Conceptual Elements of Potential Verification Strategies

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Introduction

In many circles, nuclear disarmament verification is primarily seen as a question of whether reliable radiation measurement techniques exist, and whether agreement can be reached on comprehensive onsite inspections. However, the work of the International Partnership for Nuclear Disarmament Verification (IPNDV) has also shown that other conceptual topics can become very important. A sound verification regime will be an integral part of a future nuclear disarmament agreement. Drawing on historical examples, this paper illustrates potential generic elements that could be included in a verification protocol that could assist in and contribute to confidence in the verification of such agreements.

Taking into account operational, non-operational, and retired nuclear warheads, more than 10,000 of these weapons exist worldwide. Therefore, it will not be possible to verify the complex process of dismantlement of every single warhead by onsite inspectors using time-consuming—and often intrusive—measurements. The second part of this document presents various concepts on how to react strategically to this challenge.

One option for responding to this situation is to analyze the entire nuclear weapons enterprise as a system to determine which activities have high potential for the diversion of nuclear warheads and/or their components, and to concentrate verification mechanisms on these activities. Such a systems analysis can be combined with statistical analyses of the number and types of verification activities that would be required with the goal of achieving a predetermined probability of detection of diversion-relevant activities.

In the framework of a future nuclear disarmament agreement, maximum quotas for different types of onsite inspections could be fixed, based on a proportion of the treaty accountable items

(TAI) to be inspected, or limiting the number of declared facilities that can be inspected in a given period. In addition, the amount of time provided for each inspection likely would be limited.

We also examine the influence of the logistical arrangements that a nuclear-weapon state (NWS) makes to implement the disarmament process. Significant positive and negative impacts on the required verification strategies are addressed for the construction of dedicated, special-purpose facilities for carrying out treaty-mandated activities, the creation of dedicated areas in existing facilities for such activities, the existing capacities for disarmament processes, and the duration of the required interim storage periods.

Given the large number of existing nuclear warheads, concepts for verifying their dismantlement should be as robust, effective, and efficient as possible. Using the 14-step process model as an example, this paper shows how such a concept can be adapted and supplemented in a targeted manner to counter specific options for the diversion of nuclear warheads or their components.

Illustrative Generic Elements of a Verification Framework

Effective nuclear disarmament agreements contain specific verification provisions that encapsulate commonly accepted verification principles as well as identify information required to verify compliance with the agreement. Detailed processes, procedures, techniques, and technologies (PPTT) are included that allow inspectors to make evidence-based assessments of a party's compliance with the agreement's obligations.

Future nuclear disarmament agreements will be negotiated and implemented in the international security environment and geopolitical setting existing at the time. However, certain generic elements, derived from historical nuclear and conventional arms control norms,[1] and agreements like New START are worth considering to illustrate what could be included in a future agreement. The goal is to build confidence in verification and compliance in general.

These generic elements could include:

- *Definition of the overarching objective* of the verification framework. Such a definition is very often reflected in the preambular paragraphs
- *Definition of the scope* of the arms control and/or disarmament framework terms of TAI and thus the scope of verification
- *Definition of terms* used, in particular TAI and specific locations (e.g., storage or reduction sites)
- *Provisions on existing types of TAI* and, if applicable, other relevant equipment (without revealing specific proliferation-sensitive characteristics/capabilities)
- Provisions on differentiating *"look-alikes"* of TAI and dual use items)

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[1] See in particular, The Treaty on Conventional Armed Forces in Europe (CFE), the Vienna Document on Confidence- and Security-Building Measures (VD), and the Treaty on Open Skies (OS).

- *Provisions and limits for TAI* in active military units
- *Provisions for designated permanent storage sites*, including location and content
- *Provisions for reductions* of TAI, including specific verification procedures for reductions and reduction techniques
- *Information exchange on TAI,* including overall numbers, and specific numbers of items located at declared sites
- Annual *information exchange* on force structures
- *Specific verification measures*, for example:
    - Onsite, area, and challenge inspections and visits
    - Overflight rights
    - National and multinational technical means
- *Modalities of onsite inspections*, potentially including, but not limited to:
- Passive inspection quotas (inspections, in which a State Party is obliged to receive within a specific time period at declared inspection sites)
- Active inspection quotas (the total number of inspections that may be carried out within a specific time period)
- Passive challenge inspection quotas, with a right of refusal for reasons of national security (inspections carried out anywhere on the territory of a State Party within an area of application, in particular to increase the likelihood of detecting TAI at sites not declared in the exchanged data)
- *Short-notice inspections* to ensure the "surprise" character of inspections for:
    - Announcing the intent of an inspection
    - Announcing which declared site or specified area is intended for an inspection
- *Definitions of rights and obligations for inspectors and hosts* (what and how to conduct inspections), for example:
    - Right to observe, count, and record TAI
- Right to enter buildings only when they were capable of housing TAI
    - Right of inspected state to shroud individual sensitive items of equipment or to declare "sensitive points" to its security (equipment, locations, or structures) not open to inspection
- Provisions for verification techniques and other inspection rights
- A consultation and clarification mechanism empowered to:

- Address disputes about the provision of the agreed data
    - Address disputes about verification measures
    - Facilitate resolution of any emerging ambiguities and conflicts
    - Initiate appropriate adaptation of verification measures
    - Facilitate decisions on compliance/non-compliance
    - Undertake exchanges to address changes of arms and other relevant military technologies and verification technologies

In addition, there may also be complementary confidence and security building measures, such as:

- Military-to-military contacts and cooperation
- Demonstration of new types of nuclear warheads, delivery systems, and, if applicable, other relevant equipment (without their specific military characteristics/capabilities)
- Allowing flights over specific sites using set rules to safeguard national security.

Systems Approach

IPNDV focused initially on an *item-based approach* to verification that tracks individual TAI or a continuing series of TAI through a notional disarmament process. It then began to address how to build a verification system that could handle a large number of items moving through a variety of locations and processes. To do so, it recognized that it would be useful to use a *systems approach* to verification.

The systems approach outlined below considers a state's nuclear weapons enterprise (NWE) as a whole, composed of various subsystems, and analyses how to verify that it operates consistent with treaty requirements. At a minimum, such an approach would include all TAI, the infrastructure that supports them, and all operations and processes involving them. Depending on the specifics of a nuclear disarmament agreement, a systems approach could be broader to include all nuclear warheads and associated infrastructure and activities in a nuclear armed country.

