Verification of Each of the 14 Steps of Nuclear Weapon Dismantlement

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Abstract

This paper captures the results of a major part of the work in Phase II of IPNDV's Working Group 5. The paper puts forward a conceptual description of the verification process at each of the 14 steps in the nuclear weapon dismantlement process that was outlined by IPNDV in Phase I of its work. In particular, the paper includes a series of "step maps" that elaborate verification objectives, information requirements and possible inspection approaches for each step, including routine inspection and ad hoc tasks. Potential inspection technologies, as well as constraints on inspection activities are examined, as well as possible pathways for diversion and/or substitution of declared items. The paper discusses in further detail many of the issues in verification of the nuclear weapon dismantlement that are common to one or more of the 14 steps, or that focus on the dismantlement process as a whole.

Contents

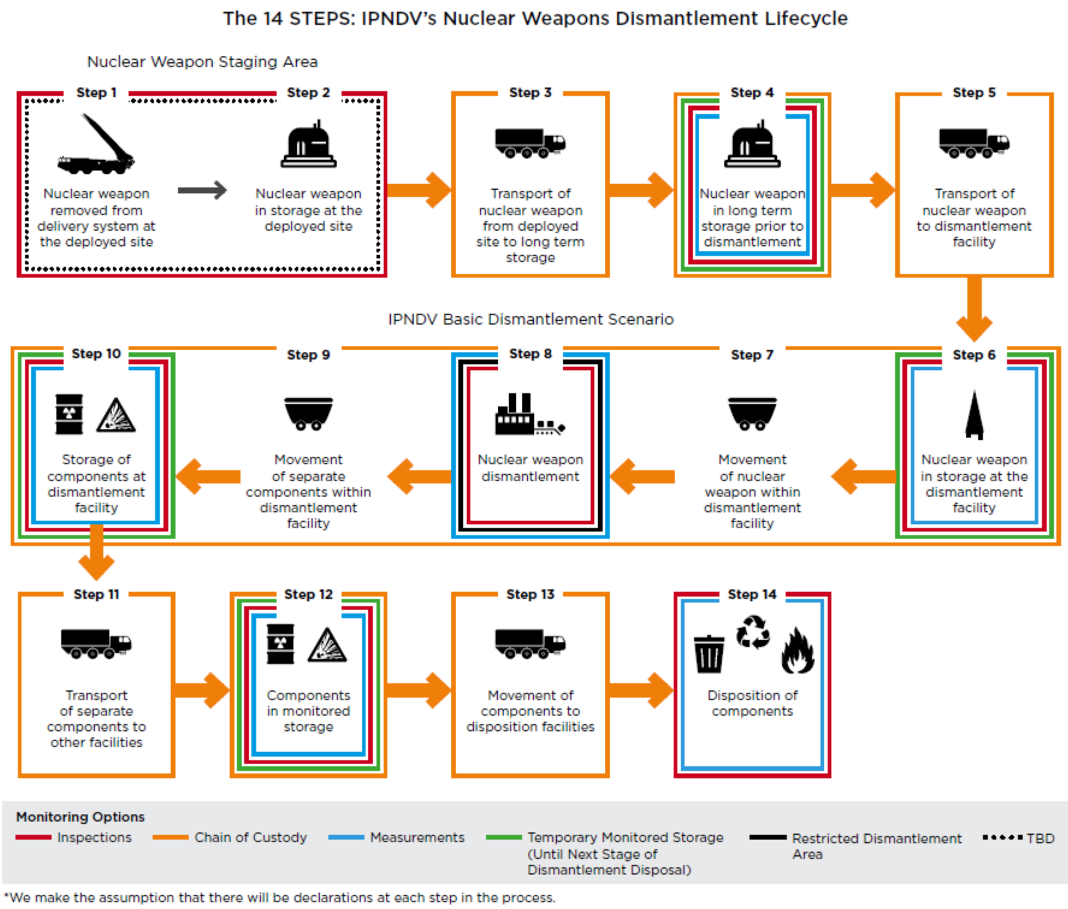
Part 1. Introduction

Effective tools and methods to verify a process for dismantling nuclear weapons are essential for providing assurance to parties to a disarmament agreement that obligations are being observed, for deterring non-compliance, and for building confidence that States are working to fulfil their disarmament commitments. That confidence is a critical enabler of a continuing process of nuclear disarmament. In alignment with the objectives for Phase II of the International Partnership for Nuclear Disarmament Verification (IPNDV), this paper focuses on verification for all of the 14 steps that may be involved in the dismantlement. Dismantlement in this context is the separation of Special Nuclear Material (SNM) and High Explosives (HE) that were contained in a nuclear weapon.

1.1. The 14-Step Conceptual Model

In Phase I of the Partnership, a 14-Step conceptual model of the overall process involved in the dismantlement of nuclear weapons and the disposition of the resulting materials in disarmament was developed. Depicted by Figure 1 below, this model is intended to describe all the possible dismantlement steps until the disposition of the resulting SNM and HE.

Figure 1. The 14-Step Dismantlement Process



The 14-Step Process depicted by the conceptual model begins with the removal of a nuclear explosive device (NED) from its delivery system at a deployment site and concludes with the disposition of its components. The activities within the 14 steps can be broken into several types:

- Removal of a NED from its delivery system and short-term storage at a deployment site;
- Long-term storage of the NED[1] and/or components as they progress through the 14-Step Process;
- Physical separation of a NED into its components and associated shorter-term storage;
- Transport of NEDs and components between and within facilities; and
- Processing of critical components to ensure they are no longer capable of being used in a NED or other means of disposition so that they are no longer capable of being used in a NED.

This 14-Step Process model is a valuable analytic tool that has been used to frame the verification[2] objectives at each of these steps, possible inspection[3] approaches to achieve those objectives, and associated technologies. However, this sequence of 14 steps is not prescriptive. Future disarmament agreements might only include a limited sequence of these steps—for example, where the NED was already separated from a delivery vehicle prior to verification. Moreover, some of these steps may not exist for the dismantlement of certain weapon types (see section 3.4.1) and given unique national programs, some of them may not exist in some countries with nuclear weapons. Thus, which specific steps would take place in a verified process of NED dismantlement—and the point of "initialization" of the process where the NED becomes subject to monitoring[4]—would need to be defined by a future disarmament agreement reflecting the specifics of national nuclear weapon programs.

