initiative, the IAEA considered a number of funding vehicles which might provide instructive examples, including voluntary funding and assessed contributions either to the IAEA's regular budget or through a special fund.[73]

69 "Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement", pg. 3, Office of Arms Control and Nonproliferation, United States Department of Energy, 19 May 1997.

70 See Noah Mayhew and Ingrid Kirsten, "Navigating the IAEA Budget Process," VCDNP, 13 June 2023. Available at: https://vcdnp.org/navigating-the-iaea-budget-process/.

71 Leonardo Bandarra, Noah Mayhew and Malte Gottsche, "The IAEA and Irreversibility: Addressing Political, Institutional and Technological Verification Challenges in Former Nuclear-Armed States," Journal for Peace and Nuclear Disarmament, 14 December 2024.

72 Thomas Shea, "Verifying Nuclear Disarmament", Routledge, 2019.

73 The Secretariat's report submitted for consideration by the board included voluntary funding and mandatory (assessed) funding. The voluntary model considered was the establishment of a fund financed through voluntary contributions. The regular budget assessed funding options were: (1) funding in accordance with the regular budget scale of assessment; (2) funding in accordance with the existing formula for assessed contributions to safeguards costs; or (3) funding in accordance with a different formula (or formulas). There was a fourth assessed funding option presented to the Board for the establishment of non-regular-budget special fund(s), with contributions based on a mandatory assessment in accordance with the regular budget scale of assessment, the existing safeguards formula or a revised formula. For more information, see IAEA, "Financing Agency Verification of Nuclear Arms Control and Reduction Measures" (GOV/INF/1999/9), 21 May 1999.

That said, there is some reason to think that the economic trade-off may be found worthwhile by any country party to the disarmament process. First, the security benefit for all concerned, arising from complete or substantial NWS disarmament, would perforce be substantially greater than that obtained from IAEA safeguards implementation alone. Second, especially for the NWS but also others, the additional costs of implementation can be compared to and may even be offset by the savings that arise from no longer having to maintain as expensive a nuclear weapons or other military complex, due to the increased international security that would be anticipated through the implementation of the treaty. Even leaving aside the human, environmental, and social costs, the direct economic costs associated with an actual nuclear exchange or the threat thereof are historically known to be high, and the strong possibility that these costs would be lessened can be balanced against treaty-related expenditures in any reckoning of the economic impacts of disarmament treaty implementation.

Politics and Negotiations

As noted above, any decision on the specific relationship between irreversibility and feasibility will be affected by international politics, as well as the diverging interests and aspirations of the States participating in the negotiations. The role of NWSs will undoubtedly be significant, but the positions of NNWSs will play an important role, too. States negotiating an agreement or a package of agreements on nuclear disarmament will likely hold divergent views on the degree of irreversibility, the verification system, the costs, and other tangible issues. The outcome will be a compromise between various parties. Some experts believe, as described above, that NWSs may want to include a withdrawal provision, i.e., to factor in the option of reversibility, while NNWSs will likely insist on strong guarantees of irreversibility and may even object to the inclusion of the withdrawal clause at all.

Another potentially divisive issue is the future of nuclear energy. As described above, irreversibility of nuclear disarmament is stronger if all nuclear material production facilities are eliminated. This option, however, will also entail an end to nuclear energy sector because it will be impossible to produce nuclear fuel. Closure of all such facilities will also reduce the costs of verification. Without doubt, some States will insist on that option, but there will also be a strong group – among them developing countries – that will argue for the continued use and further development of civilian nuclear sector, including electricity generation.

Who will implement the verification activities and who will pay for both nuclear disarmament and verification of irreversibility? It is logical that costs are primarily borne by NWSs, who possess weapons and relevant infrastructure, and will have to eliminate them. That, however, may limit the involvement of NNWSs, including in verification, but this group will likely be reluctant to entrust maintenance of the irreversibility regime to former NWSs and will want to be full-fledged parties to any agreement. This would probably entail the need to support some costs of verification. Related to that, if representatives of NNWSs participate in verification activities, it will be necessary to develop measures to prevent access to classified information related to the design and production of nuclear weapons.

The list of issues can be continued, but even these most apparent ones demonstrate that there exist multiple trade-offs and that no option is perfect; the achievement of one goal may hinder the achievement of others. All these and many other issues will have to be resolved at the negotiating table, where expediency and compromise often overrule theoretical constructs. Further, much will depend on the general state of international relations. It is much easier to achieve more far-reaching agreements when relations among negotiating parties are cooperative. The ground-breaking agreements of the 1990s, which laid the groundwork and tested many of the disarmament verification options, were reached when relations between the United State and Russia were at their best; it is doubtful that anything similar could be achieved today or in the near future.

Addressing Non-Compliance

Implementation of international agreements is never smooth. There are always questions, concerns, and even suspicions of violation. This is particularly true for technically complex treaties that affect core security interests of parties and the international community in general. If these issues are not addressed properly and in a timely fashion, treaties may collapse or, at a minimum, relations among the parties could worsen and create even more implementation hurdles and hamper negotiations on other agreements.

To facilitate the implementation of treaties, parties often create special bodies, where they can address questions, concerns, and suspicions and agree on additional measures or changes in the process of implementation as long as these do not alter the text of the treaty. International bodies of this kind have become a standard feature of arms control agreements only relatively recently, starting with US-Soviet/Russian (SALT I and II, ABM, INF, START I) and multilateral treaties (CTBTO, OPCW, OSCE). Outside of arms control, EURATOM, the IAEA, and the Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean (OPANAL) also serve as a check on non-compliance. The NPT does not have one as such, instead entrusting the IAEA and its safeguards system to act as its verification body under the authority granted to it under its Statute and safeguards agreements.

The work of dedicated bodies usually remains outside the public eye, even when they address violations, technical or unintended, and only becomes public knowledge when disagreements reach the political level and escalate to a full-fledged crisis. Smooth functioning of such bodies depends on the goodwill of parties and implementation of treaties may continue even when contradictions cannot be resolved. The United States and Russia, for example, never succeeded in resolving several accounting and weapons conversion issues in START I and New START, but this did not prevent these treaties from being successfully implemented.

Things can change when political will is absent. The United States and Russia, for example, failed to use the Special Verification Commission (SVC) to properly address US charges of Russian violation of the INF Treaty. The issue was addressed only at a high level, and eventually publicly at the political level, resulting in the collapse of the Treaty in 2019. This case further underscores the importance of a positive international environment and the political will of the parties to exercise caution and invest in peaceful resolution of outstanding issues, and the proper use of dedicated technical fora.

What should the response of the international community be in cases where a violation of a nuclear disarmament agreement is detected, especially when such a violation goes to the core of obligations undertaken by its parties? Generally speaking, there are few tools available to the international community short of withdrawal of other parties leading to the complete or de facto collapse of the treaty. There can be, of course, other, more limited actions, such as international sanctions.

IAEA safeguards include well-established procedures for dealing with cases of non-compliance. Ultimately, however, the IAEA cannot "punish" non-complying States – only detect and report actions. In extreme cases of wilful non-compliance, the IAEA would report the State to the UN Security Council (UNSC). As the case of North Korea demonstrates, however, a State that is determined to pursue a nuclear weapons programme is unlikely to be deterred by UNSC action, including international sanctions.

Ian Anthony points out that, should the UNSC retain its existing structure and one of the five permanent members were the State accused of non-compliance, the UNSC would be paralysed to take action in response. In this respect, he argues that the future work of the Council would need to be embedded into whatever legal irreversibility framework, and that disarmed status would have to be codified as an absolute legal requirement to avoid this issue.[74] While there is no broad agreement in existing literature about what the consequences of non-compliance should be for a State taking steps to reconstitute a nuclear weapons programme, this would certainly influence the feasibility of the implementation of a legal framework.

74 Ian Anthony, "Irreversibility in Nuclear Disarmament: Political, Societal, Legal and Military-Technical Aspects", pg. 25, SIPRI, September 2011.

This raises a question as to what the consequences of non-compliance should be. Returning to the irreversibility paradox referenced by Joseph Rodgers and Heather Williams, it is conceivable that the fear of other States cheating may deter States from entering into a binding agreement or make them limit such an agreement to the most basic measures, which would be reversible. Such behaviour is not impossible, but the shallower the agreement, the more difficult is verification and the easier is violation. John Carlson argues that a State's assessment of the risks in violating an agreement includes "whether the violation will be detected, whether a non-compliance finding will be reached, and whether enforcement action will be taken, i.e., whether other States will intervene either pursuant to a Security Council decision or on their own account."[75]

It remains an open question whether the prospect of sanctions and international isolation would be sufficient to prevent reversion to a nuclear weapons programme. In all likelihood, were a State to make such a radical decision, it would be prepared for consequences and judge its situation sufficiently grave to warrant any costs. This consideration reinforces the role of political aspects of the sustainability of nuclear disarmament, specifically the need to make sure that no State capable of acquiring nuclear weapons finds itself in a critical situation, which might prompt it to consider the nuclear option. On the other hand, experience suggests that such decisions should be extremely rare. Iran, for example, has not chosen the "nuclear path", although it has had the technical ability to do so for many years. Overall, the number of defections from the NPT is low. In fact, only one (North Korea), while India, Pakistan, and Israel remain outside the NPT and have not undertaken any obligations in this respect. This shows that the non-proliferation norm is strong and, accordingly, the likelihood of States making a decision to reverse nuclear disarmament obligations is very low.

Ultimately, the strongest sanction against the violating State is the prospect that other States will also reverse their commitments. In fact, the irreversibility of nuclear disarmament rests on the expectation that either everyone will remain non-nuclear or multiple States will reacquire nuclear weapons. This will be an important element of the calculation of a State that may wish to entertain the reversal option. In the end, any benefits such a state might reap will be short-lived and its situation will return to what it is today. Thus, the stability of a nuclear disarmament commitment will depend to a large extent – perhaps critically – on whether the international system in the non-nuclear world does not create incentives to return to the status quo ante, effectively, to the present "nuclear stalemate". As long as the dangerous and the inherently unstable present-day situation does not appear preferable compared to a non-nuclear world, violation of a disarmament treaty will remain unlikely.

75 John Carlson, "Key Nuclear Verification Priorities – Safeguards and Beyond", IAEA Safeguards Symposium, 2010. Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/42/081/42081446.pdf?r=1&r=1.

Yellowcake uranium packed into barrels. Credit: Dean Calma/IAEA.

Confidence versus Feasibility in the Process of Nuclear Disarmament

This section details the technical steps in the disarmament process and estimates the technical difficulty for the disarming State to reverse each step and the difficulty for counterparties to verify that the step has been achieved. In the previous sections, legal, political, economic, and other normative barriers to rearmament were considered. These are seen to also affect the difficulty of rearming in ways that can be of equal or greater importance compared with technical considerations, but with impacts on the time to rearm that are more difficult to quantify.

The difficulty of reversal of a given technical step is captured by an estimated time to reverse it. The authors judge that these time estimates are relatively stable, and, barring major technological changes, the significance of a step in a technical sense is also likely to be stable. Associated with the time requirements is the ability to conceal relevant activities. Time limits may be considerable, but if other States do not notice these activities, the disarming State may be able to pursue its goals. The concealment variable is closely related to verification.

Unless otherwise specified, rearmament is assumed to mean that ten or more weapons are produced following some disarmament process. This somewhat arbitrary limit is a concession to the reality that NWSs today have anywhere from dozens to several thousand nuclear warheads. When and if stockpiles dwindle, the time to rearm at the few-weapon level can be more carefully estimated and will undoubtedly be shorter than the durations described. Furthermore, in a non-nuclear world, ten or so nuclear weapons may be highly consequential, at least in the immediate aftermath of reversal.

Taking into account all these factors, we estimate the overall level of impact – limited, moderate, or significant – for the irreversibility of each step in the disarmament process. The higher the impact, the harder it is to rearm upon completion of the indicated step. One should be cognisant that, whereas each separate step may have a limited or moderate degree of reversibility, it is also important to assess their cumulative impact. Taken together as a system of measures, they may produce a much higher degree of irreversibility of nuclear disarmament than each of these measures taken separately.

A technical analysis of the disarmament process, conducted by one of the authors, Dr. Adam Bernstein, and informed in part by the five end states identified in the 2011 VERTIC study, has yielded the following steps on the path towards nuclear disarmament.

- Removal of Warheads and Verified Disablement of Delivery Systems
- Monitoring of Stored Warheads/Pits
- Verifiable Destruction of Nuclear Pits
- Verifiable Cessation of Production of Pits
- Destruction or Disablement of Pit Manufacturing Facilities
- Weapons-Usable Fissile Material Disposition
- Destruction or Disablement of All Military HEU Enrichment and Plutonium Reprocessing Facilities; Destruction or Disablement of All Plutonium Production Reactors
- Cessation of Investment in Nuclear Weapons Design Laboratories and Related Infrastructure
- Destruction of all HEU Enrichment and Plutonium Reprocessing Facilities

Removal of Warheads and Verified Disablement of Delivery Systems

Consequence for Irreversibility: Limited

This early step in the disarmament process provides reassurance that treaty-accountable items are not deployed. Removal of nuclear warheads from delivery vehicles has been a long-standing initiative known as de-alerting: if nuclear warheads are not mated to delivery vehicles, a surprise nuclear strike, whether large-scale or limited, becomes impossible. While originally not part of the nuclear disarmament agenda, the de-alerting initiative de facto represents a possible first step on that track, at least to the extent that nuclear weapons lose immediate relevance in the global security landscape. Further, if all nuclear weapons are kept in storage, it becomes easier to accurately account for nuclear weapon stockpiles and to verify them.

