# From Absence Measurements to Verified Dismantlement of Nuclear Weapons

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**Abstract.** Arms-control agreements between the United States and Russia negotiated after the end of the Cold War have imposed limits on the number of deployed strategic nuclear weapons. It is widely believed that future arms-control agreements, either bilateral or multilateral, would place limits on all weapons in the stockpiles, including those in storage or slated for dismantlement, so that the gap between existing weapons and those captured by arms-control regimes can be closed. Verification of such "all-warhead" agreements is likely to face some fundamentally new and complex verification challenges. This article examines three types of monitoring regimes that could be used to verify such agreements: the absence regime, the limited-access regime, and the confirmation regime. These regimes can build on each other, and they can be gradually phased in. While research and development on advanced verification technologies continues, all-warhead agreements could initially be verified using absence or limited-access regimes, where technology gaps are small.

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## Background

Arms-control agreements between the United States and Russia negotiated after the end of the Cold War have imposed limits on the number of deployed strategic nuclear weapons. It is widely believed that future arms-control agreements, either bilateral or multilateral, could place limits on all weapons in the stockpiles, including those in storage or slated for dismantlement, so that the gap between existing weapons and those captured by agreements can be closed.[1] Verification of such "all-warhead" agreements, especially if they also envision verified reductions, are likely to face some fundamentally new and complex challenges and may require new verification technologies and approaches to nuclear inspections. To avoid a situation where concerns about the intrusiveness and complexity of verification become an early obstacle in ongoing and future arms control efforts, here we argue it is critical to offer "on-ramps" for nuclear verification and to consider approaches that all relevant parties can support.

This article proposes and examines three different monitoring regimes that could be used to verify limits on the nuclear arsenals and to enable nuclear disarmament. The concepts here are all based on the premise that the parties make declarations as part of the agreement. These would typically include baseline declarations made at the outset followed by regular updates, data exchanges, and notifications.[2] Fundamentally, such a framework is aimed at confirming treaty compliance at declared sites and, as always, there remains the possibility that undeclared items exist at undeclared sites. While onsite inspection regimes may also provide some confidence in the absence of undeclared sites, other monitoring approaches may have to be used to adequately address this concern.

## Monitoring Regimes

A major objective of onsite inspections is to confirm the correctness of a declaration and to deter and detect non-compliance at those (declared) sites where verification activities take place. This can include the presence of undeclared items "hidden in plain sight," but such a strategy is risky for a non-compliant state even for the most basic verification regime. The more robust a regime with onsite inspections becomes, the more likely a non-compliant party would have to consider undeclared sites for prohibited activities including, for example, storage of undeclared items. Ideally, any regime should therefore also allow challenge inspections elsewhere. One of the most stringent inspection regimes would be one that includes the verified dismantlement of nuclear weapons. This is introduced as the confirmation regime below. It is important to recognize, however, that such a regime only becomes relevant and worthwhile as part of a comprehensive verification framework that tracks nuclear warheads from deployment through dismantlement and has strong provisions in place to also address concerns about potential undeclared sites. Warhead dismantlement verification is not particularly meaningful when other aspects of the weapons complex remain shrouded in secrecy. As such, it is natural to consider simple, non-intrusive verification regimes first and to phase-in additional elements over time as the parties seek additional confidence in the correctness and completeness of declared warhead inventories.

Here, we propose three different monitoring regimes: the absence regime, the limited-access regime, and the confirmation regime. This sequence of regimes is similar to the one proposed and discussed in Chen et al. (2016).[3] Verifying an all-warhead agreement could begin with an absence regime, which is relatively straightforward to implement and uses only technologies and approaches that are already being used. The limited-access regime could follow such a minimal regime to provide additional confidence in treaty compliance; it would introduce unique identifiers for all treaty-accountable items. Finally, the confirmation regime would further strengthen the monitoring regime by confirming the authenticity of declared items and by tracking them through the dismantlement process. Ideally, the recovered materials would be placed under safeguards or eliminated to ensure a degree of irreversibility of the process. Importantly, these three regimes build on each other and could be gradually phased in.