The dismantlement of nuclear weapons could be part of either an incremental process of reducing numbers of nuclear weapons or a process to eliminate some or all nuclear weapons. NED dismantlement is part of a broader process of nuclear disarmament. That broader process includes measures such as a cut off in the production of fissile material for nuclear weapons, controls on stocks of nuclear weapon materials, limits on delivery systems, and the safeguarding of peaceful nuclear activities.

[1] In this document the term Nuclear Explosive Device (NED) is used to refer to an object containing SNM and HE that is capable of producing a nuclear explosive yield. The term is particularly used instead of "nuclear weapon" to describe such an object that is separated from its delivery system and is dismantled through the 14-Step Process. The term nuclear weapon is used to refer to an item that includes a NED, but may also include other parts of a weapon system.
[2] "Verification" refers to the processes of gathering, analyzing, and assessing information, to enable a determination of whether a State party is in compliance with the provisions of an international treaty or agreement.
[3] "Inspection" refers to on-site activities conducted by technical specialists on behalf of a verification entity or inspecting team under an agreement.
[4] "Monitoring" refers to technical processes for confirming declared data and gathering data relevant to whether an inspected State is in compliance with the provisions of an agreement.

1.2. Verification Principles, Specific Inspection Objectives, and Assumptions

This paper builds on verification principles[5] developed in IPNDV, including:

- **Non-Proliferation.** Inspection procedures and measurement techniques need to ensure there is no release of proliferation-sensitive information, and managed access is applied to protect other information that may be classified for national security reasons.
- **Effectiveness.** Verification must provide parties with sufficient confidence in the compliance by other parties, while managing its intrusiveness and cost.
- **Building confidence.** Verification should help build confidence in the good faith implementation of the agreement, based on the continuing implementation of agreed verification procedures.

This paper also reflects a set of assumptions on several key issues:

- The physical dismantlement of a NED is defined to be the separation of the SNM and the HE. This occurs at Step 8 of the 14-Step Process. Verification of activities at each of the 14 steps would add substantial assurance of a State's commitment to irreversible dismantlement of a number of NEDs.
- To protect proliferation-related and other sensitive information, there would be no direct visual observation by inspectors of the physical dismantlement of a NED and separated SNM and HE from dismantled NEDs would be in sealed containers. There would be no direct visual inspection of the external surface of the NED where sensitive information may be revealed. This obviously will present challenges to inspectors. Constraints related to proliferation, security, and security risks are further discussed in section 3.3.1.
- The terms of a verification agreement, together with site-specific arrangements, would elaborate procedures, equipment, and other requirements for inspections and monitoring. In order to prevent the disclosure of proliferation-sensitive information, the agreement would codify the kinds of observations and measurements that inspectors may make. Inspections would be subject to managed access procedures that protect sensitive information but ensure that compliance is verified.
- The use of radiation detection technologies to confirm the presence of a NED or of separated SNM or HE would entail use of an information barrier[6] system that would protect sensitive information while still providing a "pass or fail" indication of whether certain physical attributes[7] have been detected.
- It is assumed that verification of the NED dismantlement process takes place under a multilateral framework, with inspections carried out by teams from a multilateral entity.

[5] For a broader set of IPNDV verification principles, see http://ipndv.org/wp-content/uploads/2017/11/WG1-Deliverable-One-Final.pdf.

[6] A description of an information barrier is in section 3.4.1.

[7] In its Phase I, IPNDV proposed attributes based on the presence of minimum quantities of certain fissile material as well as HE.

1.3. Verification Objectives

A verification agreement would aim to provide assurance to its parties that a designated number or group of NEDs is dismantled and that the disposition of SNM ensures it is no longer available for use in a NED. Such assurance will rely on the results of on-site inspections carried out by technical specialists. The measures applied by inspectors would track accountable items (normally a containerized NED or components). The verification objective would be that inspectors, by systematic verification across the 14 steps, would gain credible assurance that:

- Each accountable item is consistent with what it is declared to be by the inspected State.
- There is no interference with the integrity of an accountable item when in storage or transport.
- An accountable item is not diverted.
- Inventories of accountable items at a facility or location are as declared.
- There is no diversion of SNM (in particular during Steps 8 and 14).

At a practical level, the following kinds of measures would be applied:

- Measurement of agreed physical attributes of accountable items;
- Ensuring the chain of custody (CoC) through the application of containment and surveillance (C&S) techniques;
- Counting of accountable items at a facility;
- Physical integrity checks of buildings where accountable items are stored.

Confidence that dismantlement has taken place will result from an amalgam of many observations, with different inspection findings reinforcing each other and, as needed, compensating for limits on procedures and technologies at given steps. Confidence should also grow as the dismantlement process is followed over time as more verification activities are carried out.

1.4. An Overview of This Paper's Results

1.4.1. Inspection Approaches across the 14-Step Process

Table 1 provides an overview of this paper's results. It highlights the objectives that need to be met in each step as well as the options for inspection approaches to meet those objectives. Across the 14 steps, numerous inspection approaches could be used. These approaches would be subject to what is specified by the disarmament agreement. Proliferation, security, and security risks (see section 3.3.1) would be addressed through managed access procedures, including the use of information barriers for certain technologies to protect sensitive information. Specific approaches include:

- Visual and other observation by inspectors, including with agreed equipment;
- Measurement of attributes of an accountable item for consistency with what it is declared to be and/or to check against an applicable template for that item;
- Confirmation by inspectors of inter-facility transfers of accountable items;

- Checking by inspectors of tags, seals, and unique identifiers (UIDs) on containers with accountable items against available documentation;
- Continuous remote monitoring, including portal monitoring, of storage and other areas subject to inspection, with periodic inspector reviews of the data;
- Measurement of the physical dimensions of storage and other treaty-defined areas, with comparison of those measurements to information on design specifications;
- Inspector monitoring of movement and transport of accountable items.

Technology options have also been identified to support the inspection process. Possible technology options are described in each of the 14 step descriptions in this paper and are further described in sections 1.4.2, 3.4.2, and 3.5.