Technically speaking, this step is fairly easy to reverse, which has been the main argument against de-alerting. On the other hand, reversal on a militarily tangible scale may be relatively time-consuming and detectable, even by national technical means, such as satellites, prompting other NWSs to do the same. Thus, in a reasonably stable international environment, the decision to return nuclear warheads to delivery vehicles is not likely.

It may also be attractive to convert delivery vehicles (missiles and aircraft first and foremost), so that they are no longer capable of carrying nuclear weapons. While efficient on the surface, the process will be time-consuming, expensive, and technically complicated as it would involve partial dismantlement of delivery vehicles and highly intrusive verification (effectively, looking inside each aircraft or missile); for some categories of missiles it may be simply impossible. Any such action – whether conversion or elimination – would profoundly, perhaps irreparably, affect conventional forces of nuclear-armed States and will most likely be rejected outright. For that reason, it may be more productive to concentrate on nuclear weapons, leaving delivery vehicles outside disarmament measures.

As an alternative, it may be possible to contemplate destruction of nuclear warhead bodies, a procedure that was part of the INF Treaty. Whereas that Treaty allowed parties to retain nuclear explosive devices (weapons) from eliminated intermediate-range ground-launched missiles, it provided for smashing of the bodies of warheads intended for these missiles as an additional measure to make elimination of delivery vehicles comprehensive and less reversible.

Monitoring of Stored Warheads/Pits

Consequence for Irreversibility: Limited

In this step, nuclear weapons and nuclear pits are stored at declared facilities and are verifiably monitored by parties, providing reassurance that declared warheads are not deployed on launchers, or that the disassembled pits have not been re-incorporated into warheads. While some cooperative studies and negotiations related to stored pit verification were undertaken by the US and Russia, no pit or warhead monitoring protocol has yet been implemented in any nuclear treaty.

The principal challenge of negotiating this measure is the high sensitivity of nuclear weapon storage facilities noted in the previous section. This challenge appears less overwhelming if the measure is part of a nuclear disarmament treaty, i.e., storage is temporary while warheads are waiting for their turn for dismantlement. Further, it is possible to utilise new technical approaches to make verification of nuclear weapon stockpiles less intrusive while keeping it sufficiently reliable.[76]

Assuming assembly facilities have not been verifiably disabled (see step 4), this step is technically easy to reverse, but in practice would be difficult to implement because any improper use of warheads or pits would be detectable using agreed verification procedures. Regardless of its other merits, proper accounting of nuclear stockpiles is a vital first step in the movement toward nuclear disarmament.

Verifiable Destruction of Pits

Consequence for Irreversibility: Moderate

The heart of any treaty on nuclear disarmament is the elimination of nuclear weapons, which is usually understood as the removal of the nuclear pit, consisting of weapons-usable fissile material manufactured into a form which optimises its explosive properties and deployability. Nuclear pits are central to the design of a warhead, the element without which a nuclear weapon is impossible, with many properties – such as shape, weight, and other features – that are usually classified.

Dismantlement of nuclear weapons, in the simplest form, is typically understood as verified removal of nuclear pits and other fissile materials from the weapon, after which it ceases to be explosive. The main challenge of dismantlement in the context of an international regime is verification – inspectors, especially those coming from NNWSs, cannot be allowed to see the design of a nuclear weapon. Several studies reviewed in the previous section proposed the creation of an information barrier, which would allow inspectors to reliably verify the removal of fissile materials from the weapon while not looking inside the weapon itself.

The next stage in the process is the elimination of nuclear pits. If pits are verifiably destroyed, the considerable effort that went into pit manufacture must be re-expended in order to rearm. This step is, therefore, technically significant in terms of reversibility with time needed for the manufacture and deployment of nuclear weapons measured in years depending on the scale of rearmament. Of course, if pit manufacturing capabilities remained intact, this step could be more readily and quickly reversed, but the time required to actually manufacture an appreciable number of pits would nonetheless be on the scale of months to a year with a dedicated effort and an operating facility.

76 Miles Pomper, William Alberque, Marshall L. Brown Jr., William M. Moon, and Nikolai Sokov, "Everything Counts: Building a Control Regime for Nonstrategic Nuclear Warheads in Europe," CNS Occasional Paper 55, Center for Nonproliferation Studies, May 10, 2022. Available at: https://nonproliferation.org/op55-everything-counts-building-a-control-regime-for-nonstrategic-nuclear-warheads-in-europe/.

Another highly important advantage of this step in terms of irreversibility is that it removes much or all of the classified information related to weapons and weapons-usable fissile material. This eases subsequent technical verification steps and facilitates deeper inclusion of NNWSs in later verification protocols.

Verifiable Cessation of Production of Pits

Consequence for Irreversibility: Moderate

In this step, the production of nuclear weapons and of nuclear pits is verifiably ceased at relevant declared manufacturing facilities. This is another important step towards irreversibility. It adds months or years to the time needed to manufacture approximately 10-100 pits with a working facility (months if minimal or no safety standards applied) and perhaps equal time to manufacture nuclear weapons using these pits, even if other components of weapons are preserved.[77] Consequences for irreversibility are estimated as moderate since the specifics of the termination of the weapon and pit production facilities may vary, greatly affecting the time to re-start production.

This step is truly efficient only in conjunction with the former, verifiable elimination of weapons and pits; otherwise, rearmament could be achieved in a relatively short time. The inevitable challenge for the cessation of both weapon and pit production is the risk of a clandestine programme, which may be difficult to detect, even with reasonably intrusive verification measures; one of the tools that might help guard against such a scenario are suspect-site inspections, which are discussed below. Considering the inevitable costs, political risks, and technical challenges, clandestine resumption of weapon or pit production appears unlikely as long as the overall security climate remains sufficiently benign, reducing the motives for tolerating political, economic, and other costs associated with rearmament.

Destruction or Disablement of Pit Manufacturing Facilities

Consequence for Irreversibility: Significant

This is a significant step towards a high degree of irreversibility, extending well beyond the cessation of production, since the actual production facility is to be verifiably destroyed or disabled. In the absence of dedicated facilities, the time required to manufacture a significant number of nuclear weapons will considerably extend to several years.

It is worth keeping in mind that “elimination” (“destruction,” “disablement”) of a facility is a legal term, the precise meaning of which will have to be agreed by parties to any future agreement. In the context of US-Russian arms control agreements, “elimination” of various facilities, such as missile bases, missile storages, and others, usually involved destroying only elements of such locations directly relevant to storage, maintenance, or other activities associated with treaty-limited items (e.g. missiles, missile motors), whereas the rest could be abandoned or converted to other, unrelated uses. The guiding principle of “elimination” is the removal of all elements of the facility without which it cannot support the original function. Further, the “elimination” of a facility could be verified through an on-site inspection and subsequently the same facilities could be visited from time to time to confirm that they were not reverted to their original function. Similar – perhaps stricter – procedures may be advisable in the case of weapon or pit manufacturing.

Even if known pit manufacturing facilities were verifiably disabled or destroyed, the principle of irreversibility will likely require long-lasting monitoring to help ensure continued compliance with this step in the disarmament process. Moreover, advances in manufacturing, including additive manufacturing (also called 3D printing), could conceivably make it easier to manufacture pits in a less observable and less costly manner compared with the current state of the art. Similarly, it will likely be easier for States to develop clandestine, hard-to-detect capabilities to manufacture a relatively small numbers of pits, compared to the dozens or hundreds that current manufacturing plants can produce.

77 [Name Redacted], “Manufacturing Nuclear Weapon “Pits”: A Decisionmaking Approach for Congress”, Congressional Research Service, 15 August 2014. Available at: https://www.everycrsreport.com/reports/R43685.html.

Weapons-Usable Fissile Material Disposition

Consequence for Irreversibility: Significant

In the context of the disarmament process, disposition is broadly defined as the transformation of fissile material from a weapons-usable to non-weapons-usable form. The degree of difficulty of returning the material to weapons-usable form varies with the disposition method. A US National Academy of Science study developed a useful and widely accepted definition for non-usability, known as the spent fuel standard for fissile material disposition.[78] The spent fuel standard is achieved for a given disposition process when the fissile material is turned into a physical form, from which it as difficult to restore to a weapons-usable state as it is to recover such material from spent fuel. The logic of this standard is that there is far more plutonium in spent fuel, which is highly radioactive and from which it is difficult to extract from spent fuel than is present in the largest military fissile material inventories. Therefore, transforming fissile material into a spent-fuel-like physical form makes its military threat marginal, similar to the relatively low threat inherent in the existence of global civil spent fuel inventories.

Disposal of HEU and plutonium would be a significant step towards irreversibility. Once completed, it would increase the time needed to manufacture an appreciable number of nuclear warheads by at least two to five years.

The technical, political, and financial obstacles to achieving the disposition of HEU have proven to be far less formidable than those for plutonium. The disposition technique for HEU is to blend it in gaseous form with natural uranium (or low-enriched uranium), with the blended product having an enrichment at the level of LEU. This was the approach taken under the HEU Purchase Agreement, referenced above, also called downblending. The approach proved cost-effective, since the cost of downblending is relatively low, while the resulting LEU product is usable in nuclear power generation and could be sold on the open market. The spent fuel standard is achieved once the fuel made from the downblended HEU is irradiated in a reactor.

Plutonium disposition is more complicated for both technical and policy reasons. First, no method has yet been found which is at once politically acceptable to historic participants, requires reasonable time, and is cost-effective. Focusing on Russia and the US, the National Academy of Sciences study estimated at least a decade for the fastest options. Experience with those options – immobilisation of plutonium with highly radioactive waste and the manufacture of MOX fuel from the plutonium, followed by the irradiation of the resulting fuel in a commercial reactor – has shown that they are even more complex than originally envisioned. Second, the use of plutonium in civil fuel cycles has historically been a polarising topic, with the US and other countries frequently disagreeing on the wisdom of fostering a civil nuclear fuel cycle that is capable of making use of directly weapons-usable material, such as separated plutonium.

Considering the large amounts of separated plutonium in NWSs, especially in the United States and Russia, the implementation of this perhaps most important step in nuclear disarmament may prove both time-consuming and expensive. More studies and experiments may be needed to find a mutually acceptable solution.

78 "Management and Disposition of Plutonium," National Academy of Sciences Committee on Arms Control and International Security, 1994. Available at: https://www.ans.org/pi/ps/docs/ps47-bi.pdf.

Destruction or Disablement of All Military HEU Enrichment Facilities and Plutonium Reprocessing Facilities; Destruction or Disablement of All Plutonium Production Reactors

Consequence for Irreversibility: Significant

This step would also significantly contribute to the irreversibility of nuclear disarmament, as it would increase the time needed to manufacture a weapon by an estimated five years (less if significant civil infrastructure were already in place). Historically, the production of fissile material has been one of the greatest obstacles to acquiring a weapon. Destruction of military enrichment and reprocessing facilities as well as plutonium production reactors would essentially reinstate this formidable barrier to nuclear weapons acquisition. This is especially true for nuclear weapons programmes with dozens or hundreds of weapons, since the infrastructure is costly to build, operate, and maintain.

As noted above, the practical meaning of the term "elimination" would have to be determined by the parties to negotiations and need not have to involve the physical destruction of relevant facilities. An enrichment or reprocessing facility may be converted for or limited to the production of fuel for nuclear power reactors. In that case, verification procedures need to be designed most likely along the lines of IAEA safeguards to ensure that these facilities no longer produce weapons-grade fissile material (or at least that it is not diverted).

Cessation of Investment in Nuclear Weapons Design Laboratories and Related Infrastructure

Consequence for Irreversibility: Significant

Maintenance of existing design expertise or closely related skills is critical to a rapid rearmament capability. For example, part of the purpose of the US stockpile stewardship programme is to maintain weapons expertise in the nuclear complex. Of course, even absent a trained cadre of experts, significant funding could reduce the time needed for rapid restoration of relevant capacity. For example, the Manhattan Project was an all-out effort that produced the first nuclear weapons in a period of approximately four years (1942-1945) with virtually no existing nuclear-specific infrastructure or pre-existing knowledge.

Moreover, there is always a risk that secret weapons design programmes could be initiated or continue. Some have argued that the risk of a clandestine attempt to rearm might even increase if unclassified capabilities were shut down. The logic to this argument is that States would be less inclined to start a secret programme if they knew that reversal was an option, and if their nuclear weapons manufacture capabilities are known to adversaries.[79] That risk notwithstanding, the reduction or redirection of scientific and engineering expertise specific to a nuclear weapons programme would increase the costs and political risks of rearmament considerably, and would send a powerful message that the state was serious in its commitment to irreversibility.

Verifying a ban on investment into nuclear weapons work is difficult. As long as a country continues to possess a civilian nuclear sector (not necessarily nuclear power – other applications will almost certainly survive even the strictest disarmament regime), such laboratories and relevant infrastructure will continue to exist. Related programmes will also likely be pursued at universities and by private businesses. Monitoring of funding and research programmes at such facilities will be difficult and not fully reliable, same as the monitoring of government funding.

79 "Management and Disposition of Plutonium," National Academy of Sciences Committee on Arms Control and International Security, 1994.