*Absence Regime: Confirming numerical limits without access and identification*

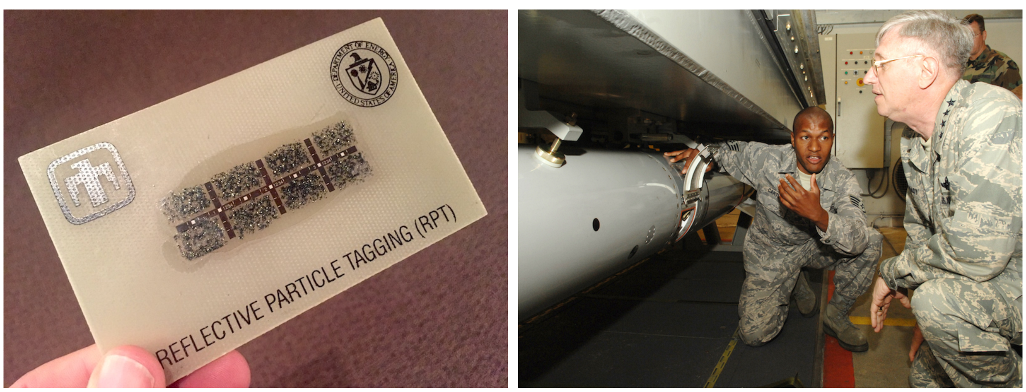
The most basic approach to confirming numerical limits as part of an all-warhead agreement is to rely solely on baseline declarations followed by regular data exchange. No tags are needed, and no treaty-accountable items are ever accessed or inspected. This is essentially the approach followed by New START for deployed strategic nuclear weapons, but it can in principle be expanded to non-deployed weapons. In this case, during an onsite inspection of a site selected by the inspector, which can either be a site that is declared to hold treaty-accountable items or not, the host gets "credit" for the number of items declared for that site and identifies those items as such. These declared items will be accepted as treaty-accountable items and never accessed or inspected.[4] The inspectors would then be allowed to confirm that other items available at the site are in fact <u>not</u> treaty accountable. During the negotiations of the underlying agreement, the parties could agree on certain physical characteristics of objects that qualify for further inspection, such as the minimum dimensions of a storage container. In many cases, the host may be able to simply provide visual access to items or containers that have been flagged by the inspector to demonstrate that the item is not treaty accountable; there may be cases, however, where this approach is not possible or practical. In these cases, the inspector could be allowed to make radiation measurements to confirm the "absence of a nuclear weapon" or, more specifically, to confirm that a container does not contain sufficient amounts of plutonium or uranium to make a nuclear weapon. In principle, this can be done with simple neutron or gamma (gross) count measurements.[5]

In a verification regime based on absence measurements, no weapons should ever be part of an inspection, and safety and security concerns would therefore be dramatically reduced. Information barriers, if needed at all, could be relatively simple. Overall, a verification regime based on absence measurements may offer the most promising catalyst for phasing in verification and enabling multilateral nuclear arms control in the 2020s.

*Limited-access Regime: Confirming numerical limits with positive identification*

An absence measurement regime avoids access to treaty-accountable items altogether. Inspection activities would be focused entirely on other objects that are present during an inspection of a declared or undeclared site, say, on storage containers that are large enough to accommodate a treaty-accountable item. This follow-up regime can build on this simple and least-intrusive regime, but it would add some elements of positive identification to it in order to gain additional confidence in the correctness of the declarations made by the other party.