Table 1. Nuclear Warhead Dismantlement: Summary of Verification Objectives and Inspection Tasks for the 14 Steps						
Activity (Step) / Objective	Removal of NEDs from Delivery Vehicle (Step 1)	Short-term Storage of NEDs at Deployed Site (Step 2)	Inter-Site Transport of NEDs and SNM (Steps 3, 5, 7, 9, 11, 13)	Storage of NEDs and SNM (Steps 4, 6, 10, 12)	NED Dismantlement (Step 8)	Disposition of SNM (Step 14)
Confirm that a nuclear explosive device (NED) or Special Nuclear Material (SNM) from a NED is as declared	Observe removal of NED and confirm no remaining NEDs	Attribute/template measurements with information barrier	N/A	Attribute/template measurements with information barrier	Attribute/template measurements with information barrier	Attribute/template measurements (with information barrier as necessary)
Apply, confirm, or sustain chain of custody (including through C&S)	Participate in transport of NED; apply tags/seals/UIDs	Check tags/seals/UIDs on containers	Monitor movement; check tags/seals/UIDs before and after movement; check consistency of notifications	Check tags/seals/UIDs; continuous remote and perimeter monitoring	Check tags/seals/UIDs; continuous remote and perimeter monitoring	Check tags/seals/UIDs; observations and/or continuous remote and perimeter monitoring
Ensure integrity of storage areas and other facilities	N/A	Inspect storage area	N/A	Inspect storage area; comparison with design/prior information	Inspect storage area; comparison with design/prior information; inspect with radiation and explosive detectors	Visual or other observation; comparison with design/prior information

Establish or reconfirm inventories as necessary—depending on step—of NEDs *or* separated SNM/HE *or* input/output of SNM from disposition process	**N/A**	**N/A**	**N/A**	**Item count; check tags/seals/UIDs; radiation measurements**	**Visual observation and radiation measurements**	**Varies with option: non-destructive analysis techniques; process monitoring; chain of custody, inspect storage, in-situ measurements**

1.4.2. Technology for Verification of NED Dismantlement

Technology options to support the inspection process have been identified and are summarized in Table 2. Many could be adapted from available technologies used by existing verification regimes. Possible technology options are laid out in each of the 14 step descriptions in this paper and are further elaborated in section 3.5. IPNDV has also prepared technology tables [8] that assess individual technologies and note challenges related to their development and use.

Significant developmental work is still required to develop some key technologies, especially those for measuring sensitive attributes of NEDs and, following dismantlement, their separated components. This is especially the case where sensitive information must be protected by an information barrier that can be trusted by both sides in an inspection. IPNDV has explored concepts for the design of such technologies.

The choice of technologies and the work needed to develop a usable system would depend also on the confidence required in verification. As weapon numbers are reduced, the importance of strong confidence would increase.

Table 2. Summary of Technology Options for Verification of NED Dismantlement

Task	**Technology Options**
Establish/check the identity of accountable items	• Tags, UIDs, Radio Frequency Identification tags (RFID)s,[9] 3D container identification; • Gamma detectors and neutron counters for making template measurements by spectrometric or imaging technologies.
Confirm certain physical attributes of accountable items are consistent with declarations	• Gamma detectors and neutron counters for making attribute measurements by spectrometric or imaging technologies; • Muon tomography, calorimetry to measure the thermal power output of nuclear materials; • Raman, nuclear quadrupole resonance, and x-ray methods for checking the presence of HE.
Detect unauthorized access to accountable items	• Seals, accelerometers to detect any movement of an item; • Surveillance equipment like cameras and portal monitors; • Container identification and integrity assessment technologies.

[8] Full URL: https://www.ipndv.org/reports-analysis/working-group-6-technology-tables

[9] See section 3.7 for a list of abbreviations.

Check the presence or absence at a location of objects with attributes similar to those of accountable items	• Radiation detectors for checking gamma and neutron count rates at defined positions to check the presence or absence of a nuclear object; • Raman, nuclear quadrupole resonance and x-ray methods for checking the presence of HE.
Check physical integrity of facilities/containers where accountable items are stored/handled	• 3D laser, optical change detection, and/or container integrity assessment for initial mapping and subsequent inspections; • Seals and surveillance equipment like cameras.

1.5. A Roadmap to This Paper

The second section of this paper comprises a series of "step maps" that offer a conceptual description of the verification process at each of the 14 steps in the dismantlement process. Each step map sets out:

- Main verification objectives for the step (other objectives listed in section 1.3 may also be relevant);
- Baseline information and arrangement that would be available to the inspecting entity;
- A possible inspection approach, including routine inspection and ad hoc tasks to accomplish more specific functional objectives;
- Potential constraints on inspection activities, taking into account the need to protect proliferation-sensitive and national security sensitive information as well matters such as physical security and health and safety;
- Potential inspection technologies to be used to support specific objectives and tasks;
- Assurance attained and uncertainties remaining; and
- Potential pathways for diversion and/or substitution of the declared accountable item.

Each of these step maps sets out inspection/monitoring options (including, as appropriate, options for inspection/monitoring technologies) for that step. They are not intended to provide a single, definitive "answer." The ultimate inspection approach to achieve the broad objectives at any given step will depend on the eventual disarmament agreement and associated verification provisions. In the course of a process of disarmament that involved the verified dismantlement of NEDs, there also would be a verification learning process as well as the development of new technology options. Both factors also would shape the specific approaches negotiated. Nonetheless, what stands out from the 14 step maps is a reconfirmation of the basic judgment of Phase I of the Partnership, now extended to all 14 steps, that "while tough challenges remain, potentially applicable technologies, information barriers, and inspection procedures provide a path forward that should make possible multilaterally monitored nuclear warhead dismantlement while successfully managing safety, security, non-proliferation, and classification concerns in a future nuclear disarmament agreement."

The third section of this paper discusses in further detail many of the issues in verification of the NED dismantlement that are common to one or more of the 14 steps, or that focus on the process as a whole.