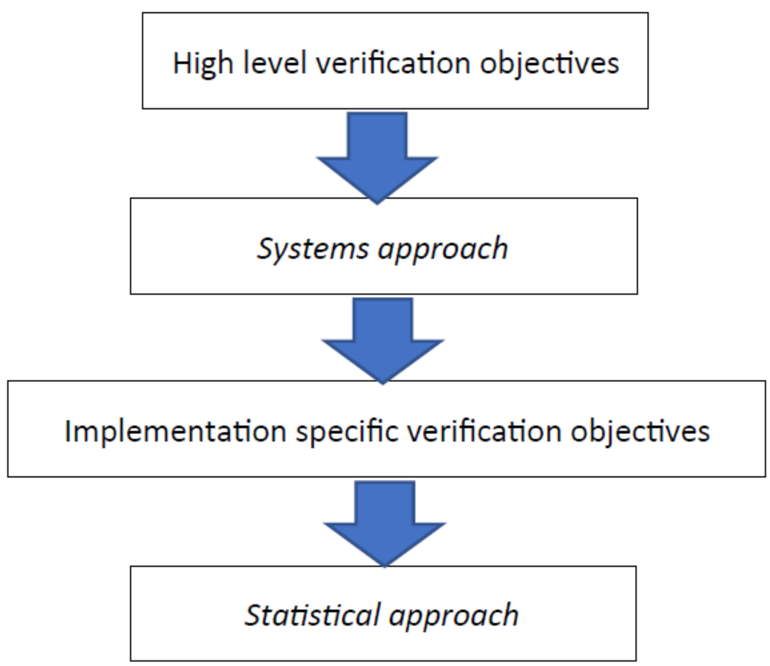
Although the 14-step model focuses on verification and the potential for *diversion* of declared nuclear warheads or components as they move through dismantlement and disposition processes, the broader systems approach can consider the capabilities of the NWE to produce or maintain undeclared nuclear warheads also by other means.

One reason for looking at the NWE as a whole is the fact that inspection resources are limited, and that it may not be possible to always verify all individual movements of items within the enterprise. By identifying verifiable subsystems and understanding their relationships, it should be possible to see behaviour consistent with what has been declared across the NWE system as a whole and build confidence in a state's compliance with treaty obligations.

Note that specific treaty provisions may result in a distinction between how the NWE is seen for verification purposes based on treaty definitions and the realities of the system. For example, under New START the verification system assumes that a heavy bomber counts as only one warhead in the overall total allowed. The actual number of warheads carried by a heavy bomber and stored at the base is greater. That latter number also is known only to the host. That said, many of the most important subsystems (e.g., deployment bases, production sites, storage sites, and their specific holdings in the case of actual declared warhead numbers would be the same.

As shown in Figure 1, the systems approach can be used to identify *implementation-specific verification objectives (*e.g., confirm dismantlement of nuclear warheads*)* to achieve the high-level objectives (e.g., a reduction from 1,000 to 500 deployed nuclear warheads) set out in an agreement.[2] A statistical approach can then be used to distribute verification resources among implementation-specific verification objectives. It basically relies on the random selection of TAI for verification analyses, while holding all items at risk. Numbers are chosen as a function of the population of items present and of the probability of detecting a noncompliant item or activity if present.[3] The random selection may also include the passage of each item through the 14-step process model.

Figure 1: Relationship Between Verification Objectives and System and Statistical Approaches



[2] *Insights from a Decade of the International Partnership for Nuclear Disarmament Verification*, June 2024, https://www.ipndv.org/wp-content/uploads/2024/06/IPNDV-Capstone_FINAL-1.pdf.

[3] A more detailed overview of statistical approaches are provided in *Working Group 4: Verification of Nuclear Weapons Declarations*, 2020, https://www.ipndv.org/reports-analysis/working-group-4-verification-of-nuclear-weapons-declarations.

To assess possible diversion pathways, the systems approach should identify key capabilities as subsystems in the NWE. They do not necessarily represent a site. A nuclear weapons assembly and disassembly site may also contain storage facilities. Each subsystem will have different diversion risks and its own implementation-specific verification objectives, activities, and priorities.

The NWE will comprise activities involving the subsystems. Verification mechanisms should build confidence that these subsystem activities are consistent with treaty requirements (e.g., declared dismantlement processes are taking place and manufacture of undeclared TAI is not taking place).

The systems approach to nuclear disarmament verification could be seen as partly analogous to the International Atomic Energy Agency (IAEA) State Level Concept for safeguards, where generic verification objectives are developed into state-specific technical objectives through an acquisition path analysis. It could be possible to develop quantitative analysis of attractiveness of different diversion pathways based on a model of the NWE in a manner analogous to the physical model and the concept of acquisition pathway analysis used in IAEA safeguards. This would require assigning specific numerical values to rank the attractiveness of pathways in cost and time. This type of analysis will be beyond the scope of the conceptual work of IPNDV, but a qualitative assessment of attractiveness of acquisition and diversion pathways has been performed.[4]

Inspection Quotas

One of the fundamental questions regarding the use of onsite inspections as a part of a nuclear disarmament verification regime is how many inspections are enough to confidently confirm a state's compliance with treaty obligations? However, onsite inspections consume significant resources, both for the inspectors as well as the hosts, and are disruptive to the inspected state's day-to-day operations. As a result, a balance must be struck between enough inspections to confirm compliance and reasonableness in not placing undue strain on limited resources.

In addition to numerical quotas, and perhaps even more important, including different types of onsite inspections in a treaty's verification regime allows for more narrowly focused inspections, tailored to achieve specific verification objectives. For example, the START treaty included provisions for eight different types of inspections, many with unique quotas, and all with specific purposes that required inspection-specific procedures.

Historical Treaties and Their Respective Quotas

Various approaches have been used to calculate quotas for different inspection types in bilateral and multilateral arms control treaties. Inspection types also vary widely across different agreements and are designed to achieve specific verification objectives. A review of these options in past agreements illustrates the menu of possibilities for future agreements.

[4] IPNDV, Report of the Reductions Working Group, 2025.