Destruction of All HEU Enrichment and Plutonium Reprocessing Facilities

Consequence for Irreversibility: Significant

The disablement and destruction of all HEU production and plutonium reprocessing facilities, including civil infrastructure, would considerably increase the obstacles to rearmament. This is due to the fact that civil HEU enrichment and plutonium reprocessing facilities could be used to manufacture weapons-usable material if the State chose to. Indeed, even the existence of civil reactor and LEU enrichment facilities already represent a significant technological step in the direction of nuclear weapons production.

The verified elimination of HEU enrichment and plutonium reprocessing facilities would increase the time needed to manufacture a few dozen weapons by five to ten years, perhaps longer, and would be detectable with relative ease. Examples of civilian-to-weapons conversion of infrastructure include India, Pakistan, Israel, and North Korea.

Such a measure would be easily verifiable simply because it can be easier to verify the absence of items or activities than limits on them or on their use, though this can depend on whether verification takes place at a specified location or verifying the absence of nuclear material and activities in the States as a whole; the latter is very challenging. Considering long lead times for creating new – especially clandestine – enrichment facilities, the likelihood of detection becomes very high.

On the other hand, one can confidently expect strong resistance to that measure, especially on the part of countries with strong dependence on nuclear power generation. In effect, they would be asked, in addition to assuming very expensive obligations related to the elimination of nuclear weapons and related infrastructure, to also spend on the phase-out and replacement of power generation capacity. Use of natural uranium for power generation (for example, in CANDU reactors) would be unacceptable, too, because these reactors can produce plutonium and, from the point of view of both non-proliferation and disarmament, are perhaps more challenging from a proliferation perspective than the production of LEU.

For these reasons, it would be difficult to expect that this most reliable and far-reaching disarmament measure would be accepted during any negotiations on nuclear disarmament. That could change, of course, if alternative sources of power are developed that would be a cost-effective replacement for traditional sources of power generation, causing the “natural death” of the latter.

UN Member States' flags in front of the United Nations headquarters in New York. Credit: UN Photo/Joao Araujo Pinto.

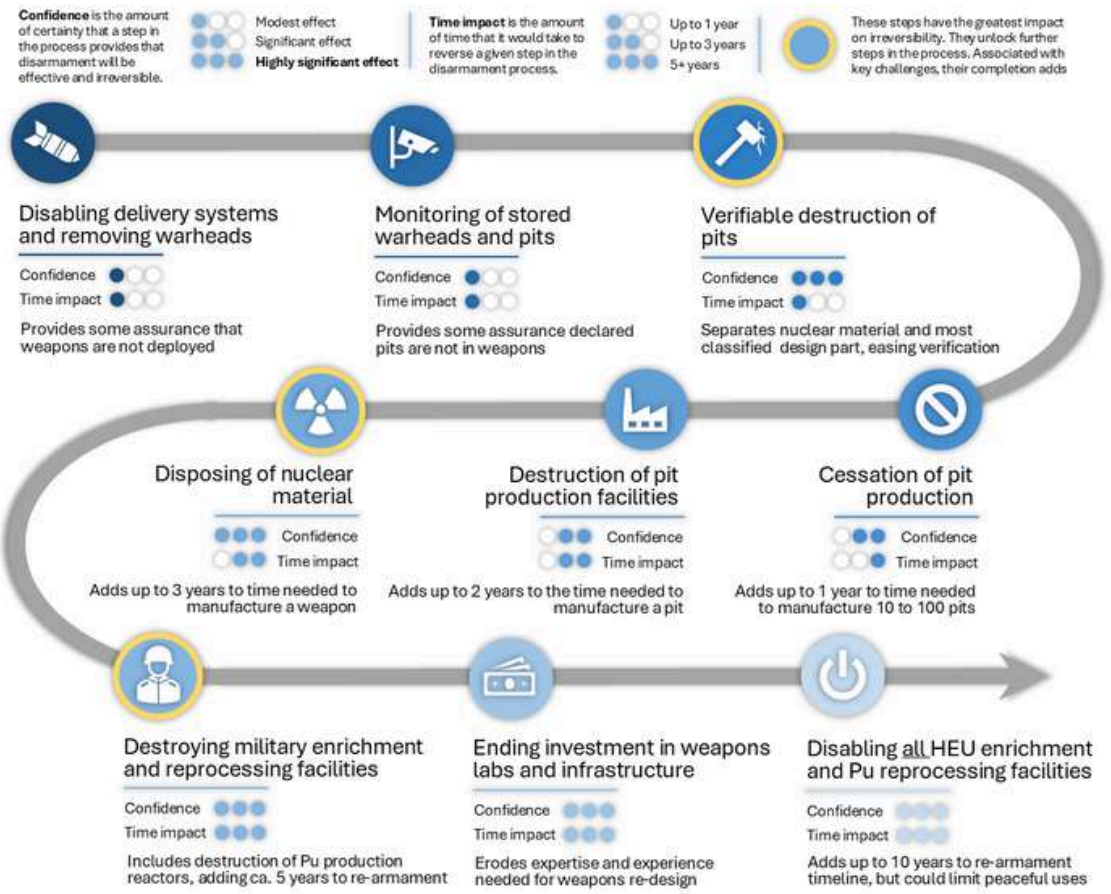
NPT States Parties' Views on Irreversibility and Feasibility

Since 2000, irreversibility in nuclear disarmament has largely been discussed in the context of the NPT. As such, the extent to which it advances in the future will depend largely on the perspectives of NPT States Parties and the evolving views on irreversibility. To better understand these perspectives, the VCDNP conducted 16 off-the-record interviews with State Party officials from all UN regional groupings, including at the 2024 NPT Preparatory Committee meeting. The insights gleaned from these interviews were supplemented by a targeted, anonymous survey. The consultations and the survey included input from three of the five nuclear-weapon States (NWSs) and 14 non-nuclear-weapon States (NNWSs).

The consultations and the survey addressed five broad themes: (1) activities toward disarmament; (2) assurances against rearmament; (3) obstacles to disarmament; (4) cost of disarmament; and (5) actors in disarmament.

Activities in Disarmament

This section draws largely from the nine technical steps on the path to disarmament described above.



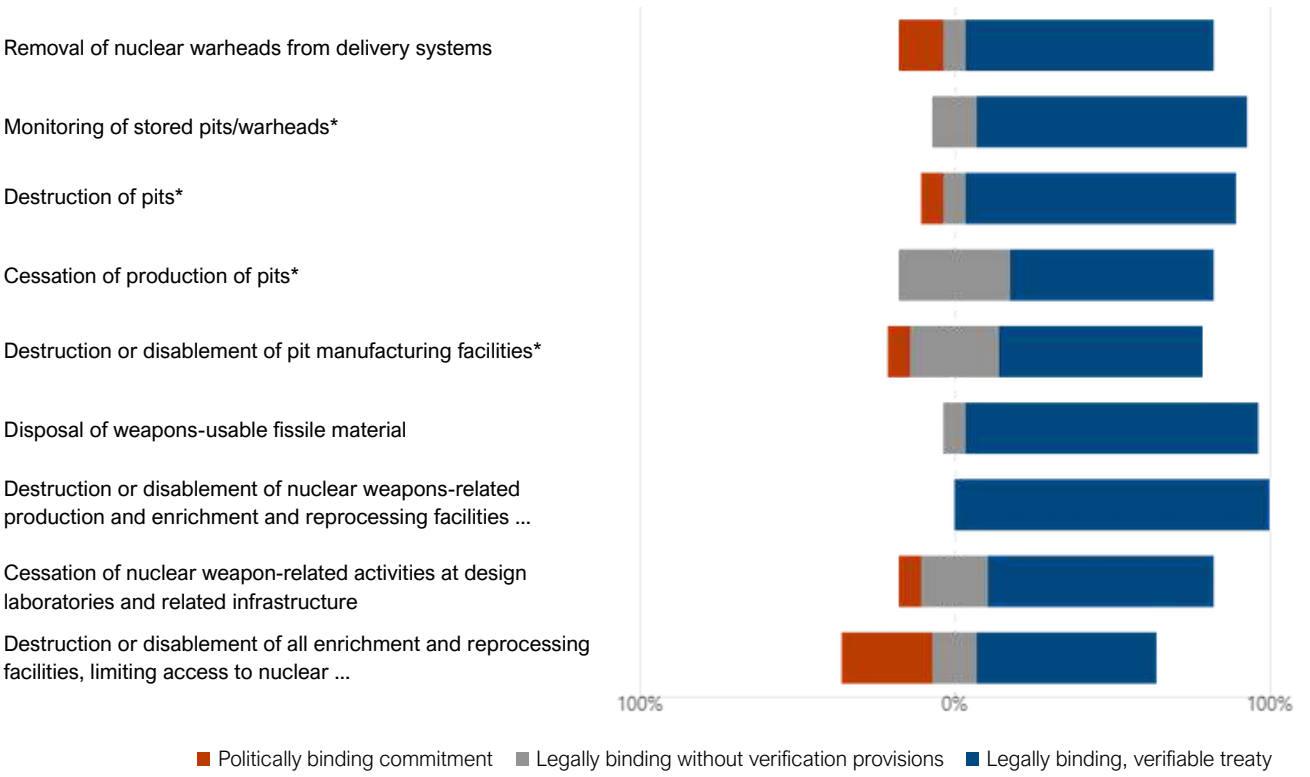
Respondents were asked, for each of the nine steps, what would be required to provide confidence that each of the steps was implemented and not reversed: a politically binding commitment, a legally binding treaty without verification provisions, or a legally binding verifiable treaty. NNWS respondents largely expressed a preference for a legally binding treaty with verification.

For steps, such as removal of warheads from delivery systems, destruction of pits and pit manufacturing facilities, cessation of weapons-related activities in laboratories, and destruction/disablement of all enrichment and reprocessing, some respondents accepted either a politically binding commitment or a legally binding treaty without verification. It is notable that no NNWS respondent indicated that they would accept anything other than a legally binding verifiable treaty to provide confidence that nuclear weapons-related enrichment and reprocessing facilities has been destroyed or dismantled. During consultations, one NNWS official noted that moving towards nuclear zero would affect the entire international community and, on that basis, noted that the NWSs alone having confidence would not be enough.

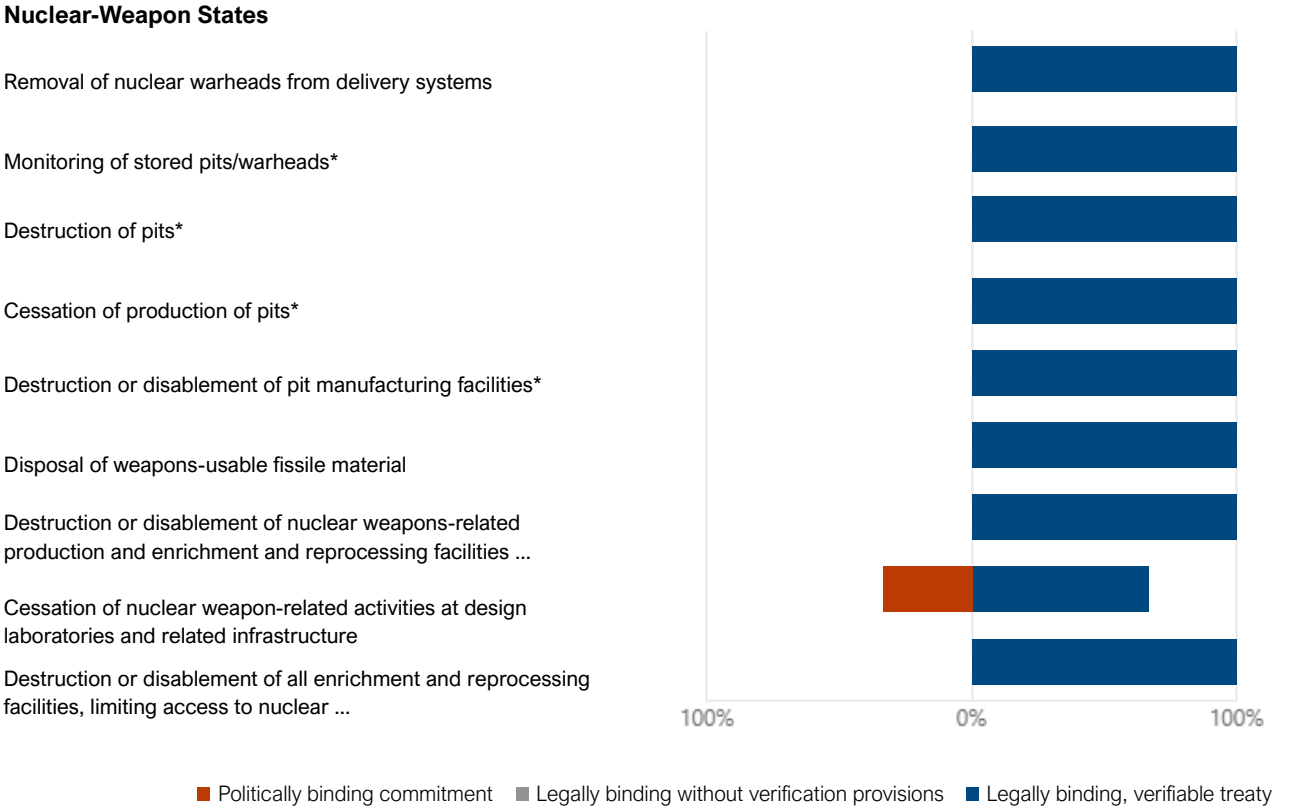
Similarly, NWS respondents also largely supported the proposition that a legally binding verifiable treaty would provide the most confidence that a step on the path to disarmament was not being reversed. The only exception was related to the cessation of weapons-related activities at laboratories, for which one NWS respondent indicated that a politically binding commitment would suffice. Several interviewees for the project noted the value of politically binding steps as a path towards legally binding measures, but nevertheless characterised such measures as the ultimate goal, even if done in a patchwork. One NNWS official used the Latin phrase *nullum crimen sine lege* – no crime without law – to express the view that everything that is not prohibited is permitted, and thus everything needs to be codified as early as possible.