Part 2. Verification Process: Step by Step

Step 1

Nuclear Weapon Removed from Delivery System at the Deployed Site

Verification Objectives	**Objectives** at this step aim to build assurance that nuclear weapons subject to a verification agreement are consistent with their declaration as a warhead or bomb. Inspectors would observe removal of a nuclear weapon from a delivery system and confirm placement into a sealed storage container (thereby initiating chain of custody).
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Notifications of an inspection and/or of events triggering a possible inspection (see section 3.1.2). • Section 3.4 describes four different types of nuclear weapon delivery systems that may pose different challenges for the procedures at this step.

Inspection Approach
 	
Routine Inspection Tasks
	(1.1) Confirmation that warheads and bombs mated to the delivery system associated with this inspection were removed from the delivery system.
	• The inspection team observes the process of removal of the warhead or bomb from the delivery system.
	    o It is highly unlikely that the team would observe the actual removal of the warhead or bomb from any delivery system, but the team would likely observe the process under managed access procedures.
	    o The team would likely observe a delivery system and mated warhead that is subject to inspection prior to removal.
	• The team would:
	    o Confirm that there are no additional warheads remaining on the delivery system (assuming that the agreement provides for complete elimination of all warheads on that system).

	(1.2) Visual observation of the transportation from the deployment area to the Weapon Storage Area (WSA) associated with the site.
	• The inspection team observes:
	    o For missiles, torpedoes, and gravity bombs: the off-loading of the weapon from the carrier (aircraft, ship, submarine, transport erector launcher, silo);
	    o Loading of the abovementioned weapon for transportation.
	• To confirm non-diversion, the team would participate in the convoy of the warhead, bomb, or missile from the deployment site to the WSA and confirm the removal of warhead or bomb from the transport vehicle and its placement in the WSA disassembly room.
	
	(1.3) Confirmation that warheads and bombs associated with this inspection were packaged in a storage container, and application/confirmation of associated UIDs, tags, and seals.
	• The team would:
	    o Confirm that storage containers to be used for removed warheads or bombs are empty;
	    o Confirm absence of additional warheads from each delivery vehicle/disassembly room;
	    o Confirm the absence of non-declared warheads;
	    o Verify UIDs associated with storage containers and ensure the container is sealed with tamperproof seals after the inspected State's technicians complete the process of placing the bomb or warhead[10] in its storage container.

Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 1, the following issues may be highlighted: • Inspection activities at an operational base, particularly at a WSA, are likely to be subject to significant and challenging security and safety requirements, consistent with regulatory requirements of the inspected State. • Inspection team movements may be constrained by military activities not associated with the inspection. • Access to locations other than the declared WSA. • The inspected State may also use other means to protect sensitive information regarding a warhead in its container. Such means could include shrouding for other equipment not associated with the purpose of the inspection, as well as physical proximity restrictions.

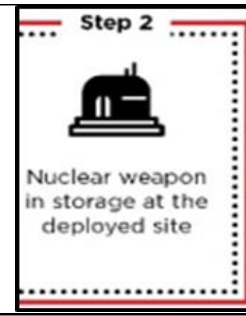
[10] This paper assumes that the process of de-mating warheads from delivery systems would take place at the WSA associated with the deployment site. Alternately, the de-mating process may take place at a separate nuclear weapon dismantlement facility (Step 8).

	• Physical security of warheads, missiles, ships, aircraft, and associated equipment and buildings will have to be maintained throughout the inspection. • Difficult weather conditions may hamper inspection activities.

Potential Inspection Technologies *(technologies are further described in section 3.5)*	• For inspection approach (1.1)
	  o Visual observations with managed access.
	• For inspection approach (1.2)
	  o Visual observation with managed access.
	• For inspection approach (1.3)
	  o Seals, UIDs (3D container identification), tags (e.g., RFID);
	  o If allowed per treaty, possible use of absence measurements, radiation templates, and passive neutron counting for SNM detection.

Assurance and Uncertainties	• Confirmation that the declared warheads/bombs were removed and placed into storage containers; and • (If completeness of declarations is being verified) that no additional warheads remain on any declared missile.

Potential Pathways for Diversion and/or Substitution	• If completeness of declarations is being verified:
	  o Concern that additional vehicles with mated warheads that are not subject to this inspection are not ultimately inventoried and inspected. This may require inspector access to additional buildings and facilities on the installation that otherwise would not be part of this inspection to confirm the absence of additional warheads or bombs.
	  o Concern that additional warheads are concealed in inaccessible parts of the launch vehicle, in equipment used to remove warheads from, and in vehicles used to transport warheads to the storage facility.

<table>
<tr><td>Step 2</td><td>Nuclear Weapon in Storage at the Deployed Site</td><td>
</td></tr>
<tr><td>Verification Objectives</td><td colspan="2">Inspection activities specific to this step aim to maintain chain of custody (including sustaining C&S) on nuclear weapons in a facility within the WSA[11] associated with an operational military base. Inspectors also would seek to confirm that the item is as declared and to ensure the integrity of the storage area.</td></tr>
<tr><td>Baseline Information and Arrangements</td><td colspan="2">• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1).
• A negotiated facility arrangement should be in place (see section 3.1.3).
• Notifications of an inspection and/or of events triggering a possible inspection (see section 3.1.2).
• Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.</td></tr>
<tr><td>Inspection Approach

Routine Inspection Tasks</td><td colspan="2">(2.1) Check that on-site observations are consistent with declarations and confirm chain of custody for accountable items.
• An inspection team:
  ○ Checks tags, seals, and UIDs on accountable items against applicable accounting documentation and the declared inventory;
  ○ Visually checks storage containers, including for consistency with declared design criteria;
  ○ Checks that each storage container appears to contain a nuclear object (e.g., using simple radiation detectors);
  ○ Confirms the absence of additional nuclear objects in the storage room/area (e.g., using simple radiation detectors).</td></tr>
</table>

[11] It is assumed that the declared warheads subject to this inspection are stored in containers in a secure facility within the WSA associated with the operational base. These warheads were removed from the applicable delivery system in Step 1. However, there is also the possibility that spare warheads in containers of the same type as were removed in Step 1 are also stored in this WSA and that the inspected State will include such spares in this type of inspection. Warheads subject to this inspection should be stored separately from other warheads also stored in this WSA but that are not subject to this inspection.