Option 1

The first option is to set quotas in the text of the treaty, including the following examples

- The START Treaty provisions defined the following inspections:
    - *Baseline data inspections* beginning 85 days and ending 250 days after entry into force of the treaty
    - *Data update inspections* with up to 15 inspections per year, but no more than two inspections per site
    - *New facility inspections* at facilities not specified in the state's initial declaration, but not later than 60 days after it was provided
    - *Suspect-site inspections*, beginning not earlier than 165 days after entry into force of the treaty (the number of suspect-site inspections per year will reduce the total number of data update inspections available)
    - *Re-entry-vehicle inspections* with up to 10 inspections per year, but not more than two inspections per site
    - *Post-exercise dispersal inspections* for mobile launchers, with a maximum of 40 percent of the number of intercontinental ballistic missiles (ICBMs) involved in the exercise
    - *Conversion and elimination inspections* not earlier than 45 days after entry into force of the treaty
    - *Closeout inspections* at facilities following their elimination from treaty accountability
    - *Formerly declared facility inspections with* up to three inspections per year, not earlier than 165 days after entry into force of the treaty, with no more than two at any one facility.
- The U.S.-Russia New START Treaty provides for a quota of 18 onsite inspections annually, of which 10 are permitted for sites with deployed and nondeployed strategic systems (Type I inspections), eight for sites with only nondeployed strategic systems (Type II inspections).[5]
- No participating State of the Organization of Security and Cooperation in Europe (OSCE) is obliged to accept on its territory within the zone of application for cconfidence and security building measures more than three inspections per calendar year.[6]

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[5] 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), Art. XI, paras 2–3; Protocol to New START, Chapter Five.

[6] OSCE, Vienna Document 2011 on Confidence and Security Building Measures, FSC.DOC/1/11, para 76, 2011.

- Each Open Skies Treaty member is obliged to accept a number of overflights over its territory proportional to its geographical size.[7] For example, Portugal had a quota of two flights per year, Russia (together with Belarus) had a quota of 42 overflights annually.
- The Intermediate-Range Nuclear Forces Treaty (INF) provided for five inspection types:
- *Baseline Inspections:* Quotas have not been set for onsite inspections during the Baseline verification period, but the number deemed necessary by the inspecting state to verify the information provided by the inspected state in its Baseline declaration.[8]
    - *Elimination Inspections:* Numbers and frequencies of onsite inspections during the elimination period, which were not limited by quotas.
    - Continuous Portal Monitoring Inspections: Beginning 30 days after entry into force of the treaty, portal monitors could be operated continuously for 13 years at one site per State for production site verification with resident teams of up to 30 inspectors.
    - Closeout Inspections: After notification for each declared site, the elimination of all TAI could be verified.
    - Short-Notice Inspections: These were provided for during the 13 years following the entry into force of the treaty. This is the only inspection type with quotas; 20 per year during the first three years, 15 per year during the medium five years, and 10 per year during the last five years.

During the Residual Period following the total elimination of accountable missiles, the treaty did not provide for any onsite inspections but relied on notifications and National Technical Means.

Option 2

A second option is setting quotas in relation to the number of sites of interest for inspection. For example:

- The OSCE document on Confidence and Security Building Measures for each state sets an annual inspection quota of one per 60 combat units (regiment, brigade, and equivalent) and formations with a minimum of one and an upper limit of 15 visits per year.

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[7] Treaty on Open Skies (OS Treaty), Annex A, Section I, paras 1–2, 1992.

[8] Numbers and locations of all TAI were provided in the Memorandum of Understanding Regarding the Establishment of the Data Base for the Treaty Between the Union of Soviet Socialist Republics and the United States of America on the Elimination of Their Intermediate-Range and Shorter-Range Missiles, INF Treaty, 1987.

- The Treaty on Conventional Armed Forces in Europe (CFE Treaty) includes a quite detailed procedure for calculating passive quotas.[9] The CFE Treaty defines the following four consecutive time intervals:
    - *Baseline Validation Period*: The first 120 days after the entry into force of the Treaty
    - *Reduction Period*: The 36 months following the Baseline validation period
    - *Residual Level Validation Period*: The next 120 days
    - *Residual Period*: Covers the time until the end of the treaty.

For each of the time intervals under the CFE Treaty, separate quotas are set for the inspections at declared sites, which are calculated as a percentage of the respective objects of verification that are located there[10] (see Table 1).

Table 1: Percentage of Quotas for Inspections of Objects of Verification at Declared Sites

Baseline Validation Period	Reduction Period	Residual Level Validation Period	Residual Period
20%	10%	20%	15%

In the same way, passive quotas have been set for challenge inspections (with a minimum of one inspection per period) (see Table 2).

Table 3: Percentage of Passive Quotas for Challenge Inspections

Baseline Validation Period	Reduction Period	Residual Level Validation Period	Residual Period
15% of passive declared sites quotas			23% of passive declared sites quotas

Optimizing Quotas

Setting quotas for inspections that are too low poses a risk of reducing confidence in the verification regime. The following criteria could provide significant contributions to limiting such risk:

[9] Treaty on Conventional Armed Forces in Europe (CFE Treaty), Protocol on Inspections, Section II., para 10-11, 1990.

[10] For each time period, a minimum of one inspection has been set.

- The inspection quotas should include all declared sites where diversion of TAI could occur.
- Quotas should be agreed on both for routine as well as for challenge inspections as needed to strike a balance between holding TAI at risk and limiting impact on hosts' day-to-day operations.
- A systems approach analysis should confirm that proposed quotas provide satisfactory statistical confidence for detecting anomalies, including the diversion of TAI.
- Such an analysis should take into account potential restrictions proposed for the duration of single inspections.

Logistical Arrangements

In order to meet its obligations to reduce its stockpile of nuclear warheads under a nuclear disarmament treaty, each party will need to make extensive practical arrangements to implement it. One of the most challenging implementation decisions involves the facilities where nuclear disarmament verification activities take place. The following section analyzes the advantages and disadvantages of potential implementation approaches to such facilities.

Building Dedicated Facilities for Implementing Verification Activities

The construction of dedicated facilities would be the most comprehensive option for creating a separate infrastructure for implementing verification activities. Its aim is to ensure that no routine activities not related to treaty implementation take place in proximity to nuclear disarmament verification activities. This could include the construction of specific facilities for long-term interim storage and in particular for the dismantling and disposition of TAI and their components.

Advantages

- Reduces the risk of unintended disclosures of sensitive information.
- Reduces the risk of unintentional confusion between treaty-related and other activities as no material that is not subject to treaty requirements would be present in such a facility.
- Allows optimization of design to eliminate potential diversion pathways and support effective verification procedures.[11]
- Supports inspection activities, resulting in both faster and more robust verification activities (e.g., by providing only a small number of potential diversion routes that need to be mitigated).

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[11] A potential example is the "Room within a Room" concept for optimizing perimeter monitoring in a dismantlement or disposition facility. See J. Tenner et al., "The 'Room within a Room Concept' for Monitored Warhead Dismantlement," 35th ESARDA Meeting, Bruges, Belgium, May 2013, 28–30.