Question: What would suffice to provide confidence in the irreversibility of the below activities: politically binding unverifiable commitments, legally binding agreements without verification, or legally binding verifiable treaties? Please indicate your choice by marking one of the options.

Non-Nuclear-Weapon States



Nuclear-Weapon States

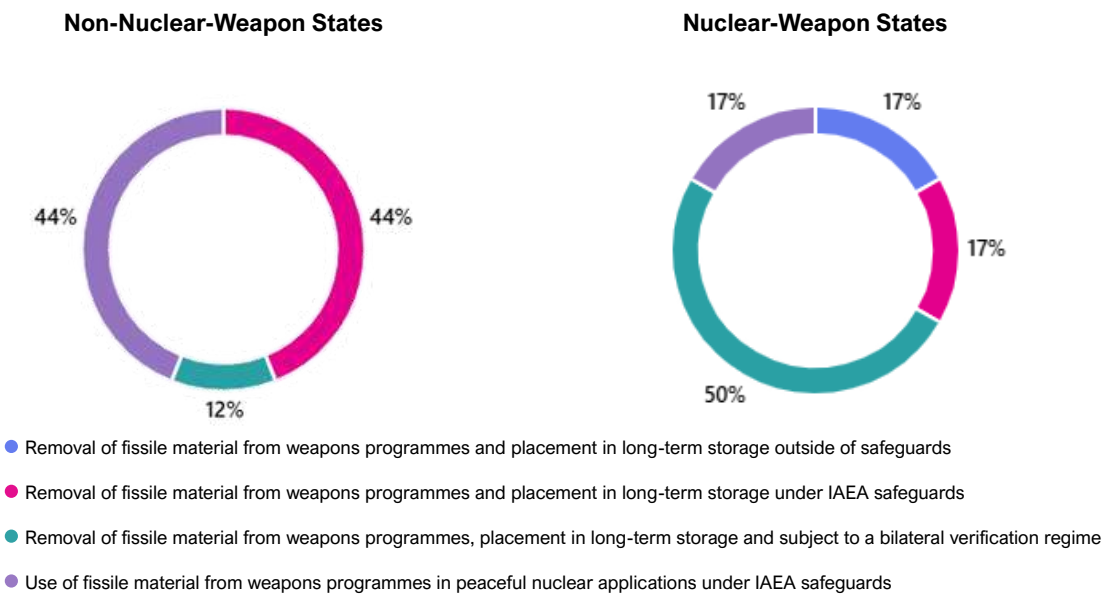


As noted above, a nuclear weapons complex can be said to consist of three components: fissile material, delivery vehicles, and the infrastructure and personnel that make up the nuclear weapons complex. With respect to fissile material, respondents were asked which activities would provide sufficient confidence that nuclear material is irreversibly removed from a weapons programme:

- Removal of fissile material from weapons programmes and placement in long-term storage outside of safeguards;
- Removal of fissile material from weapons programmes and placement in long-term storage under IAEA safeguards;
- Removal of fissile material from weapons programmes, placement in long-term storage and subject to a bilateral verification regime; or
- Use of fissile material from weapons programmes in peaceful nuclear applications under IAEA safeguards.

NNWS respondents largely indicated that removal of fissile material and placement in long-term storage or use for peaceful purposes – both under IAEA safeguards – would provide sufficient confidence. There was some, albeit lesser, support for bilateral verification, and no support for storage outside of IAEA safeguards. Among NWSs, support was broadest for a bilateral verification regime, though each of the other options was considered sufficient.

Question: Which of the following activities would provide sufficient confidence that nuclear material is irreversibly removed from weapons programmes (multiple answers possible).

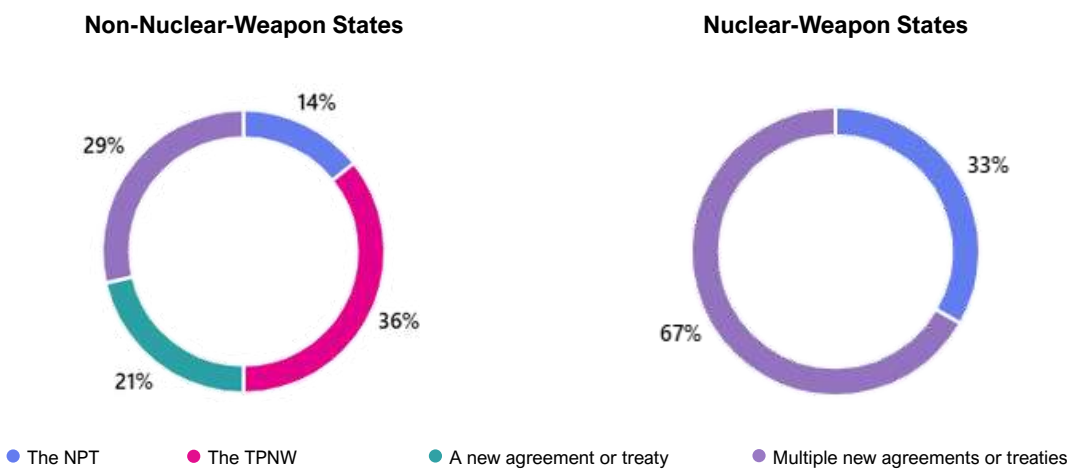


When asked to explain their answer, both NWSs and NNWSs noted that the process from one step to another could be very long and may not be linear. Indeed, during consultations, one NWS interviewee noted that the discussion today is not about reductions, but rather about limitations of nuclear arsenals. This complication is compounded by the form of the material in question (e.g. whether or not it retains classified characteristics). The NNWSs all indicated that placing fissile material under IAEA safeguards would certainly be the ultimate goal, but that this may not be feasible early on in the disarmament process. One NWS respondent expressed the view that a reversal of national policy would render any of these steps reversible.

Today, confidence that States are honouring non-proliferation commitments is provided by the NPT, IAEA safeguards, and other bilateral and multilateral arrangements. Does this change in a disarming or disarmed world? Respondents were asked a series of questions to assess States Parties views on this question.

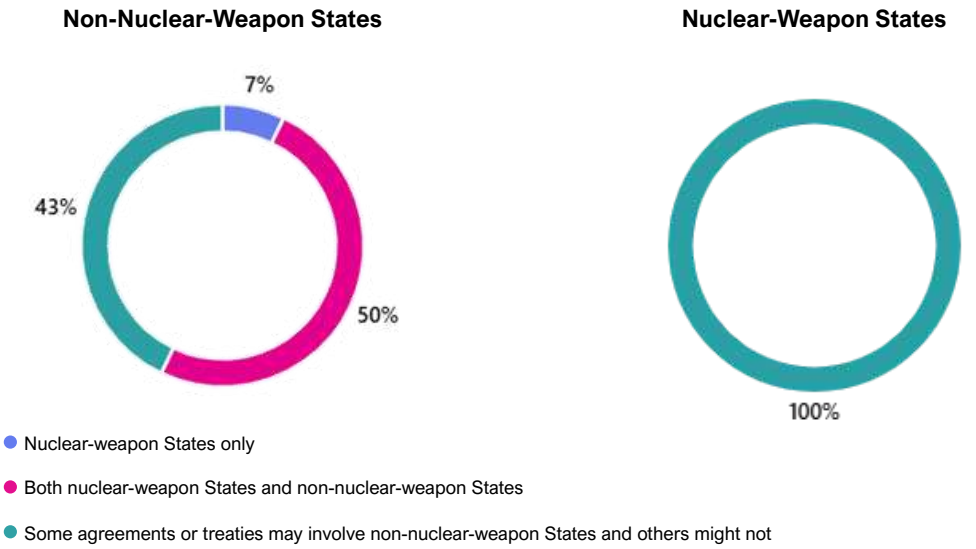
First, which treaty or agreement is most suitable as a framework for assurance of irreversibility? There was no clear majority of views among NNWSs, with a slim majority indicating the TPNW as the proper vehicle, followed by a preference for multiple new agreements or treaties, a single new agreement or treaty, and the NPT in last place. Two of the three NWS respondents indicated multiple new agreements or treaties, with the third NWS respondent pointing to the NPT. It is important to note that no State Party official interviewed for this project expressed any view suggesting that the NPT should be abandoned; indeed, one NNWS official noted that there would be no need for a separate treaty, as NPT's Article VI already provides the mandate for nuclear disarmament among States Parties. One NWS interviewee also expressed the view that an irreversibility treaty, at least today, is infeasible.

Question: Which treaty or agreement is most suitable as a framework for providing assurance of irreversible nuclear disarmament?



The question then becomes who should be included in such a framework: NWSs only, both NWSs and NNWSs, or will It depend on the agreement or treaty in question? Half of the NNWS respondents indicated that both NWSs and NNWSs should be involved in a disarmament framework and slightly less than half answered that some may involve both and others may not. Two NNWS interviewees noted that NNWSs would need to have broad agreement among themselves that the NWSs were disarming correctly. Only one NNWS responded that a framework providing assurance of irreversibility should include NWSs only. All of the NWS respondents answered that some may involve both and others may not.

Question: Should new agreements or treaties be required for implementing irreversible nuclear disarmament, they should include:



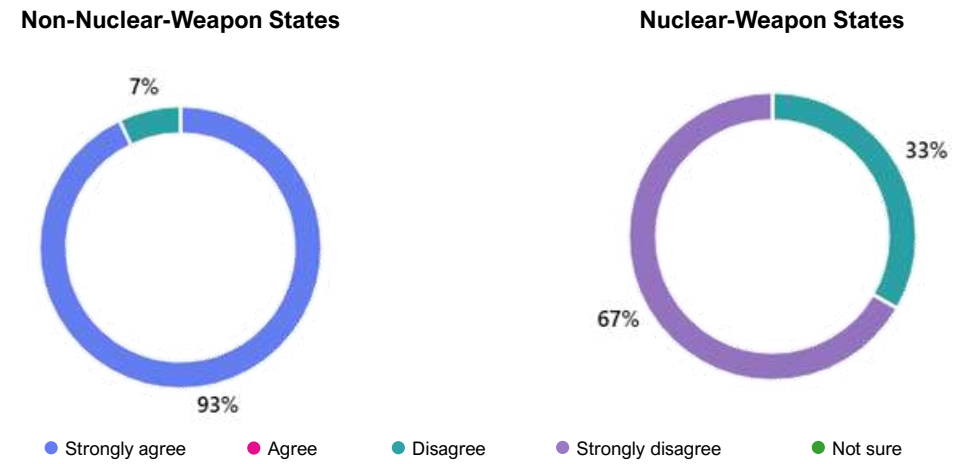
When asked to explain this answer, respondents expressed the view that their answer might change depending on how far along the path to disarmament States were, and that all nuclear-armed States (including non-NPT nuclear-armed States) would have to be involved in a process of reducing and limiting their stockpiles. The NNWS respondents reiterated the view that, in earlier stages, it would be sufficient for NWSs alone to be involved in a framework that provided confidence on irreversibility to prevent the proliferation of weapon-sensitive information, but that NNWSs would need to be involved in later stages.

Legal and Normative Aspects of Disarmament

In addition to technical disarmament and verification measures, this study examines the normative, political, and legal requirements to provide credible assurance of non-rearmament. It is important to note that these measures have significant overlap. It is the view of the authors that attempting to artificially categorise them is not a useful exercise to advance the principle of irreversibility. This view notwithstanding, respondents were asked a series of questions to better understand these aspects of irreversibility.

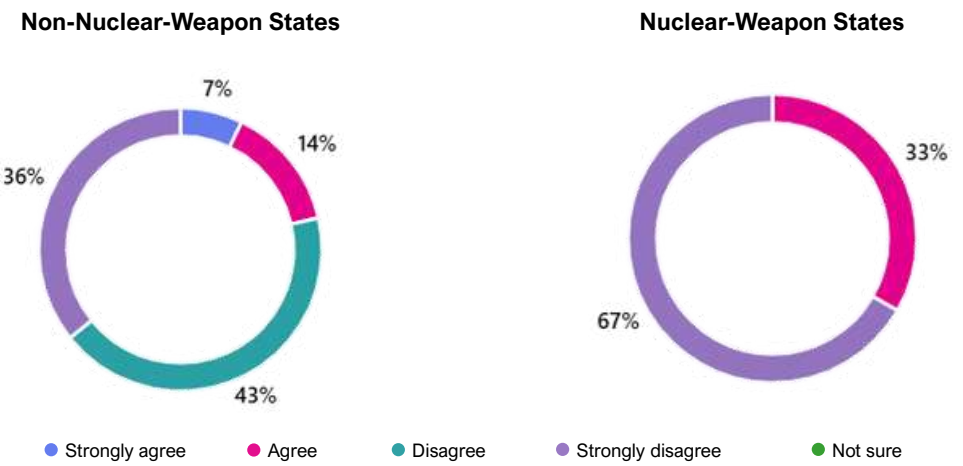
One such question related to the informal norm on the non-use of nuclear weapons – the so-called "nuclear taboo" – and whether this taboo should be transformed into an explicit political commitment by NWSs. Almost all NNWSs strongly agreed with this sentiment, while the NWS respondents either disagreed or strongly disagreed.