	(2.2) Confirm integrity of storage area within the WSA. • An inspection team: ○ Visually checks storage area for diversion pathways, including for consistency with declared design information. *(The above inspection approach assumes that the accountable items are stored at this site for only a short period. If storage extends over a longer period, additional measures, such as those in Step 4 or 6 may be required.)*

Inspection Approach
 	
Ad Hoc Inspection Tasks
	• An inspection team re-confirms the physical integrity against possible diversion and for consistency with declarations, including:
	  ○ Visual or other observations using agreed equipment;
	  ○ Measurements of physical dimensions;
	  ○ Comparison of laser mapping with initial (reference) maps.

Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 2, the following issues may be highlighted: • Inspection activities at an operational base, particularly at a WSA, are likely to be subject to significant and challenging security requirements. • Inspection team movements may be constrained by military activities not associated with the inspection. • Access to locations other than the declared WSA. • The inspected State may also use other means to protect sensitive information regarding a NED in its container. Such means could include shrouding for other equipment not associated with the purpose of the inspection, as well as physical proximity restrictions. • Difficult weather conditions may hamper inspection activities.

Potential Inspection Technologies
(technologies are further described in section 3.5)
	• For inspection approach (2.1)
	  ○ Visual observation with managed access;
	  ○ Seals, UIDs (3D container identification), tags (e.g., RFID);
	  ○ Attribute/template measurements using radiation detection techniques with information barrier on containerized NEDs (passive gamma detection, passive gamma ray imaging, fast neutron imaging, passive neutron counting);
	  ○ Absence measurements on containerized NEDs using radiation detection techniques (passive gamma detection, passive gamma ray imaging, fast neutron imaging, passive neutron counting).

Assurance and Uncertainties	• Confirmation of the accuracy of the declaration of NEDs/UIDs associated with this WSA and that are subject to this inspection and that no additional NEDs remain in the specific WSA storage room being inspected.

	• Confirmation that NEDs subject to inspection have not been diverted to other, non-inspectable parts of the WSA.
Potential Pathways for Diversion and/or Substitution	• Concern that additional NEDs that are not subject to this inspection are not ultimately inventoried and inspected. • Unauthorized removal of the NED from the WSA without detection given limits on use of C&S means.

Step 3	**Transport of Nuclear Weapon from Deployed Site to Long Term Storage**	

Verification Objectives	Inspection activities at this step aim to: • Confirm chain of custody on accountable items that are transported between sites. • Ensure timely detection of any failure of chain of custody related to such movements and, if necessary, reconfirm that affected items are as declared.

Baseline Information and Arrangements	• Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.
	• Notification, within a specified period, by the inspected State of completion of the transport between sites of a consignment of accountable items, including:
	  ○ Originating and destination sites;
	  ○ Time period of transport;
	  ○ Data identifying each item transported;
	  ○ Advice of any incident or damage that may affect chain of custody measures.
	• Standing notification by the inspected State of expected duration of transport between specified sites.
	• Possible arrangements for in-situ surveillance of accountable items during transport.

Inspection Approach
 	
Routine Inspection Tasks
	(3.1) At some time prior to departure from deployed site, confirm chain of custody for accountable items that could be moved between sites.
	• An inspection team:
	  ○ Checks tags and seals for accountable items;
	  ○ Makes documentation checks.
	
	(3.2) If arrangements have been agreed, monitor accountable items during transport.
	• An inspection team:
	  ○ Reviews surveillance data at the receiving site;
	  ○ Could arrange for surveillance measures to be applied during transport to provide additional assurance that chain

	of custody is maintained, and to promptly identify any problems; o May apply seals to transport vehicle if additional assurance is required. ***(3.3) Confirm chain of custody for accountable items at receiving site.*** • As necessary to confirm chain of custody, an inspection team: o Checks tags and seals for accountable items; o Makes documentation checks; o Checks that the time period over which the transfer took place is consistent with the declared transfer; o Makes attribute/template measurements on randomly selected item(s).
Inspection Approach **Ad Hoc Inspection Tasks**	***(3.4) Monitor activities where containment is/may be broken and recover from any break in chain of custody*** *(see section 3.4.6).*
Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 3, the following issues may be highlighted: • Information about transfers may pose a security risk. o Provision of information in advance of transfer may not be agreed; o Information would be limited to that needed for inspectors to carry out activities according to their mandate. • Any equipment for surveillance during transfers would be installed in anticipation of movement and must be capable of operating in isolation from an inspection team. • Any damage to containers during transport may risk exposure of proliferation-sensitive information and could pose a safety hazard.
Potential Inspection Technologies *(technologies are further described in section 3.5)*	• For inspection approach (3.1) o Seals, UIDs, RFIDs, 3D container identification. • For inspection approach (3.2) o Radiation rate counter in unattended mode; o Seals. • For inspection approach (3.3) o Seals, UIDs, RFIDs, 3D container identification; o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies. • For inspection approach (3.4) o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies;

	o Container identification and integrity assessment technologies.
Assurance and Uncertainties	• Good, if chain of custody is maintained. • Weaker, if there is a break in chain of custody and steps are needed to re-establish knowledge of accountable items (see section 3.4.6).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items that enables diversion and/or substitution of critical components. • Assurance of non-diversion is reduced if a significant number of accountable items are in transit and outside verification at a given time.

Step 4	Nuclear Weapon in Long Term Storage Prior to Dismantlement	
Verification Objectives	Objectives specific to this step are to: • Establish and routinely check inventories of accountable items in storage. • Maintain chain of custody for accountable items, including through applying C&S as well as checks on the physical integrity of facilities, buildings, and storage containers.	
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Notifications of an inspection and/or of events triggering a possible inspection (see section 3.1.2). • Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.	

Inspection Approach
 	
Routine Inspection Tasks
	(4.1) As necessary, establish an initial inventory for the facility of accountable items.
	• Based on State declarations, an inspection team:
	  o Observes and measures item attributes (mainly radiation measurements) to confirm consistency with declared verifiable characteristics;
	  o Records templates to compare against matching items, and/or to enable future integrity checks;
	  o Reviews applicable accounting documentation and confirms tags and seals to accountable items, including any UIDs assigned to the item;
	  o Establishes C&S over accountable items.
	