In the most straightforward case, unique identifiers (tags) would be applied to all treaty-accountable items. Tagging treaty-accountable items with unique identifiers (UIDs), which transforms a numerical limit into a ban on untagged items.[6] The identity of selected treaty-accountable items—but not their nature—could be confirmed during onsite inspections by confirming the integrity and the ID of the tag. Over time, the inspecting party would therefore develop an understanding of the movements of treaty-accountable items through the weapons complex of the other party. Based on these movements, the inspecting party would gain some confidence in the fact that the monitored item is in fact a nuclear weapon, i.e., the provenance of the item could gradually be established.[7]




On the left: The Reflective particle tag (RPT) is one of several unique identifiers that are considered extremely difficult to duplicate or otherwise compromise.[8] On the right: Demonstration of the B61 nuclear weapon disarming procedures on a "dummy" (inert training version) in an underground vault at Volkel Air Base in the Netherlands in June 2008. It is plausible to assume that an international inspector would be allowed to approach a gravity bomb close enough to read out a unique identifier. *Source: Author and U.S. Air Force.*

Tagging treaty-accountable items may pose some challenges but none of them should be insurmountable even with existing verification technologies and approaches. Warheads in storage are (or can be) containerized. These containers can then be tagged and sealed; ideally, containers could also serve as tamper-indicating enclosures to provide additional confidence in the integrity and nature of its content. The unique identifier of the container would then "represent" the warhead itself, whose serial number could be reported as well. Similarly, it should be possible to uniquely identify gravity bombs. A wide variety of tags and seals is available to accomplish this task, and the parties could choose from several options balancing security, cost, and complexity. Monitored storage of warheads or bombs could be complemented by additional containment and surveillance methods (including, remote monitoring) if desired. Some of the required procedures may be complex, but all relevant technologies are available.

For deployed warheads on missiles, different approaches may have to be pursued. New START currently uses unique identifiers only for missiles (ICBMs, SLBMs) and heavy bombers; warheads are counted but not identified. Uniquely identifying a deployed warhead given access restrictions may be challenging. It may well be that the parties agree on a simplified method for these warheads, for example, by simply accepting serial numbers or other identifiers provided by the host. Even without verifying these numbers independently during inspections of deployed systems, inspectors may over time gain confidence in the correctness of these numbers based on overall consistency of the declarations over time. Occasionally, warheads may also appear in storage or during maintenance where their identity may be more easily confirmed.

Another approach supporting a limited-access regime could be the use of "Proximity Tags" or "Buddy Tags." First proposed in the late 1980s, this concept seeks to overcome concerns about safety and intrusiveness by separating the tag from the treaty-accountable item itself.[9] In a tagging regime using buddy tags, a party would declare its inventory of treaty-accountable items and receive exactly one (unique and unclonable) tag for each. The monitored party would then co-locate these tags with the items. The basic idea is that, during a short-notice onsite inspection later on, the inspected party must be able to present one buddy tag for each treaty-accountable item present at the inspected site. This concept could be modified to support a limited-access regime.

Overall, it may well be that a limited-access regime, i.e., a verification regime without confirmation measurements, could be considered fully adequate even for deep cuts in the nuclear arsenals.

### *Confirmation Regime: Warhead confirmation and verified dismantlement*

At some point prior to dismantlement, and even if verification arrangements seeking to confirm numerical limits on nuclear warheads have been in place for extended periods of time, the inspecting party will prefer or require reassurance that declared warheads are authentic so that further reductions in the arsenals can be considered credible. Such a confirmation regime could build on the ones discussed earlier (i.e., the absence regime and the limited-access regime) but include actual measurements on nuclear weapons. It's the only regime where significant technology gaps continue to exist. Even though major research and development efforts have been underway for over the past thirty years, no inspection system has been successfully demonstrated in a true inspection setting, i.e., with measurements on actual nuclear weapons and the participation of international inspectors, while meeting the requirements for certification and authentication of instruments and data.

The confirmation regime envisions measurements to confirm the authenticity of declared nuclear weapons prior to dismantlement (using an attribute or template-matching approach) and perhaps also during the "life cycle" of randomly selected weapons. The confirmation regime provides the highest confidence in the correctness of declared inventories and reductions. Several types of inspection systems using a variety of radiation measurement techniques have been proposed for confirmation measurements. These measurements are generally considered highly intrusive, and authentication and certification of information barriers has so far proven difficult.