Disadvantages

- Significant delays in commencing treaty verification activities would result due to complex and lengthy construction and certification procedures involved with such facilities.
- The costs involved with constructing such facilities would make them prohibitively expensive. For states with comparatively limited stocks of nuclear weapons, such economic considerations would be particularly important.

Despite their advantages, the disadvantages of relying on establishing dedicated facilities could render this option impractical.[12]

Establishing Dedicated Areas in Existing Facilities/Sites

Establishing dedicated areas for conducting nuclear disarmament verification activities within existing facilities offers an alternative implementation approach that maintains separation between treaty-related and non-treaty-related activities, while allowing for the commencement of verification at treaty entry into force. This approach may require physical modifications such as separate entrances, closing connections to other areas within the site, additional walls, or separate perimeters.

Advantages

- Reduces the risk of unintentional disclosure of sensitive information.
- It helps host and inspectors distinguish between treaty-related and other activities.
- Makes it more difficult for diversion of TAI. However, this potential is lower than for purpose-built dedicated facilities.
- Facilitates effective inspections, allowing for long-term storage and easy retrieval of inspection equipment. Could allow for permanently installed inspection equipment to conduct allowed measurements.
- Reduces the disruption to ongoing non-treaty-related nuclear weapons activities.

Disadvantages

- Even minor structural changes in existing facilities can cause delays as they may require extensive construction and certification procedures.
- Existing facilities may limit structural modifications.
- Ongoing non-treaty-related activities may result in limited space, which could be reserved for dedicated, treaty-related areas.

[12] For verification of weapon dismantlement this conclusion has been drawn by A. Axelsson et al., "Verified Nuclear Weapon Dismantlement: An Analysis and Methodology for Facility Assessment," *Science and Global Security* 29, no. 1 (2013): 17–63.

Despite the potential disadvantages, creating treaty-related dedicated areas in existing facilities present a number of advantages similar to those from using dedicated facilities, but without requiring excessive time and financial resources to be realized.

Implementation Capacities Versus Disarmament Obligations

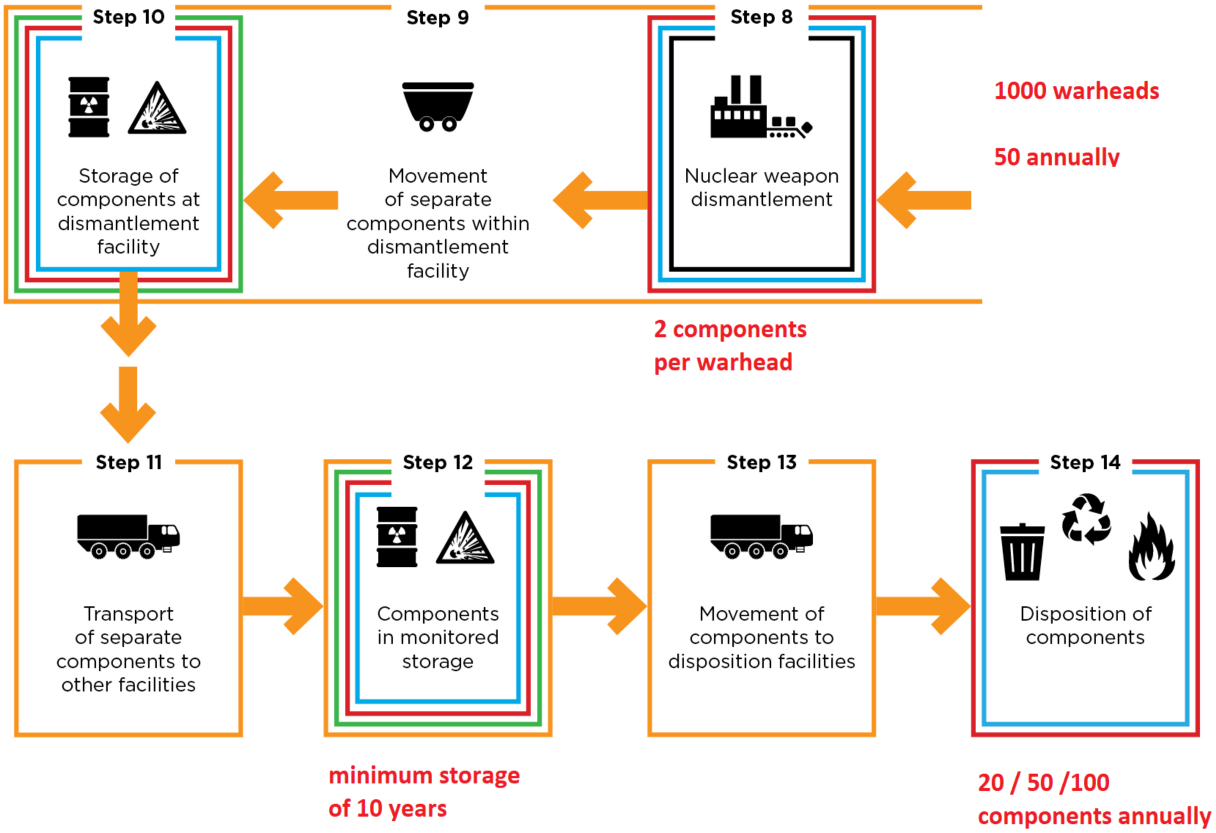
The following section examines the influence of a nuclear-weapon state's capacity to implement its disarmament obligations. This is a variable that is rarely considered in verification strategy concepts, but it is one that past experience with arms control treaties has shown to be quite important (e.g., it took far longer than scheduled in the Chemical Weapons Convention for the United States and Russia to eliminate their chemical weapons because of start-up delays and constrained capabilities to do so). Ideally, the capacities[13] should be in balance with the disarmament obligations, which may be set out explicitly or may follow from the overall reduction agreed in a treaty. The advantages of such a situation include:

- Allows a steady flow of nuclear warheads through the dismantlement process, avoiding a piling up of warheads and their components in interim storage facilities.
- Avoids increases in numbers and duration of verification activities in parallel with the number of warheads and components that are stored.
- Reduces the probabilities of technical failure of chain of custody (CoC) technologies by limiting intermediate storage times for warheads to be dismantled.

The large impact of an imbalance between existing capacities to carry out a treaty-mandated activity and the magnitude of that activity can be further illustrated by a simple example (Figure 2). It uses the IPNDV 14 Step dismantlement process model and illustrates the potential impact of an imbalance between the number of nuclear warheads dismantled (step 8) and the capacity to dispose of the components derived from those warheads (step 14). Such an imbalance would result in a significant build-up of components from dismantled nuclear warheads, and potential concern as a diversion risk and as a burden on the inspection regime.