	(4.2) Maintain chain of custody for accountable items through C&S.
	• An inspection team:
	  o Checks tags, seals, and UIDs on accountable items against accounting documentation and the declared inventory;	

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<li style="list-style-type:circle">Reviews surveillance data on site, and maintains permanently installed monitoring and inspection equipment.
Continuous remote monitoring of C&S status by the verifying entity (e.g., data from portal monitors and automated inventory monitoring systems).
(4.3) Confirm the design and integrity of storage facilities/buildings/storage containers based on design information declared by the inspected State.
An inspection team re-confirms the physical integrity against possible diversion and for consistency with declarations, including:
Visual or other observations using agreed equipment;
Measurements of physical dimensions;
Comparison of laser mapping with initial (reference) maps.
(4.4) Routinely confirm inventories of accountable items in storage at the facility.
To re-verify physical inventory (according to a statistical plan as appropriate), an inspection team:
Counts accountable items and checks tags, seals, and UIDs on the items against applicable accounting documentation and the declared inventory;
Observes and measures item attributes to confirm consistency with declared verifiable characteristics;
Checks accountable items against an applicable template;
Confirms the absence of undeclared accountable items.
</td></tr>
<tr><td>Inspection Approach

Ad Hoc Inspection Tasks</td><td>(4.5) Monitor inter-site transfers of accountable items following guidance set out in Step 3.

(4.6) Monitor activities where containment is/may be broken and recover from any break in chain of custody (see section 3.4.6).</td></tr>
<tr><td>Potential Constraints on Inspection Activities</td><td>A general description of such constraints is at section 3.3.1.
For Step 4, the following issue may be highlighted:
The kinds of data to be transmitted by remote monitoring equipment would be constrained and measures would be needed to ensure their security and integrity.</td></tr>
<tr><td>Potential Inspection Technologies
(technologies are further described in section 3.5)</td><td>For inspection approach (4.1), (4.2), (4.4), and (4.6)<ul style="list-style-type:circle">
Seals, UIDs, RFIDs, accelerometers;
Surveillance equipment like cameras and portal monitors;
Radiation detectors for checking gamma and neutron count rates at defined positions;</td></tr>
</table>

	- Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies (excluding active probing); - Automated inventory monitoring systems; - Muon tomography. - For inspection approach (4.3) 3D laser, optical change detection, and/or container integrity assessment for initial mapping and subsequent inspections; - Seals, surveillance equipment like cameras.
Assurance and Uncertainties	- A history of observations, as well as attribute and template measurements of an item prior to receipt at the facility would add useful assurance that the item is consistent with declarations. If not available, attribute measurements on all accountable items is needed. If template techniques are available to enable comparison between items of the same model, stronger assurance could be achieved. - Fully effective C&S on accountable items, along with confirmation of the integrity of storage areas, would offer strong assurance of their non-diversion and continued integrity. However, the risk for failure or breach of C&S cannot be excluded. - The frequency and intensity of inspection activities should be consistent with ensuring the timely detection of diversion of accountable items (see section 3.2.2).
Potential Pathways for Diversion and/or Substitution	- C&S measures are defeated without timely detection. - Undetected direct access to accountable items that enables diversion and/or substitution of critical components. - Authorized direct access (for safety and inventory checks) enables diversion. - Items could be mis-declared by the inspected State.

Step 5	**Transport of Nuclear Weapon to Dismantlement Facilities**	

Verification Objectives	Inspection activities at this step aim to: • Confirm chain of custody on accountable items that are transported between sites. • Ensure timely detection of any failure of chain of custody related to such movements and, if necessary, reconfirm that affected items are as declared.

Baseline Information and Arrangements	• Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.
	• Notification, within a specified period, by the inspected State of completion of the transport between sites of a consignment of accountable items, including:
	    o Originating and destination sites;
	    o Time period of transport;
	    o Data identifying each item transported;
	    o Advice of any incident or damage that may affect chain of custody measures.
	• Standing notification by the inspected State of expected duration of transport between specified sites.
	• Possible arrangements for in-situ surveillance of accountable items during transport.

Inspection Approach
 	
Routine Inspection Tasks
	(5.1) At some time prior to departure from deployed site, confirm chain of custody for accountable items that could be moved between sites
	• An inspection team:
	    o Checks tags and seals for accountable items;
	    o Makes documentation checks.
	
	(5.2) If arrangements have been agreed, monitor accountable items during transport.
	• An inspection team:
	    o Reviews surveillance data at the receiving site;
	    o Could arrange for surveillance measures to be applied during transport to provide additional assurance that chain

	of custody is maintained, and to promptly identify any problems; o May apply seals to transport vehicle if additional assurance is required. ***(5.3) Confirm chain of custody for accountable items at receiving site.*** • As necessary to confirm chain of custody, an inspection team: o Checks tags and seals for accountable items; o Makes documentation checks; o Checks that the time period over which the transfer took place is consistent with the declared transfer; o Makes attribute/template measurements on randomly selected item(s).
Inspection Approach **Ad Hoc Inspection Tasks**	***(5.4) Monitor activities where containment is/may be broken and recover from any break in chain of custody*** *(see section 3.4.6).*
Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 5, the following issues may be highlighted: • Information about transfers may pose a security risk. o Provision of information in advance of transfer may not be agreed; o Information would be limited to that needed for inspectors to carry out activities according to their mandate. • Any equipment for surveillance during transfers would be installed in anticipation of movement and must be capable of operating in isolation from an inspection team. • Any damage to containers during transport may risk exposure of proliferation-sensitive information and could pose a safety hazard.
Potential Inspection Technologies *(technologies are further described in section 3.5)*	• For inspection approach (5.1) o Seals, UIDs, RFIDs, 3D container identification. • For inspection approach (5.2) o Radiation rate counter in unattended mode; o Seals might also be applied to transport vehicle. • For inspection approach (5.3) o Seals, UIDs, RFIDs, 3D container identification. • For inspection approach (5.4) o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies; o Container identification and integrity assessment.
Assurance and Uncertainties	• Good, if chain of custody is maintained.

	• Weaker, if there is a break in chain of custody and steps are needed to re-establish knowledge of accountable items (see section 3.4.6).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items that enables diversion and/or substitution of critical components. • Assurance of non-diversion is reduced if a significant number of accountable items are in transit and outside verification at a given time.