Note that a regime that includes verified dismantlement of nuclear weapons and places constraints on the fissile materials recovered from them, i.e., by applying safeguards on these materials or by verifying their elimination or disposition, would provide additional opportunities for inspectors to confirm the correctness and completeness of declarations. In particular, knowledge about the total amounts of fissile materials produced by a country could provide confidence in the fact that undeclared stockpiles of weapons do not exist. Historic production of plutonium and highly enriched uranium can be estimated using methods of nuclear archaeology.[10] These number could be reconciled as material from dismantled warheads is becoming available.

It is also worth pointing out that, over time, inspectors would be able to draw some conclusions about the average amounts of plutonium and uranium contained in dismantled weapons.[11] While the host party may generally be concerned about revealing this information, some early verification concepts were based on the assumption that the aggregate quantities and average isotopic composition of materials "contained in a mix of several different types of warheads can be declassified in the course of future treaty negotiations."[12] Such a concept could drastically simplify the verification of deep cuts as confirmation measurements may not be considered essential at all. This question has received relatively little attention as part of past and ongoing studies but deserve more attention.

## Conclusion and Outlook

For thirty years, international research and development efforts have sought to develop inspection systems that can confirm the authenticity of a nuclear weapon to support the verification of future arms-control treaties, which may include non-deployed weapons and verified dismantlements. With few exceptions, little progress has been made toward certifying and authenticating such candidate systems, primarily due of security concerns associated with such measurements involving highly sensitive items. In this article, we have examined a different approach and consider three basic regimes for nuclear disarmament verification beginning with a simple regime that is straightforward to implement and only uses existing technologies and already established procedures. The other regimes can build on this foundation and be gradually phased in as technologies become available and treaty parties seek to strengthen the verification regime.

First, an absence measurement regime can provide a reasonable starting point for verifying all-warhead agreements. Here, we follow the proposition of simply accepting as weapons all "items declared as weapons" by the host. The technologies needed to support an absence regime are mature and already used for other arms-control applications. In particular, Russia and the United States have been using neutron detectors for many years as part of New START inspections. In a verification regime based on absence measurements, no weapons should ever be part of an inspection, and safety and security concerns would therefore be dramatically reduced.

Second, a limited-access regime with positive identification of treaty-accountable items could be phased in over time. Serial numbers or unique identifiers would be used to identify declared items. Measurements on treaty-accountable items are still not envisioned at this stage, i.e., the authenticity of the warheads themselves is not confirmed. The only new technologies required to support a limited-access regime are tags and seals. Containment & surveillance technologies could also play a relevant role; in particular, declared warheads or warhead-components in long-term storage could be monitored remotely with minimum efforts and interference. Again, all technologies needed to implement such a verification regime are available today, and ongoing and future research could be focused on joint development of advanced tags and seals. It is likely that the access procedures required for this regime would be the more difficult part to negotiate, and international efforts could usefully focus on these aspects, in particular, how to apply and read-out unique identifiers on treaty-accountable items.

Third, a confirmation regime would finally require those instruments that have so far been elusive, i.e., radiation measurement systems with information barriers for attribute or template measurements. These systems would be used as part of a comprehensive verification framework, which may track nuclear warheads from deployment through dismantlement. A confirmation regime that involves verified dismantlement of nuclear weapons would provide the highest level of assurance that reductions are real. In particular, if the fissile materials that are recovered from dismantled warheads are placed under international safeguards or, better, eliminated or disposed-of, this regime would also provide the highest degree of irreversibility and ensure that recovered materials and components are not simply re-entering the weapons complex, where they could be used to make new weapons. While there remain technical challenges for warhead confirmation measurements, more important—and perhaps more difficult to achieve—may be the buy-in from nuclear weapon states to seriously consider verification approaches based on such measurements. International verification exercises, involving both weapon and non-weapon states, are one way to facilitate this process.

In the meantime, warhead dismantlements continue without any verification provisions. These are welcome activities, which accelerated after the end of the Cold War; at the same time, however, unverified dismantlement may create ambiguities for future arms-control agreements that limit total stockpiles of nuclear weapons. While efforts toward first bilateral or multilateral all-warhead agreements are underway, it should be in the interest of all parties to document these dismantlements in ways that inspectors will find credible at later times.