Question: The informal norm on the non-use of nuclear weapons ("nuclear taboo") should be transformed into an explicit political commitment by nuclear-weapon States.



Respondents were also asked whether a political declaration of a disarming country could provide sufficient assurance that dismantled military nuclear facilities were not being rebuilt. The majority of the NNWS respondents either disagreed or strongly disagreed, while two of the three NWS respondents strongly disagreed and the third NWS agreed with that proposition. That said, both NNWS and NWS officials commented on the value of political declarations in interviews. On the one hand, it was remarked that political declarations strengthen norms, "are better than nothing", and have value "in terms of process" towards a legally binding treaty. On the other hand, it was noted that the value of political commitments is limited, particularly from the standpoint of countries of the Global South, and that political declarations were "instantaneously reversible".

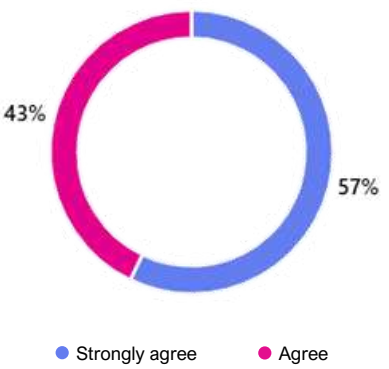
Question: A political declaration of a disarming country can provide sufficient assurance that dismantled military nuclear facilities are not being rebuilt.



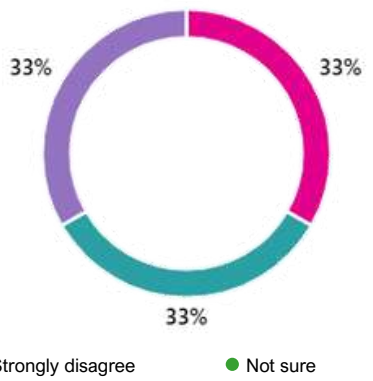
With respect to past commitments, including the 12 Practical Steps (NPT RevCon 2000) and the 64-Point Action Plan (NPT RevCon 2010), NNWSs unanimously responded that fulfilment of such commitments would increase confidence that NWSs were pursuing irreversible nuclear disarmament. Two of the three NWS respondents disagreed or strongly disagreed with that sentiment, with one NWS agreeing. One NNWS official interviewed for this project pointedly argued that the commitments made in 2000 and 2010 were not "past" commitments, but rather "existing" commitments, which should be honoured. Another NNWS official said that, while States Parties could review them to determine whether they were still current, this should not be viewed as a "parallel track" to the NPT review cycle or working towards nuclear disarmament itself. Several NNWS officials noted that, in order to be credible, any new commitments would have to be substantively accountable. One NWS official said that they would like to see States reaffirm these commitments.

Question: Fulfillment of previous NPT commitments, including actions identified in the 13 Practical Steps (2000) and the 64-Point Action Plan (2010), would increase confidence that nuclear weapon States are pursuing irreversible nuclear disarmament.

Non-Nuclear-Weapon States



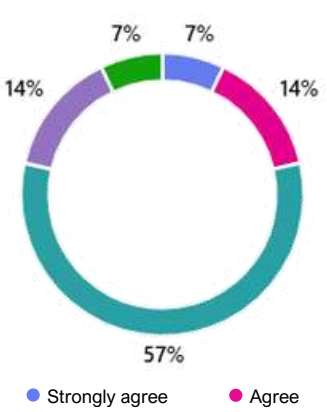
Nuclear-Weapon States



In terms of legal and technical measures required to provide credible assurance that disarmament is not being reversed, the majority of NNWSs indicated that verification measures beyond those provided for in a comprehensive safeguards agreement and an additional protocol would be required, while some respondents were unsure. Two of the three NWS respondents strongly agreed with this sentiment, while one NWS disagreed.

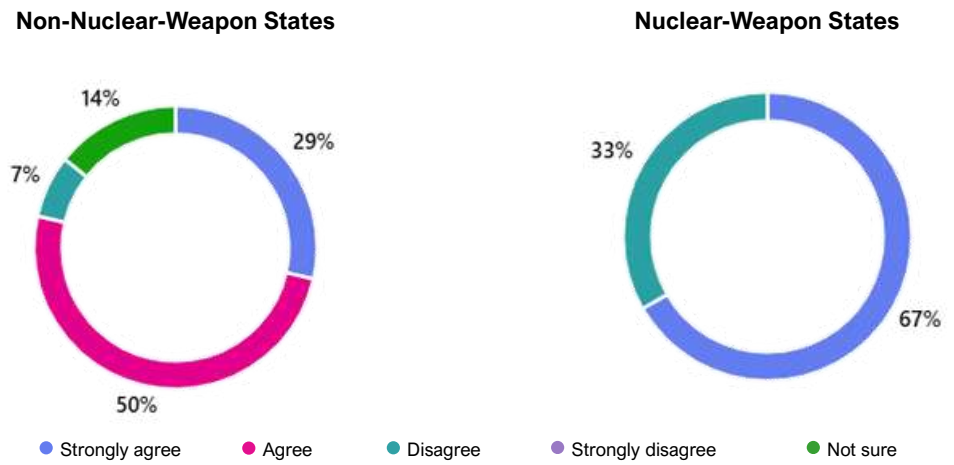
Question: Providing credible assurance that steps towards nuclear disarmament are not being reversed should be the responsibility of the disarming States alone.

Non-Nuclear-Weapon States



Nuclear-Weapon States

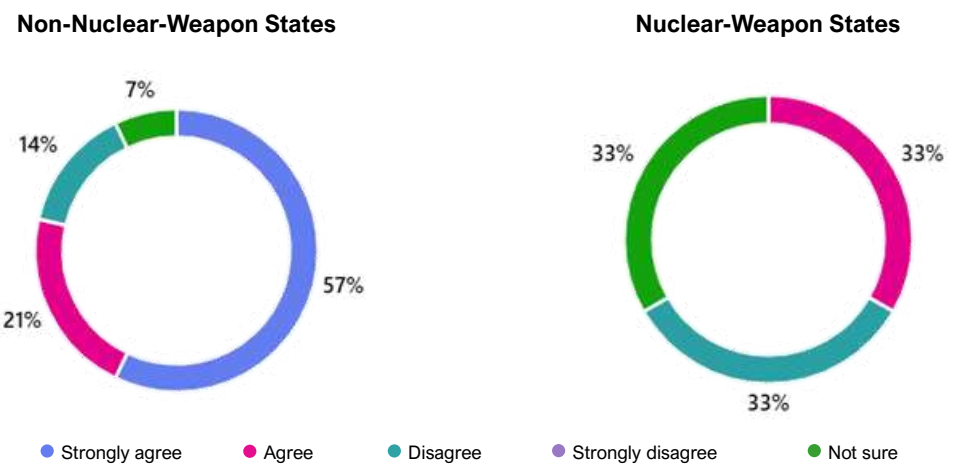
Question: Legal measures beyond comprehensive safeguards agreements and additional protocols would be required to provide credible assurance that disarmament is not being reversed.



As the NPT requires only NNWSs to conclude CSAs with the IAEA, the VCDNP also asked if the NPT would need to be amended post disarmament (or even during large-scale disarmament) to require today's NWSs to conclude such agreements as well. The majority of NNWSs either agreed with this sentiment or strongly agreed, while two disagreed and one was unsure. The NWS respondents were split on this question, with one agreeing, one disagreeing and a third unsure.

Question: Post disarmament, the NPT would need to be amended to ensure that all States have a legal obligation to conclude a comprehensive safeguards agreement with the IAEA.

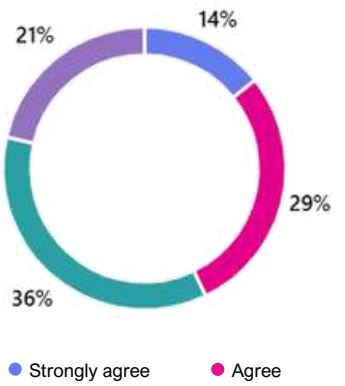
The NPT does not define nuclear-weapon States by the possession of nuclear weapons but by whether a State exploded a nuclear device prior to 1 January 1967. Per the NPT, nuclear-weapon States are not required to conclude a comprehensive safeguards agreement with the IAEA.



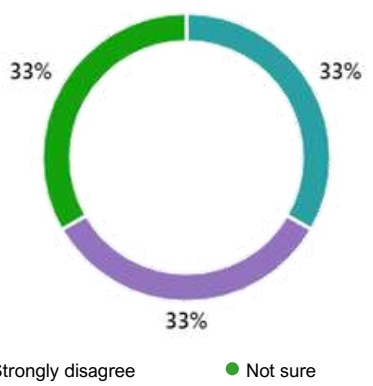
Finally, in terms of assurance against rearmament, respondents were asked if States would trust that weapons laboratories were converted to peaceful uses without international monitoring, as long as there were credible assurances that nuclear material was used exclusively for peaceful purposes. The question was posed intentionally vaguely, as international monitoring and credible assurance on peaceful uses may or may not imply IAEA safeguards in a disarmed world. NNWS respondents were split nearly evenly, with a slim majority of NNWSs indicating they would not have trust without international monitoring. Two NWSs also indicated that they would not have such trust without international monitoring, while one was unsure.

Question: In a post-disarmament world, States would trust that weapons laboratories and similar institutions were converted to focus only on peaceful nuclear activities without international monitoring, as long as there are credible assurances that all nuclear material is used exclusively for peaceful purposes.

Non-Nuclear-Weapon States

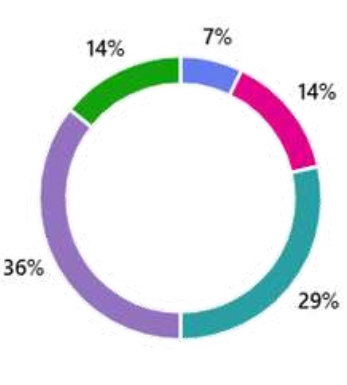


Nuclear-Weapon States

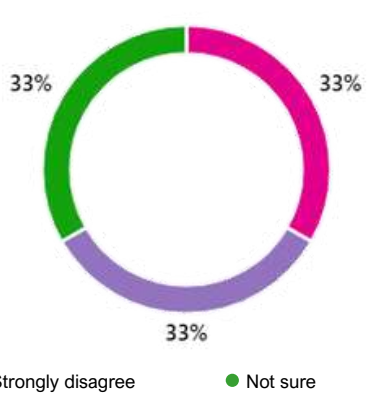


Question: A system of measures to ensure irreversibility of nuclear disarmament should include only nuclear-weapon States since only they have access to the technology and designs necessary to build nuclear weapons.

Non-Nuclear-Weapon States



Nuclear-Weapon States



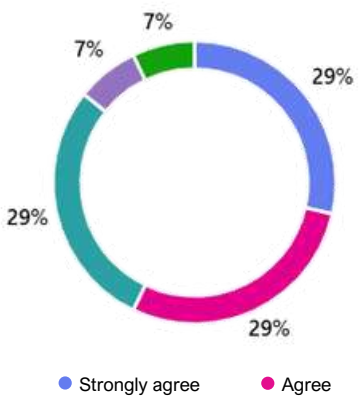
Obstacles to Disarmament

The consultations and survey conducted under this project confirmed the broadly shared view among NPT States Parties that nuclear disarmament is a long, complex, and non-linear process. All respondents – including NNWS – acknowledged that the political environment determined the feasibility of disarmament and was key to ensuring confidence in the irreversibility of disarmament. However, several NNWS officials interviewed for the project pointedly noted that the political environment should not affect the feasibility of nuclear disarmament and has not affected it in the past (recalling US-Soviet arms control during the Cold War).

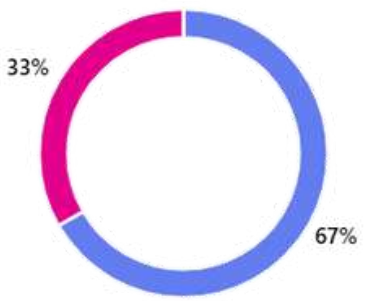
There was a divergence of views on specific aspects during consultations and in the survey responses. Among other issues, respondents were asked whether nuclear disarmament should be pursued step by step while preserving strategic stability at each stage. This has been a contentious issue in the NPT context, which was reflected by the NNWS responses: nearly half of respondents agreed with the sentiment and over a third disagreed, while one respondent was unsure. In written responses, the NNWS respondents largely expressed scepticism about the concept of strategic stability itself, characterising it as inherently subjective and intended to prevent steps towards disarmament. All of the NWS respondents agreed that disarmament should be pursued step by step while preserving strategic stability. One NWS clarified that they viewed the goal as preservation of mutual confidence between disarming States rather than as a conventional understanding of strategic stability.

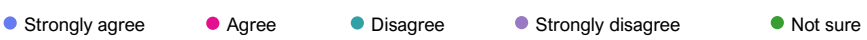
Question: Nuclear disarmament should be pursued step by step while preserving strategic stability at each stage.