Step 6	Nuclear Weapon in Storage at the Dismantlement Facility	

Verification Objectives	Objectives specific to this step are to: • Establish and routinely check inventories of accountable items in storage. • Maintain chain of custody for accountable items, including through applying C&S as well as checks on the physical integrity of facilities, buildings, and storage containers.
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Notifications of an inspection and/or of events triggering a possible inspection (see section 3.1.2). • Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.

Inspection Approach
 	
Routine Inspection Tasks
	(6.1) As necessary, establish an initial inventory for the facility of accountable items (confirming inter-site transfers).
	• Based on State declarations, an inspection team:
	    o Observes and measures item attributes (mainly radiation measurements) to confirm consistency with declared verifiable characteristics;
	    o Records templates to compare against matching items, and/or to enable future integrity checks;
	    o Reviews applicable accounting documentation and confirms tags and seals to accountable items, including any UIDs assigned to the item***;***
	    o Establishes C&S over accountable items.
	
	(6.2) Maintain C&S.
	• An inspection team:
	    o Checks tags, seals, and UIDs on accountable items against accounting documentation and the declared inventory;

	- o Reviews surveillance data on site, and maintains permanently installed monitoring and inspection equipment. - Continuous remote monitoring of C&S status by the verifying entity (e.g., data from portal monitors and automated inventory monitoring systems).
Inspection Approach **Ad Hoc Inspection Tasks**	***(6.3) Confirm the design and integrity of storage facilities/buildings/storage containers based on design information declared by the inspected State.*** - An inspection team re-confirms the physical integrity against possible diversion and for consistency with declarations, including: - Visual or other observations using agreed equipment; - Measurements of physical dimensions; - Comparison of laser mapping with initial (reference) maps. ***(6.4) Monitor receipts of accountable items following guidance set out in Step 5.*** ***(6.5) Reconfirm inventories of accountable items in storage at the facility: on a random basis, or if an agreed retention period for accountable items is exceeded.*** - To verify physical inventory (according to a statistical plan as appropriate), an inspection team: - Counts items, checks tags, seals, and UIDs; - Observes and measures item attributes to confirm consistency with declared verifiable characteristics; - Checks accountable items against an applicable template; - Confirms the absence of undeclared accountable items.
Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 6, the following issue may be highlighted: The kinds of data to be transmitted by remote monitoring equipment would be constrained and measures would be needed to ensure their security and integrity.
Potential Inspection Technologies *(technologies are further described in section 3.5)*	- For inspection approach (6.2) - Seals, UIDs, RFIDs, 3D container identification, and/or accelerometers; - Surveillance equipment like cameras and portal monitors. - For inspection approach (6.3) 3D laser, optical change detection, and/or container integrity assessment for initial mapping and subsequent inspections. - For inspection approaches (6.1) and (6.5)

	o Equipment as for (6.2); o Radiation detectors for checking gamma and neutron count rates at defined positions; o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies; o Muon tomography.
Assurance and Uncertainties	• Fully effective C&S on accountable items, along with confirmation of the integrity of storage areas, would offer strong assurance of their non-diversion and continued integrity. However, the risk for failure or breach of C&S cannot be excluded. If chain of custody is broken, procedures would be needed to re-establish that accountable items are consistent with declarations, including re-applying tags, seals, and applicable UIDs assigned to the item (see section 3.4.6). • The frequency and intensity of inspection activities should be consistent with ensuring the timely detection of diversion of accountable items (see section 3.2.2).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items that enables diversion and/or substitution of critical components. • Items could be mis-declared by the inspected State.

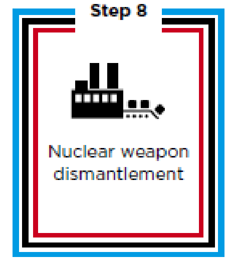
Step 7	**Movement of Nuclear Weapon within Dismantlement Facility**	

Verification Objectives	Inspection activities specific to this step aim to maintain chain of custody through C&S on accountable items during movement within the facility.
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Baseline data on accountable items to be moved include seal, tag, and UID data and history of attribute/template measurements. • Prior notification by the inspected State of the movement, made sufficiently in advance to enable monitoring and prompt advice by the verifying entity on whether an inspection team will be present to monitor the movement (see section 3.1.2). • Post-hoc declaration of the movement by the inspected State, including locations and times.

Inspection Approach
 	
Routine or Ad Hoc Inspection Tasks
	(7.1) Monitoring of intra-site movement of accountable items
	• An inspection team may:
	    o Monitor the movement during an ad hoc or routine inspection visit and may check tags, seals, and UID data before and after the movement;
	    o Check the consistency of data from remote monitoring equipment (e.g., portal monitors) with the declared movements, either in real time or subsequently.

Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 7, the following issues may be highlighted: • The kinds of data to be transmitted by remote monitoring equipment would be constrained and measures would be needed to ensure their security and integrity. • Security requirements may necessitate that observation by an inspection team of intra-site movements of accountable items is conducted under managed access.
Potential Inspection Technologies	• Seals might also be applied to transport vehicle.; • Surveillance equipment like cameras and portal monitors;

(technologies are further described in section 3.5)	• Radiation rate counter in unattended mode inside transportation vehicle; • Unique identifiers to be checked before and after transportation.
Assurance and Uncertainties	• Fully effective C&S on accountable items, along with an opportunity for an inspection team to monitor movements (perhaps on a random basis) would offer strong assurance of their non-diversion. However, the risk for failure or breach of C&S cannot be excluded. If chain of custody is broken, procedures would be needed to re-establish that accountable items are consistent with declarations, including re-applying tags, seals, and applicable UIDs assigned to the item (see section 3.4.6). • The frequency and intensity of inspection activities should be consistent with ensuring the timely detection of diversion of accountable items (see section 3.2.2).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items enables diversion and/or substitution of critical components.