[13] This does not include capacities required for not-treaty-related transport, storage, and maintenance activities of nuclear warheads and its components.

Figure 2: Model for Illustrating the Effect of Capacity Variations



Note: Assumptions are given in red.

As illustrated by Figure 2, the following simplifying assumptions have been made:

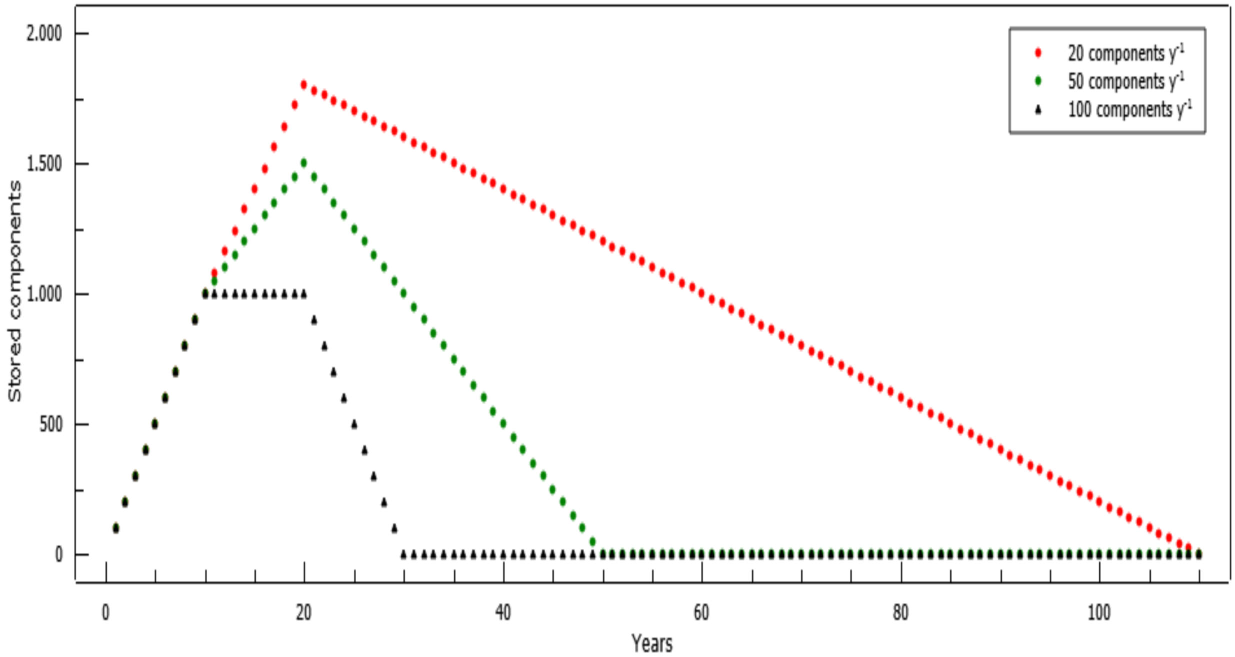
- A total of 1,000 warheads will be dismantled.
- Dismantlement will be performed with an annual rate of 50 warheads.
- Dismantlement will produce two components per warhead.
- Disposition will start 10 years after dismantlement because of the need to establish the needed procedures, facilities, and capabilities.
- Annual disposition capacities are 20, 50, and 100 components derived from the dismantled nuclear warheads, respectively corresponding to 20 percent, 50 percent, and 100 percent of the dismantlement capacity.

Figure 3 shows the inventories of components from dismantled warheads now in monitored storage as a function of time for the three simulated cases of disposition capacities. There is always an increase in these inventories until disposition is assumed to start after 10 years.

- *Case 1:* If the disposition capacity matches the dismantlement rate, inventories in storage after 10 years become stable until dismantlement is completed and are reduced to zero within the next 10 years.

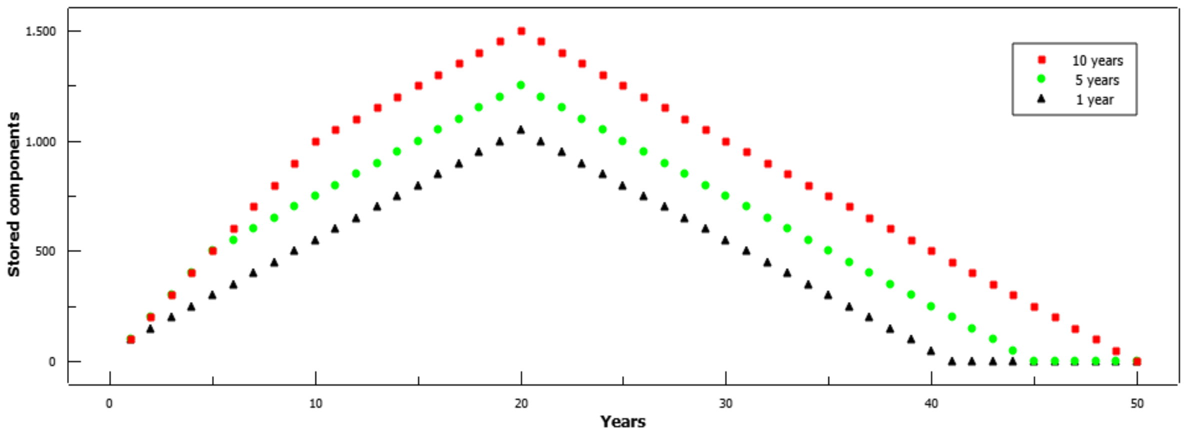
- *Case 2:* With a disposition capacity of 50 components per year (50 percent of the dismantlement capacity), there will be another increase of stored components until all warheads will have been dismantled, followed by a 30-year period until the last component will be processed.
- *Case 3:* In the case of the lowest disposition capacity of 20 components annually, the number of components accumulating in the storage facility will become higher again, but the most striking consequence is that it will require 110 years until the last component will have been dispositioned. For the NWS, this would require long-term maintenance of its nuclear weapons–related infrastructure with all its safety and security requirements, including trained staff for operating the storage and disposition facilities. For the inspection regime, it would mean a long-term burden.

Figure 3: Numbers of Components in Monitored Storage as a Function of Time for Three Different Disposition Capacities



Another variable that could be considered in this example is the amount of time that a warhead spends in interim storage prior to its being dismantled. This variable is illustrated in Figure 4. For the case of 50 percent disposition in relation to dismantlement capacity, minimum storage periods of one year, five years, and 10 years respectively were assumed. Reducing the minimum storage time will result in fewer components accumulating in long-term storage but will have little effect on the time taken to dispose of the last items, which is controlled by the capacity of the disposition facilities.