Non-Nuclear-Weapon States



Nuclear-Weapon States

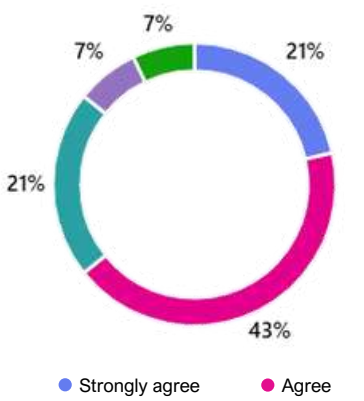




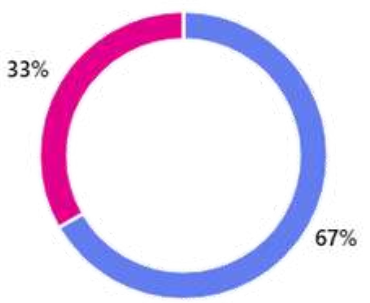
Another difficulty in nuclear disarmament is achieving a sustainable balance between verification and the willingness of disarming States to accept certain verification measures as a precondition for steps along the path to disarmament. Respondents were asked if disarmament should be adequately verifiable, even if this makes disarmament more difficult to achieve. With the exception of a third of NNWS respondents, all NWS and the majority of NNWS respondents said that disarmament should indeed be adequately verified. However, several NNWS respondents clarified that verification should not be seen as on obstacle, that it should not be used as "an excuse not to disarm", and that, given the political will to disarm, verification should be viewed purely as a technical issue. One NWS respondent noted that the term "adequate" was key, e.g., that verification was but one factor contributing to confidence that a certain step along the path to disarmament was not being reversed.

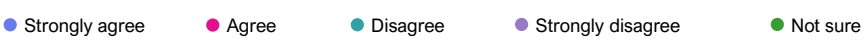
Question: Nuclear disarmament should be adequately verifiable even if this makes disarmament more difficult to achieve.

Non-Nuclear-Weapon States



Nuclear-Weapon States

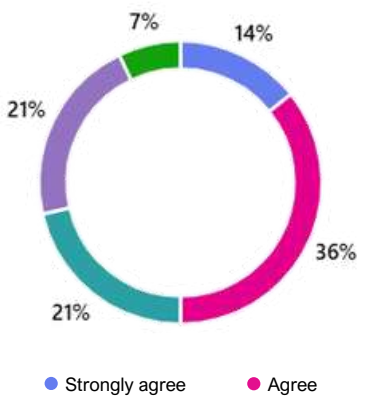




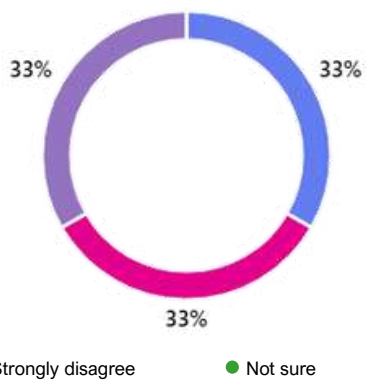
Finally, in a disarming or disarmed world, the nuclear fuel cycle may not look as it does today. Respondents were asked if confidence in irreversibility could be enhanced by restrictions on fuel cycle activities and to whom and to what activities such restrictions should apply. NNWS respondents were split evenly on this question, half answering that there should be restrictions and the other half that there should not. The States that indicated there should be restrictions on the fuel cycle largely argued that such restrictions should apply to all States and that there should be a cap on enrichment levels and a prohibition on plutonium reprocessing. One NNWS indicated that fuel cycle restrictions should include a global phase-out of nuclear power. Among the NWSs, two agreed or strongly agreed that there should be restrictions on the nuclear fuel cycle while one strongly disagreed. The two agreeing NWSs argued that restrictions should apply to all States and that there should be a cap on enrichment levels and a prohibition on plutonium reprocessing. One NWS respondent clarified that a fissile material cut-off treaty would address this issue.

Question: Confidence in the irreversibility of nuclear disarmament should be enhanced by restrictions on fuel cycle activities.

Non-Nuclear-Weapon States

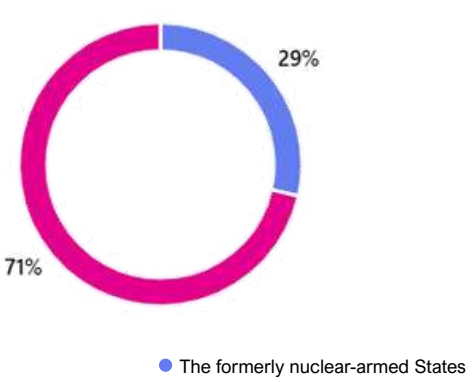


Nuclear-Weapon States



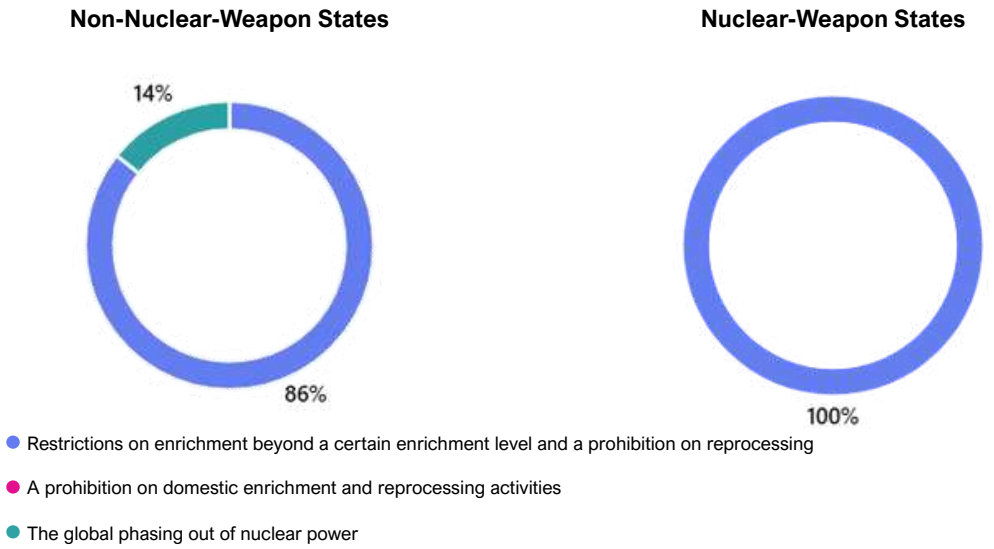
Question: Fuel cycle restrictions should apply to:

Non-Nuclear-Weapon States



Nuclear-Weapon States

Question: Fuel cycle restrictions should encompass:

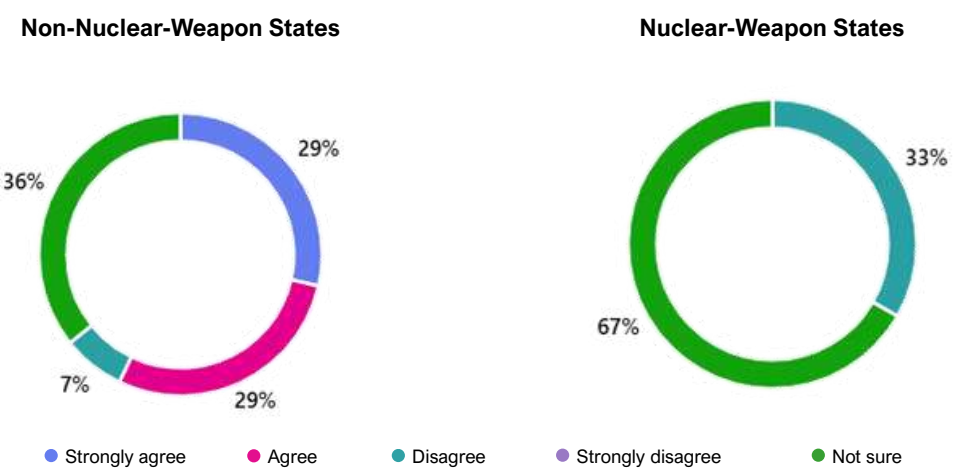


Costs of Disarmament

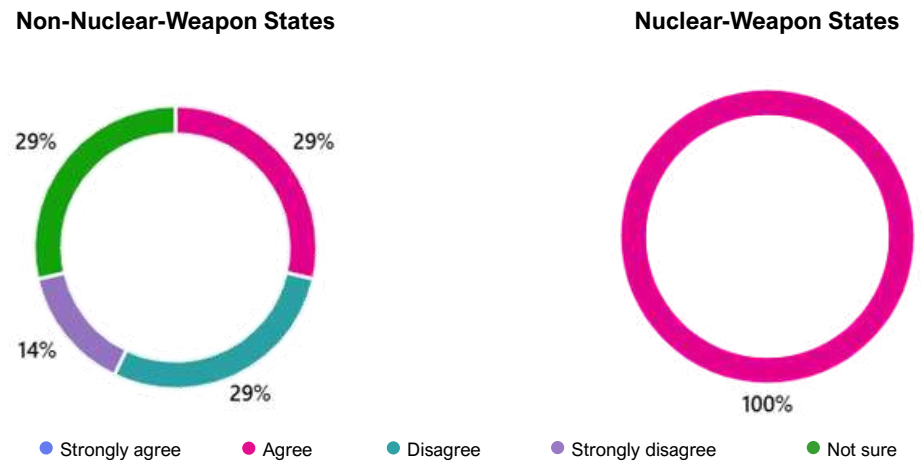
One major consideration in the feasibility of providing confidence in irreversibility is the cost of disarmament, e.g., which countries should pay and at which point in the disarmament process. Two thirds of the NNWSs surveyed indicated that the disarming countries alone should bear the cost of disarmament verification and monitoring, while one third was unsure. When asked if it is in the interest of NNWSs to contribute financially to disarmament verification and monitoring, the NNWSs largely disagreed or were unsure, with only a third agreeing that they did have such an interest.

Two of the three surveyed NWSs were unsure whether the cost of disarmament should be borne by the disarming States themselves, while one indicated that it should not be limited to the disarming States. All surveyed NWSs indicated the view that it was in the interest of NNWSs to contribute financially to disarmament verification and monitoring. One NNWS official interviewed for the project argued that, while the NWSs should bear the cost for their own disarmament, NNWSs would likely be willing to contribute to the IAEA safeguards system to ensure fissile material remained in peaceful uses.

Question: The cost of disarmament verification and monitoring should be carried by the disarming countries alone.



Question: It is in the interest of non-nuclear-weapon States to contribute financially to disarmament verification and monitoring activities.



In one interview, a NNWS official noted that there was some difference in perspective on costs associated with disarmament between NNWSs and NWSs. In the past, at least one NWS had expressed the view that NNWSs did not fully understand the cost of disarmament; in response to this, several NNWSs had suggested to establish a disarmament fund. The issue remains outstanding.

These responses indicate that more research should be done on the cost of disarmament verification and monitoring to provide models for NPT States Parties to consider in a disarming world. As noted earlier, it is also useful to think through the avoided costs, in terms of maintenance of a deterrent by the NWSs, or of potential military responses NNWSs envision to a nuclear event, when examining the costs of disarmament.

Actors in Disarmament

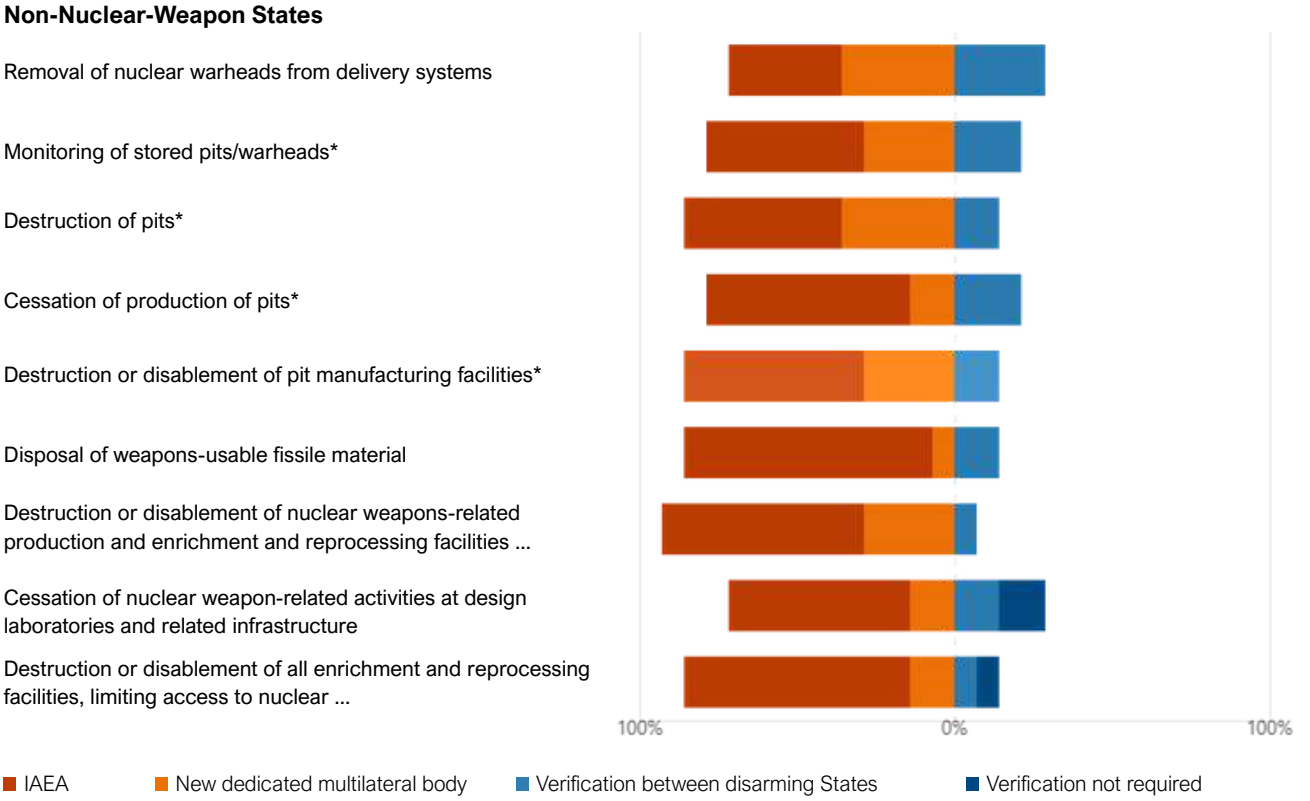
The final theme addressed in the consultations and the survey are the actors in nuclear disarmament, including who should conduct verification activities and to what extent they would have access to proliferation-sensitive information.