## Endnotes

[1]James Fuller, "Verification on the Road to Zero: Issues for Nuclear Warhead Dismantlement," *Arms Control Today,* December 2010; *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities, Committee on International Security and Arms Control,* National Academy of Sciences, Washington, DC, 2005.

[2]There may be ways to devise verification regimes that do not require baseline or other declarations. Since declarations are well established and non-controversial, we assume they would also be part of future all-warhead agreements.

[3]Cliff Chen, Crystal Dale, Sharon DeLand, Angela Waterworth, Tom Edmunds, Doug Keating, and Matthew Oster, "Developing a System Evaluation Methodology for a Warhead Monitoring System," *57th Annual INMM Meeting,* July 2016, Atlanta, Georgia.

[4]Consistent with this approach and for similar reasons, a recent report published by the International Partnership for Disarmament Verification (IPNDV) introduced the concept of "items declared as weapons." *Working Group 4: Verification of Nuclear Weapons Declarations*, International Partnership for Disarmament Verification, April 2020.

[5]On neutron measurements, see *Treaty Between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive*

*Arms* ("New START"), April 2010; Radiation Detection Equipment: An Arms Control Verification Tool, Product No. 211P, Defense Threat Reduction Agency, Fort Belvoir, VA, October 2011. On gamma measurements, see Eric Lepowsky, Jihye Jeon, and Alexander Glaser, "Confirming the Absence of Nuclear Warheads Via Passive Gamma-Ray Measurements," *Nuclear Instruments and Methods in Physics Research A,* 164983, December 2020.

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[7]C. Comley, M. Comley, P. Eggins, G. George, S. Holloway, M. Ley, P. Thompson, and K. Warburton, *Confidence, Security & Verification, The Challenge of Global Nuclear Weapons Arms Control*, AWE/TR/2000/001, Atomic Weapons Establishment, Aldermaston, United Kingdom, 2000; Arthur Tompkins, ed., *Provenance Research Today: Principles, Practice, and Problems,* Lund Humphries, London, 2020.

[8]K. Tolk, "Reflective Particle Technology for Identification of CriticalComponents," *33rd Annual INMM Meeting,* Orlando,Florida, July 1992; H. A. Smartt et al., "Status of Non-contact Handheld Imager for Reflective Particle Tags," *55th Annual INMM Meeting,* Atlanta, GA, July 2014.

[9]S. D. Drell, et al., *Verification Technology: Unclassified Version*, JASON Report,JSR-89-100A, The MITRE Corporation, McLean, VA, October 1990; Sabina E. Jordan, *Buddy Tag's Motion Sensing and Analysis Subsystem,* Sandia National Laboratory, Albuquerque, New Mexico, 1991; A. Glaser and M. Kütt, Verifying Deep Reductions in the Nuclear Arsenals: Development and Demonstration of a Motion-detection Subsystem for a 'Buddy Tag' Using Non-export Controlled Accelerometers, *IEEE Sensors Journal,* 20 (13), 2020.

[10]S. Fetter, Nuclear Archaeology: Verifying Declarations of Fissile-Material Production, *Science & Global Security,* 3 (3–4), 1993; T. W. Wood et al., The Future of Nuclear Archaeology: Reducing Legacy Risks of Weapons Fissile Material, *Science & Global Security,* 22 (1), 2014.

[11]Some information considered sensitive could be masked by working with blend stocks, as has been the case for the Plutonium Management and Disposition Agreement between Russia and the United States.

[12]Theodore B. Taylor, Verified Elimination of Nuclear Warheads, *Science & Global Security,* 1 (1–2), 1989. Taylor further elaborates on the idea by proposing that "each owner nation could mask the true value of quantities it wished to keep secret by adding appropriate items, in unrevealed amounts, to the objects to be dismantled. An example would be the addition of a large weight of sand to each of the containers for some type of warhead, without ever revealing what that weight was."