Figure 4: Influence of the Minimum Interim Storage Time on the Accumulation of Dismantled Components



As summarized by Table 3 below, these illustrative simulations of the dismantlement-disposition process in the IPNDV scenario highlight how insufficient capacities to dispose of the components from dismantled nuclear warheads could lead to excessive times until the last components are processed. The result would be greater inspection burdens. Thus, they also underline the great importance of having sufficient capacities for the realization of effective nuclear disarmament agreements.[14]

Table 3: Summary of the Most Important Results of the Simulations Carried Out Using the Assumptions in Figure 2

Ratio of Disposition to Dismantlement Capacities	Maximum No. of Stored Components	Time (in years) Until Disposition Is Completed
1 : 1	1,000	30
0.5 : 1	1,500	50
0.2 : 1	1,800	110

A Basic Verification Strategy

Several considerations should be reflected in developing generic basic verification strategies:

- Avoid unnecessary and repetitive verification activities, which do not provide significant additional confidence

[14] Comparable negative effects would result if the capacity to dismantle nuclear warheads were to be significantly lower than the number of operational warheads to be subjected to a treaty regime annually (or annually on average). Such a disproportion would lead to excessive durations and numbers of nuclear warheads in long-term interim storage.

- Focus on verification PPTT, which are less complicated to use in an inspection setting
- Outline when radiation measurements need to be taken, including how many, under what circumstances, and when they are most effective and efficient
- Identify and minimize verification activities that require the use of highly intrusive technologies to deliver a high amount of confidence
- Provide a sound basis for developing robust and efficient systems approach concepts
- Balance the safety, security, and nonproliferation requirements, in particular for steps involving fully assembled nuclear warheads, and the need to achieve confidence in the verification activity itself.

Considering these considerations, this paper first presents a list of basic assumptions. It then sets out potential verification strategies for minimizing the extent of intrusive (radiation) measurements that are most in tension with them. Options are provided for how to apply these to the 14-steps model. Neither this concept, nor any subsequent discussions on this topic are intended to create a "blueprint" of verification strategies to be used in potential future negotiations. Rather, the purpose is to illustrate one possible approach to effectively combining procedures and technologies to support further discussion of choices and trade-offs inherent in any strategy.

Assumptions

- Both deployed and nondeployed/retired nuclear warheads will be included in a future nuclear disarmament treaty.
- Different types of nuclear warheads exist. A general declaration of the type of warhead will be provided when an item enters the treaty regime.
- Each warhead may include a plutonium and/or a highly enriched uranium (HEU) subassembly (special nuclear material or SNM).
- Dismantlement results in the separation of high explosives (HE), SNM subassembly, and nonnuclear components.
- All activities are performed in dedicated areas of the facilities reserved and used for treaty-related purposes only.
- Radiation measurements will be used for the purpose of verifying the *absence* of fissile material.
- Radiation measurements verifying the presence of SNM are limited to CoC restoration.

- Radiation templates are considered to be a CoC technology. Reference templates are not required for each individual nuclear warhead entering the process but are required for each warhead type.[15]
- New reference templates need to be recorded for the SNM subassemblies resulting from warhead dismantlement.

Application to the 14-Step Model

In light of the preceding considerations and assumptions, the following sets out an illustrative verification strategy for five dimensions of the 14-step model:

- Deployed nuclear warheads before dismantlement (including addressing breakdowns of chain of custody)
- Nondeployed and retired warheads before dismantlement
- The dismantlement process
- SNM after warhead dismantlement
- Disposition of the SNM.

Deployed Nuclear Warhead Before Dismantlement

The dismantlement process begins with the removal of a nuclear warhead from its delivery vehicle followed by a series of transport and storage processes (Figure 5).

[15] This assumes that containers are specific to each warhead type.

Figure 5: Steps 1–7 of the Generic IPNDV Dismantlement Process Model

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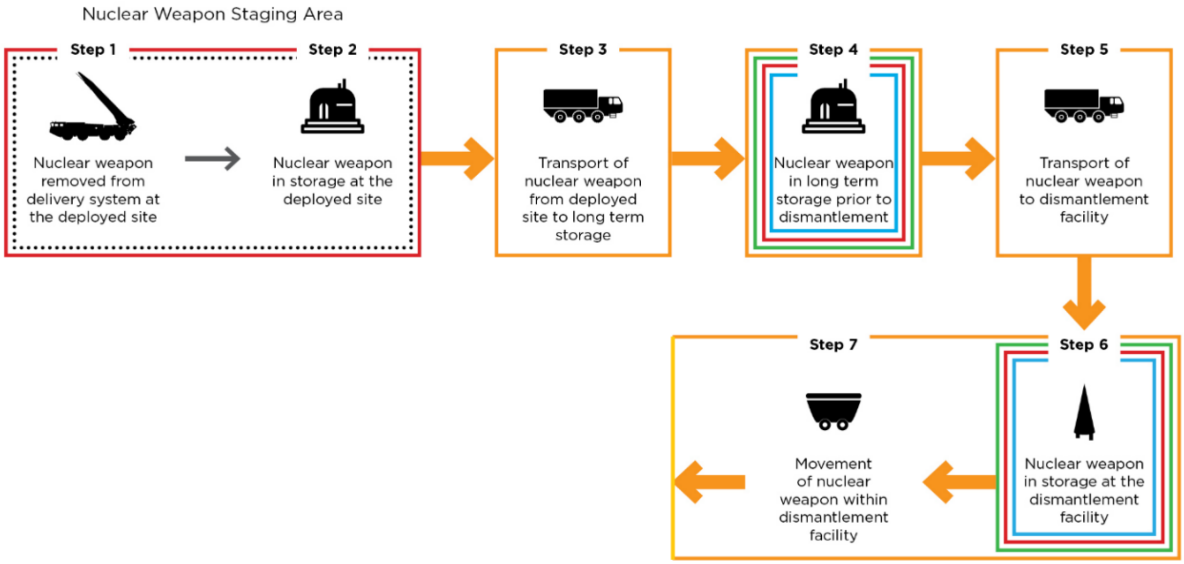


A basic verification strategy could include the following activities:

1. Confirming via visual observation the removal of an item declared to be a nuclear warhead from its delivery vehicle along with confirming its transfer into a container. Establishing provenance is the first step in building confidence in the dismantlement of nuclear warheads under the agreement.