Along the nine steps to disarmament identified above, respondents were asked which activities the IAEA could verify, which would require a new multilateral body, which could be verified between disarming States, and which activities would not require verification. The majority of NNWS respondents indicated that the IAEA or a new multilateral body should take charge of verification, with some even indicating potential involvement by such an organisation in the earlier stages, such as the removal of nuclear warheads from delivery systems. However, in these earlier stages, the NNWSs also largely accepted that verification could be implemented by disarming States, with some NNWSs arguing that the IAEA or a new body should be increasingly involved in later steps.

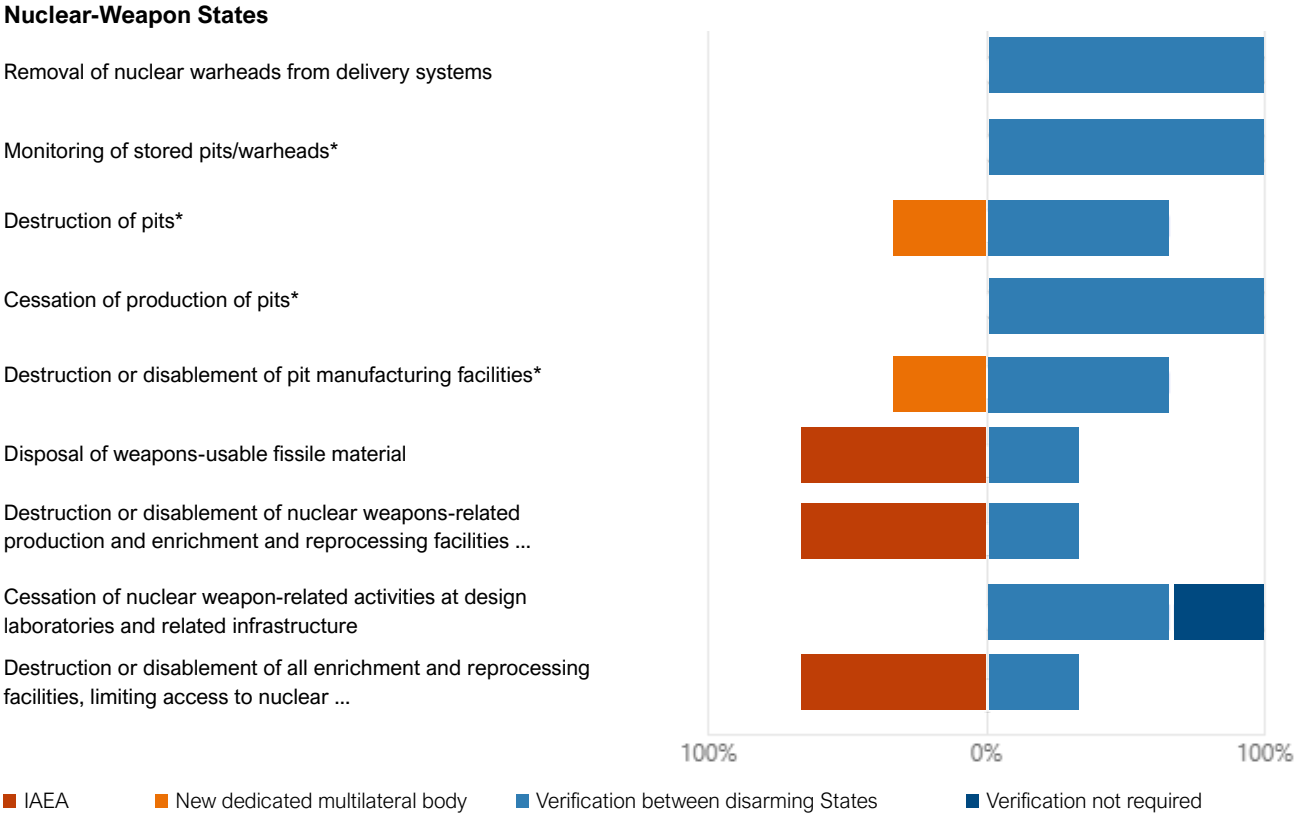
NNWS respondents further expressed the view that the IAEA had or could develop the technical capacity to conduct verification activities and that the IAEA had experience in post facto disarmament verification, such as what took place in South Africa. On that note, one NNWS respondent emphasised that the IAEA should not be delegated a new role, e.g., should not be involved in sensitive dismantlement activities, while another respondent expressed the view that the IAEA has the "expertise and institutional mechanisms to verify all steps of the nuclear disarmament process and appropriate measures can be devised to ensure that the most proliferation-sensitive steps would be cordoned off." Finally, another NNWS observed that the IAEA would need more resources to take on any version of this role.

Question: Which verification activities could be supported by the International Atomic Energy Agency (IAEA), which may require a new dedicated multilateral verification body, which could be verified betwen the disarming States alone, and which would not require verification to provide confidence? Please indicate your choice by marking one of the options.

Non-Nuclear-Weapon States



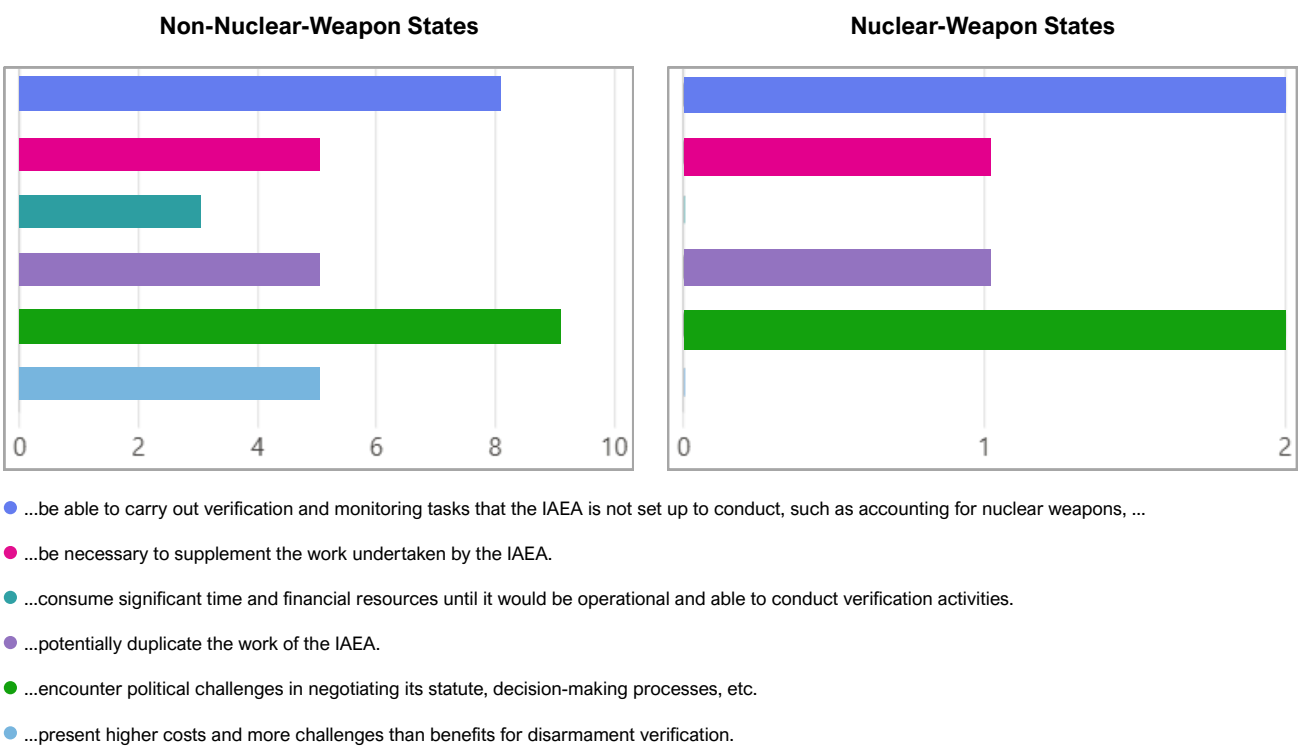
Nuclear-Weapon States



In interviews, the sentiments expressed above were largely reiterated. Some States Parties believed the IAEA had the mandate to conduct disarmament verification and others did not. One NWS official argued that the IAEA would need an extended mandate to conduct these activities and that it would need to be tied to a new treaty, other than the NPT or the TPNW. One NNWS interviewee said that, while the IAEA did not have the mandate today, it would be fairly simple to grant the Agency this mandate and that there was no need to "reinvent the wheel". A second NNWS interviewee saw no difference between the mandate today and that for nuclear disarmament, as long as weaponisation-related information was treated properly. Yet a third NNWS official argued that it might be advantageous to leave the IAEA out of the disarmament verification process to preserve the Agency's independence.

The NWSs, conversely, expressed a much greater preference for verification between disarming States, some throughout all nine steps to disarmament. Two of the three answered that the IAEA would have a role in verifying fissile material disposition and in the elimination/dismantlement of weapons-related production and fissile material enrichment and reprocessing facilities. In written explanations, one NWS expressed the view that the IAEA should be involved in the areas where it historically has the experience and competence, while another NWS responded that the "IAEA does not have the mandate to verify nuclear disarmament" and that any involvement by a third party should be determined by an agreement or treaty. This debate is reflective of tensions in Vienna over the IAEA's potential involvement in disarmament verification.

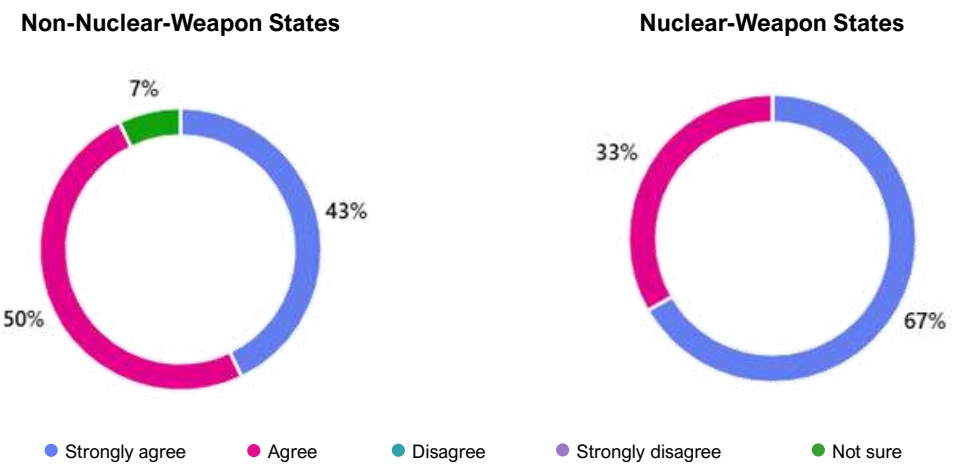
Question: Please select the statements you agree with (multiple selections possible): A newly created international body to oversee and implement nuclear disarmament verification would…



As to the roles of NWSs versus NNWSs, respondents were asked three questions: should only the NWSs be involved in the implementation of measures that ensure irreversibility; should disarming States alone be responsible for providing confidence against rearmament; and should NNWSs play a role in disarmament verification without access to proliferation-sensitive information.

The majority of both NNWSs and NWSs expressed the view that providing credible assurance that steps towards nuclear disarmament were not reversed should not be the responsibility of the disarming States alone, though roughly a quarter of NNWS respondents answered that it should. Similarly, the majority of NNWSs felt that a set of measures to ensure irreversibility should not be limited to NWSs, while opinions of the NWSs themselves were divided. All respondents, save for one NNWS that was unsure, indicated that NNWSs should play a role in disarmament verification without access to design or other proliferation-sensitive information.

Question: Non-nuclear-weapon States should play a role in disarmament verification with limits established by the NPT (no access to design or other sensitive properties of nuclear weapons).



One NWS interviewed for the project expressed the view that "if they [NNWSs] are not involved, how will they believe us?" The NWS respondent made a distinction between verifying the process of disarmament between NWSs and the end state, which would involve NNWSs in verification. Several NNWS officials raised the example of the IPNDV and the importance of continuing this cooperative work between NWSs and NNWSs.