- Applying CoC technologies (e.g., tags, seals, perimeter monitoring) to the containers and at storage facilities to ensure the Continuity of Knowledge (CoK) required.

2. Following any break in the established CoC of a containerized warhead, that container could be given priority to be transported to the dismantlement facility. After the dismantlement of the declared nuclear warhead, radiation measurements could be used to confirm the presence of SNM as part of the separated components and, thus, that no SNM diversion had taken place earlier.

3. Alternatively, record a radiation template of that warhead type initially in the verification process. Then, in the event of such a break in CoC, compare that template with that of the specific warhead to confirm its presence in the affected container after any such break in CoC. In this instance, the breach of CoC would merit the need to perform a special radiation measurement to restore confidence.

Nondeployed and Retired Warheads Before Dismantlement

These warheads will most likely enter the monitoring regime at a storage facility. Given that these items have already been removed from their delivery system and are in storage, their provenance must be established using different measures than those used for warheads still mated to delivery systems. This also applies for warheads never mated to a delivery system.

In the case of warheads with plutonium, this could be confirmed by passive radiation template measurements. Passive radiation template measurements are more challenging for confirming the presence of HEU in a containerized warhead, as the neutron and gamma signals emitted by the SNM would likely be negligible in the measurement distance to its container. Moreover, the use of neutron interrogation ("active") measurement technologies on fully assembled warheads will likely be excluded due to safety and security risks.

The Dismantlement Process

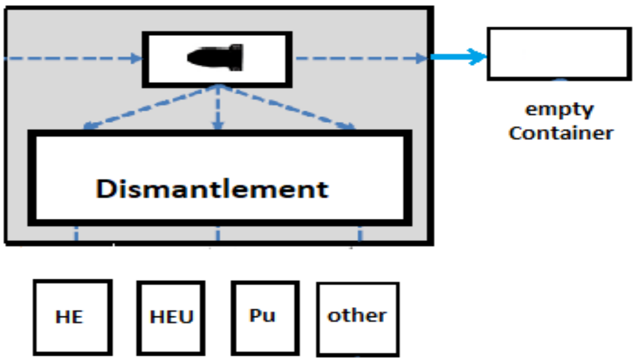
The dismantlement process involves separating the high explosives from the SNM and other nonnuclear components (see Figure 6). IPNDV has assumed this process takes about two weeks. Due to the sensitivity of these processes, the presence of inspectors is not possible. However, the inspectors would be able to conduct inspection activities on the containers emerging from the dedicated dismantlement area after dismantlement has been completed.

Developing and testing verification strategies and procedures for warhead dismantlement has been a major focus of the IPNDV and various multilateral efforts—the U.K.-Norway Initiative, the U.S.-U.K. Warhead Monitored Dismantlement Exercise, and the German-French Nuclear Disarmament Verification (NuDiVe) Exercises—based on the work of IPNDV. The approach derived from this experience includes the following steps:

- Use of radiation detection equipment in the dedicated dismantlement area for the purpose of confirming the absence of fissile material both before and after dismantlement activities;
- Use of CoC technologies (CCTV, portal monitoring, sealing overnight) and radiation absence measurements for verifying that no undeclared fissile material enters or leaves the dedicated dismantlement area;
- Use of radiation measurements for verifying the presence or absence of fissile material as declared in the containers resulting from dismantlement;[16]
- Establishing CoC of the fissile material containers.

[16] Verifying the presence of high explosives is considered optionally.

Figure 6: Dismantlement Process Scheme



This concept has been developed and successfully tested for plutonium-based warheads, excluding the presence of HEU, which shows merely small passive neutron and gamma radiation signals. As discussed in the literature, this challenge may be partially dealt with by realizing the "Room within a Room" concept[17] instead of radiation inspection of the overall dedicated dismantlement area. Identifying robust technologies for verifying the declared presence or absence of HEU in the nuclear warhead component containers requires further assessment.

Unlike the preceding steps of the 14-step model, verification approaches for the post-dismantlement component containers do not differ between deployed and nondeployed/retired warheads until their disposition.

With regards to the containers containing the separated SNM, radiation templates may be taken for the purposes of comparing and verifying to their reference templates.[18]

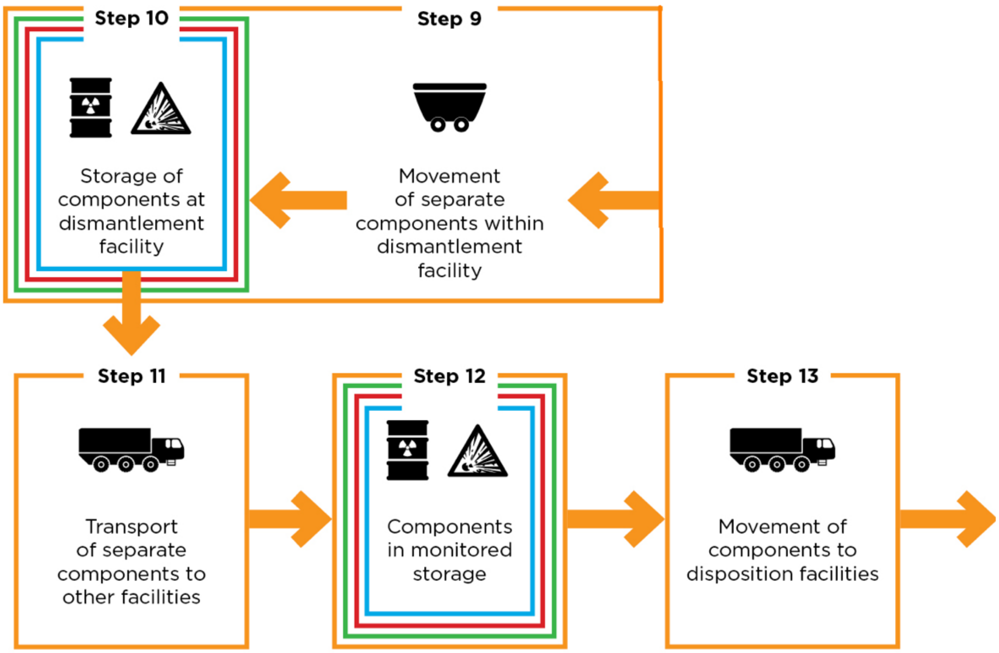
Special Nuclear Material After Warhead Dismantlement

Various transport and storage processes for the SNM containers until their disposal are to be expected (Figure 7). In general, storage of plutonium and HEU components may be at different locations.

[17] It includes creating a temporary room that encompasses the dismantlement process area and controlling its outside boundary. See J. Tenner et al., "The 'Room within a Room Concept'" for Monitored Warhead Dismantlement.

[18] Discussing whether such measurements could be done randomly is beyond the scope of this paper, but for achieving high confidence, a major focus on nondeployed items and those with a CoC break during Steps 1–7 seems mandatory.

Figure 7: Steps 9–13 of the 14 Step Model[19]



A basic verification strategy for this final aspect could include the following elements:

- Analogously to the transport and storage steps prior to dismantlement, CoC technologies used both for the container (e.g., tags, seals) and at the storage areas (e.g., accelerometers, perimeter monitoring) could ensure the CoK.
- In case of a break of the established CoC, use of a previously recorded radiation template for the SNM container from a dismantled nuclear warhead, with the appropriate information barriers, could be used to confirm the presence of SNM in the container.

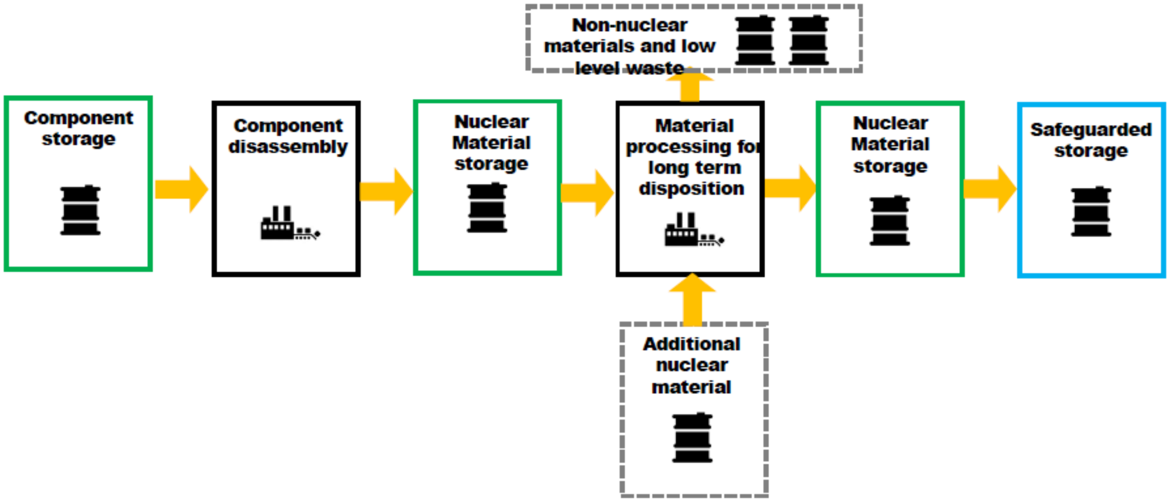
Disposition of the Special Nuclear Material

During the final disposition process, the SNM might undergo chemical processing and isotopic mixing, potentially through the addition of an unknown quantity of blending material (Figure 8). Additional steps will be needed to ensure no sensitive information is retained during final disposition.[20] Due to the sensitivity of these processes, it will not be possible for inspectors to be present in the dedicated disposition area during disposition activities.

[19] The optional monitored storage of high explosives is not considered in this paper.

[20] International Partnership for Disarmament Verification, *Nuclear Disarmament Verification Concept for the Disposition of Special Nuclear Materials*, 2025.

Figure 8: Major Processes of Nuclear Warhead Component Disposition



A detailed analysis[21] showed that the verification concept developed and tested for warhead dismantlement, which focuses on perimeter monitoring, can be applied to the disposition process, taking the following differences into account:

- The potential addition of non-treaty accountable blending material of an unknown origin implies that it is not necessary to screen the process area with radiation detectors before and after disposition activities.
- For the same reason, radiation screening is not required for incoming process materials. The only exception is the warhead component containers.
- The technical process involves a transition from item to bulk flow of the nuclear material. CoC and verification approaches developed for individual item tracking will need to be adjusted for bulk material processes. Item to bulk transitions may be continuous or batch processes. There will be breaks allowing inspectors to enter the process area and to verify the integrity of CoC technologies previously put in place.
- The waste streams may contain trace concentrations of nuclear materials. Alarm thresholds of radiation detection equipment should be adjusted accordingly.

Consideration of Potential Diversion Pathways

Any verification strategy should take into account the risks of diversion. These are examples taken from a larger set of potential diversion pathways involving declared and undeclared activities.[22]

[21] International Partnership for Disarmament Verification, *Nuclear Disarmament Verification Concept for the Disposition of Special Nuclear Materials*, 2025.

[22] For a full set of diversion pathways see "Report of the Reductions Working Group", December 2025, p. 9.

Swapping a Containerized Nuclear Warhead with a Simulated Warhead Before Dismantlement

Such an activity could be realized during each of the transport and storage steps before warhead dismantlement. Its attractiveness could be comparatively high during transport, which will neither be notified prior to completion nor escorted by inspectors.

If all warhead containers have been equipped with various CoC technologies that are expected to be tamper-indicating, their integrity can be verified after the transport event. If after the transport of a container, the identity of a containerized item becomes questionable (e.g., due to a damaged seal), a template measurement could be performed to confirm its integrity.

During storage, the presence of additional CoC technologies could impede an undetected diversion. Additionally, containers could be chosen at random for inspection involving template measurements in which a radiation measurement made of the container would be compared with a previously made radiation template of a container with a nuclear warhead, e.g., when entering the dedicated dismantlement area. This would further decrease the probability of a successful warhead diversion.

Swapping a Warhead with a Simulated Warhead During Dismantlement

Such a diversion option would include two major activities—the transport of the simulated warhead into the dismantlement facility undetected, and transport of the actual warhead out. Such diversion could be mitigated by using radiation measurements of the dedicated dismantlement area before and after each dismantlement activity.

In addition, each empty container entering the dedicated dismantlement area could be screened by neutron and gamma transmission measurements to verify that it does not include any excessive shielding and could be equipped with tamper-indicating unique identifiers and seals. If all incoming and outgoing containers declared to be empty or filled with nonnuclear material are analyzed radiologically, swapping an actual nuclear warhead for a simulated warhead could be detected.

About IPNDV the International Partnership for Nuclear Disarmament Verification

The International Partnership for Nuclear Disarmament Verification (IPNDV) convenes countries with and without nuclear weapons to identify challenges associated with nuclear disarmament verification and develop potential procedures and technologies to address those challenges. The IPNDV was founded in 2014 by the U.S. Department of State and the Nuclear Threat Initiative. Learn more at www.ipndv.org.