US President Ronald Reagan and Soviet General Secretary Mikhail Gorbachev signing the Intermediate-Range Nuclear Forces (INF) Treaty in 1987. Credit: Wikimedia Commons.

Summary of Findings

The main takeaways from the project are as follows:

First, the consultations and the survey conducted by the VCDNP demonstrated that the principle of irreversibility of nuclear disarmament is deeply ingrained in the international discourse, including in the context of the NPT. In fact, the NPT review process has emerged as the key international forum for its discussion. In the end, irreversibility is a key element of nuclear disarmament and discussion of NPT's Article VI is futile without a firm understanding of that principle. However, States Parties' views on the irreversibility principle and requirements for achieving and maintaining a nuclear weapons-free world continue to vary. Moreover, consensus on a common definition or shared vision of irreversibility remains elusive.

Second, the overwhelming majority of respondents adhere to the view of nuclear disarmament as a process rather than a fixed end state and pay greater attention to its procedural aspects than to defining a specific end state. One can conclude that the majority of States are prepared to address practical steps on an ad hoc basis, evaluating each step or activity as the process moves along until a degree of disarmament that can be characterised as sufficiently irreversible is reached.

Respondents also expressed the view that absolute irreversibility is technically impossible. Since the knowledge about nuclear weapons cannot be erased, the reconstitution of nuclear weapon programmes is theoretically only a matter of time and effort.

Accordingly, the maintenance of a non-nuclear world will require adequate verification and transparency to ensure that disarmament obligations are upheld. Responses also reflected upon the interrelationship between irreversibility, verification, and transparency, which are widely regarded as the three pillars of disarmament.

Third, the survey results reflected a significant variation of how NWSs and NNWSs conceptualise their involvement in different stages of nuclear disarmament. The majority of respondents appeared receptive to a situation where the initial stage of nuclear disarmament would be implemented by NWSs with minimal involvement of NNWSs in negotiations on and practical implementation of relevant agreements. In practical terms, the survey showed broad, though not universal, agreement that at least early steps in the process could be entrusted to NWSs.

Respondents were also largely receptive to the idea that early disarmament steps may be implemented through unilateral actions or politically binding measures between disarming States. In practical terms, this attitude applied to such measures as dismantlement of delivery systems and the extraction of fissile materials with classified attributes from weapons programmes. In a similar vein, when France dismantled its military reprocessing facility and nuclear testing, the declaration itself that such activities were irreversible was broadly considered sufficient without the need for intrusive verification.

With respect to further-reaching measures, preference predominantly leaned toward the necessity of legally binding agreements. There was also agreement that long-term confidence in the irreversibility of disarmament required binding verification regimes, even though efforts needed to reach such agreements complicate and potentially delay the disarmament process.

Fourth, in the same manner, representatives of NNWSs were less inclined to insist on involvement in verification activities at the early stage of the nuclear disarmament process, with only a few expressing a preference for such early engagement. In contrast, views on whether NNWSs should participate in verification at advanced stages of nuclear disarmament and subsequently in monitoring the denuclearised status of the world diverged much more significantly. The majority of NNWSs as well as some NWSs expressed the view that they should.

Fifth, responses varied widely with respect to the financial aspects of nuclear disarmament, specifically, who should provide funding for both disarmament activities and verification. While respondents shared varying perspectives, there were no definitive conclusions on effective costing mechanisms. Notably, the 1999 IAEA Secretariat document entitled 'Financing Agency Verification of Nuclear Arms Control and Reduction Measures' (GOV/INF/1999/9) was identified as a potentially valuable reference in addressing this challenge.

Sixth, views also diverged with respect to the institutional aspects of nuclear disarmament, e.g., whether implementation and verification should be entrusted to the IAEA or to a new international organisation, as well as to the mandate of the institution chosen for these activities. Opinions varied considerably with respect to the scope of the institution's involvement and the specific activities for which it should assume a verification role. Those who supported the view that this role should be entrusted to the IAEA disagreed whether its mandate allowed for verification of disarmament and whether its mandate should be expanded to enable that to effectively support such responsibilities.

The survey and interviews with representatives of NWSs and NNWSs conducted by the VCDNP have demonstrated that the requirement of irreversibility of nuclear disarmament and its broad contours, as well as the closely associated requirements of verification and transparency, are deeply ingrained in the international community. Moving forward, the international community can and should proceed further to a new stage in this debate. This new stage needs to address the practicalities of irreversible disarmament, verification, and transparency as well as trade-offs that are unavoidable in pursuit of these activities.

There are many options to operationalise irreversibility. The consultations and the survey have demonstrated that views on these options not only diverge, but also that, in many cases, the choice between these options is often intuitive or ad hoc rather than grounded in knowledge. To better understand the substance, consequences and costs of these options, international discussions of irreversibility should broaden and include capacity-building efforts. Views will continue to differ because, in the end, each State has its interests and its preferences, but such choices could be better informed.

A gift of the Soviet Union to the United Nations, the statue "Let Us Beat Our Swords Into Ploughshares" stands at the UN headquarters in New York. Credit: UN Photo/Rick Bajornas.

Conclusions and Recommendations

The principle of irreversibility, along with transparency and verifiability, has become one of the three defining elements of the NPT's disarmament pillar. Having its origins in the 1990s US-Soviet and US-Russian disarmament initiatives, the principle of irreversibility was seeded in the NPT context in 2000, where it has lived ever since. While it has been largely unclear since 2000 what irreversibility means in practice, a number of studies – many referenced in this report – have further explored the concept.

In this study, the authors sought to explore practical steps to ensure the irreversibility of nuclear disarmament to give policy-makers and diplomats a range of tools, with which to negotiate irreversible nuclear disarmament in the NPT context and beyond. They did this through an extensive review of literature and practice and by developing nine concrete possible stages in the disarmament process, with an assessment of the degree of irreversibility and feasibility associated with each stage. The authors also sought to explore and better understand the state of the disarmament debate, as well as the divergent views of both NNWSs and NWSs. This included identifying both preferences and the aspects that have not yet sufficiently entered the disarmament agenda or where approaches of different countries continue to diverge. The findings of this study have driven the following conclusions and recommendations.

Next Steps for NPT States Parties. While the principle of irreversibility has received much attention in recent years, interest in further developing or finding ways to implement the concept seems to be waning as the NPT review process grows ever more tense. As nuclear governance comes under increasing strain, NPT States Parties will need to decide how much priority they place on having ready solutions for the time when tensions ease. Interim steps could include:

- Building upon previous Review Conference consensus final document language on irreversibility, including by encouraging each State Party to develop its own policy position on the principle of irreversibility in nuclear disarmament, especially what it means to them in concrete terms;

- Pledging further support, including financial support, for initiatives like the IPNDV to continue their work towards finding technical solutions for nuclear disarmament verification between NWSs and NNWSs; and

- Acknowledging and further funding non-governmental organisations to continue exploration of the issue, including through Track 1.5 channels, with a view of making the principle of irreversibility as tangible and practical as possible.

Institutions for Disarmament. Nuclear disarmament will require strong institutional support, especially with verification activities. Opinions are divided as to whether this task should be entrusted to the IAEA or whether a new international organisation should be created to support this mission, or perhaps a mix of the two. Without doubt, verification with respect to fissile material after the completion of the disarmament process is very similar to the safeguards work currently implemented by the IAEA. But disarmament also involves steps that are not related to fissile material. In any event, even if the IAEA were to become the main verification body, Member States would need to agree on such a mandate, safeguards would need to be revised and adjusted to the new state of affairs, and appropriate funding would have to be allocated. If all or part of verification is entrusted to a new organisation, it would need appropriate staffing and funding, too.

The Role of the IAEA. In a world moving toward disarmament, States Parties and the IAEA will need to embrace a shift in perspective regarding the Agency's role within its mandate. The notion that the IAEA lacks the authority to contribute to disarmament verification does not align with its foundational purpose. While the Agency's past work in this area has primarily been retrospective and supported by weaponisation experts within the Secretariat, its mandate is ultimately defined by the will of its Member States – no more, no less. NPT States Parties and IAEA Member States may choose not to involve the IAEA in such activities, but it would be inaccurate to suggest that the Agency is inherently unable to serve in this role.

Solutions to the Cost Problem. No matter when nuclear disarmament occurs, verification thereof will be costly. Whether conducted in part or wholly by the IAEA, by a new verification body, or between disarming States, States Parties should be prepared with a menu of options for costing disarmament verification, drawing from previous experience in arms control and by the IAEA.[80] If the IAEA is tasked with any part of disarmament verification – even if that simply means routine safeguards as applied to fissile material in a disarmed NWS – the Agency's budget will have to grow commensurate with the new demands placed on its services. Indeed, the IAEA's budget is already under profound strain today. If a new, dedicated organisation is tasked with verifying disarmament and post-disarmament affairs, such an organisation would have to be properly funded. As study and several previous studies have demonstrated, both the process of disarmament and subsequent verification activities will take a long time; thus, State Parties need to be prepared to make commitments accordingly.

80 See the IAEA document referenced above, "Financing Agency Verification of Nuclear Arms Control and Reduction Measures" (GOV/INF/1999/9), 21 May 1999.

Reconciling Technical and Political Issues. While the principle of irreversibility is largely discussed in the NPT context, where diplomats and policy-makers negotiate agreed language, it is important to keep in mind that the issues that drive confidence in irreversibility in disarmament are often technical in nature. As noted above, States Parties should continue to fund research into further understanding irreversibility; they should also further support the work of technical experts – including national laboratories – to develop technical approaches to provide confidence that technical steps identified under this project can be implemented irreversibly.

Managing the "Human Capital" of a Nuclear Weapons Programme. Regardless of how and when nuclear disarmament takes place, scientists will retain the knowledge relevant for weaponisation, or at minimum, the ability to easily regain such knowledge. As such, work should commence now to identify plausible pathways to redirect this group of scientists towards peaceful nuclear or other activities, taking advantage of their expertise in the nuclear physics and engineering aspects of weapons design and assembly. In this respect, inspiration can be drawn from the US Cooperative Threat Reduction programme, South Africa's disarmament process and the diversification of missions in the US national laboratories at the end of the Cold War. In the latter case, many of these new missions, such as supercomputer development and studies of the human genome, were essentially unrelated to nuclear weapons design and assembly, but still took advantage of relevant expertise and tools of weapons scientists. One recommendation from a NNWS official was to prepare comprehensive legislation packages in the style of legislative support provided by the IAEA to ensure that weaponisation experts have a platform to apply their expertise to non-proliferation-related activities. The same expert recommended that the IAEA actively recruit these experts for verification activities.

The Role of Non-Governmental Organisations. Depending on the forum and the country or countries concerned, different value is placed on the role of non-governmental organisations in the nuclear governance field. One NNWS interviewee noted that the track 1.5 format for dialogue – joint work of government officials and non-governmental experts – was a helpful format to shape thought and policy on these issues. As with the IPNDV, States Parties should further support and participate in the work undertaken by non-governmental organisations in the nuclear field to take advantage of their neutral convening power and rich expertise on a given topic, such as irreversibility in nuclear disarmament, as well as greater freedom in developing and publicising innovative solutions.

A Common Definition or Shared Vision. While, in diplomatic negotiations, definitions are important, this study has revealed that discussions about a common definition or shared vision of irreversibility have diminishing returns. Despite the many definitions cited in this report, what irreversibility means will be decided at the negotiating table by the parties to a concrete agreement or treaty. Indeed, attempting to ascribe a universally agreed definition to irreversibility might even be counter-productive to progress on nuclear disarmament. One NNWS official interviewed for this study argued that irreversibility is "not a technical thing […] if you try and make it technical, you're confusing it with verification." Irreversibility is more of a process than an end point and, further, the degree of irreversibility will depend on which practical steps toward nuclear disarmament parties may agree on – the choice of measures and the depth of disarmament will also define the parameters of irreversibility and the verification regime.

The Balance Between Irreversibility, Transparency, and Verifiability. Much effort has been spent trying to understand the balance and interrelation between irreversibility, transparency, and verifiability. As with a common definition or shared vision – while this is important conceptually – there are diminishing returns on having a theoretical discussion. It is the view of the authors that the degree of transparency and irreversibility are considerations that drive the frequency, intensity, intrusiveness, and even the desirability of verification measures. As reflected in the consultations and survey results summarised above, parties to an agreement or treaty may decide that verification is not necessary to provide assurance that a step towards disarmament is not being reversed. Further, transparency measures can and should be implemented without respect to an agreement or treaty and may well facilitate the negotiation of one.

In one interview conducted under this project, the interviewee remarked that irreversibility in nuclear disarmament was practically infeasible. Indeed, the path to nuclear disarmament is fraught with challenges of a technical, political, normative, and legal nature. But these challenges are all manageable within their respective lanes. To take a page from the US-Soviet and US-Russian experience with arms control, 100 percent proof verification, as for 100 percent proof irreversibility, is impossible in principle; one can develop and agree on measures that provide an acceptably high degree of both, but that degree will be up to negotiating parties to determine.

It will take some imagination to reach a disarmed world. During a discussion on irreversibility with another interviewee, they recalled a quote from the author Douglas Adams: "A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools." There is no foolproof approach to ensuring that steps towards nuclear disarmament are irreversible, but it would be a mistake to dismiss the idea outright. It may well take the ingenuity of complete fools to achieve the goal of complete nuclear disarmament.

VCDNP

Vienna Center for Disarmament and Non-Proliferation

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.

vcdnp.org

@VCDNP

info@vcdnp.org

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