Step 8	Nuclear Weapon Dismantlement	

Verification Objectives	Inspection activities specific to this step aim to confirm for each accountable item to be dismantled: • Chain of custody is intact; • That the item is consistent with declarations; • Ensure integrity of dedicated dismantlement area and relevant containers prior to and following dismantlement; • That SNM and HE from the item are separated and placed in different containers.
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements. • Prior notification by the inspected State of each dismantlement, made sufficiently in advance to enable monitoring by an inspection team (see section 3.1.2).
Inspection Approach **Routine Inspection Tasks**	***(8.1) Confirm chain of custody for the item to be dismantled.*** • Prior to dismantlement, the inspection team checks tags, seals, and UIDs on each accountable item to be dismantled and if necessary, review surveillance data for the item. ***(8.2) If needed to re-confirm consistency with declarations of each accountable item to be dismantled, an inspection team.*** • Observes and measure item attributes (mainly radiation measurements) to confirm consistency with declared verifiable characteristics; • Checks against an applicable template for the item. ***(8.3) Confirm that no SNM or HE is present in the dedicated dismantlement area prior to or following dismantlement.***

	- The inspection team "sweeps" the area under managed access, using hand-held monitoring equipment to detect any SNM or HE.[12] ***(8.4) Confirm that the only accountable items to enter or leave it are those which have been declared and that no SNM is diverted during the course of the dismantlement operations.*** - An inspection team: - Makes visual observations and/or applies portal monitoring and other applicable C&S measures to ensure that the declared NED and empty component containers are the only accountable items to enter or be removed from the dedicated dismantlement area; - Applies seals in the dismantlement area at potential diversion pathways; - Checks host staff entering and leaving the dismantlement area by radiation monitors. ***(8.5) Confirm integrity of containers and that containers removed from the dedicated dismantlement area separately contain SNM and HE.*** - An inspection team: - Makes visual or other observation of containers; - Observes and measures item attributes (mainly radiation measurements) to confirm consistency with declared verifiable characteristics; - Checks against an applicable template for SNM container; - Confirms absence of SNM in containers other than as declared and of HE in containers other than declared; - Optionally, and if suitable managed access measures are agreed, attribute measurements could be performed on unshielded but shrouded SNM before containerization. ***(8.6) Re-establish chain of custody on containers removed from the dedicated dismantlement area with SNM and HE.*** - An inspection team: - Applies tags and seals and confirms UID data; - Uses radiation monitors and surveillance equipment to monitor movement of SNM and HE containers; - May perform a template measurement after SNM containerization (this may be useful in case of a failure of chain of custody at subsequent steps).

[12] Whether this procedure will verify the presence or absence of HEU requires further technical assessment.

Inspection Approach
 	
Non-Routine Inspection Tasks
	(8.7) Confirm the design and integrity of the dedicated dismantlement area based on design information declared by the inspected State.
	• An inspection team re-confirms the physical integrity against possible diversion and for consistency with declarations, including:
	    o Visual or other observations using agreed equipment;
	    o Measurements of physical dimensions;
	    o Comparison of laser mapping with initial (reference) maps.

Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 8, the following issues may be highlighted: • Security requirements may necessitate that observation by the inspection team of intra-site movements of accountable items is conducted under managed access. • Entry by inspection team members to the dedicated dismantlement area will be conducted under managed access.

Potential Inspection Technologies
(technologies are further described in section 3.5)
	• For inspection approach (8.1)
	    o Seals, UIDs, RFIDs, 3D container identification and/or accelerometers.
	• For inspection approach (8.2)
	    o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies.
	• For inspection approach (8.3)
	    o Portable and/or handheld radiation detectors.
	• For inspection approach (8.4)
	    o Seals, surveillance equipment like cameras and portal monitors;
	    o Gamma detectors and neutron counters for absence measurements by spectroscopic or imaging technologies.
	• For inspection approach (8.5)
	    o Seals, tags, UIDs, RFIDs, and/or 3D container identification;
	    o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies for SNM and HE; active methods necessary for absence of HEU and HE;
	    o For containerized SNM: also calorimetry;
	    o For containerized HE: also Raman, Nuclear Quadrupole Resonance, and/or x-ray based detection methods.
	• For inspection approach (8.6)
	    o Seals, UIDs, RFIDs, 3D container identification, and/or accelerometers;
	    o Surveillance equipment like cameras and portal monitors.
	• For inspection approach (8.7)

	○ 3D laser and/or optical change detection for initial mapping and subsequent inspections
Assurance and Uncertainties	• Achievement of objectives laid out above should give strong assurance that an accountable item has been dismantled and help to confirm that it, and SNM and HE components are as declared. • The risk for failure or breach of C&S cannot be excluded. If chain of custody is broken, procedures would be needed to re-establish that accountable items are consistent with declarations, including re-applying tags, seals, and applicable UIDs assigned to the item (see section 3.4.6).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items enables diversion and/or substitution of critical components.

Step 9

Movement of Separate Components within Dismantlement Facility

Verification Objectives	Inspection activities specific to this step aim to maintain chain of custody through C&S on accountable items during movement within the facility.
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Baseline data on accountable items to be moved include seal, tag, and UID data and history of attribute/template measurements. • Prior notification by the inspected State of the movement, made sufficiently in advance to enable monitoring and prompt advice by the verifying entity on whether an inspection team will be present to monitor the movement (see section 3.1.2). • Post-hoc declaration of the movement by the inspected State, including locations and times.

Inspection Approach
 	
Routine or Ad Hoc Inspection Tasks
	(9.1) Monitoring of intra-site movement of accountable items
	• An inspection team may:
	  o Monitor the movement during an ad hoc or routine inspection visit and may check tags, seals, and UIDs before and after the movement;
	  o Check the consistency of data from remote monitoring equipment (e.g., portal monitors) with the movement of SNM, either in real time or subsequently.

Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 9, the following issues may be highlighted: • The kinds of data to be transmitted by remote monitoring equipment would be constrained and measures would be needed to ensure their security and integrity. • Security requirements may necessitate that observation by an inspection team of intra-site movements of accountable items is conducted under managed access.
Potential Inspection Technologies	• Seals might also be applied to transport vehicle; • Surveillance equipment like cameras and portal monitors;

(technologies are further described in section 3.5)	• Radiation rate counter in unattended mode inside transportation vehicle; • Unique identifiers to be checked before and after transportation.
Assurance and Uncertainties	• Fully effective C&S on accountable items, along with an opportunity for an inspection team to monitor movements (perhaps on a random basis) would offer strong assurance of their non-diversion. However, the risk for failure or breach of C&S cannot be excluded. If chain of custody is broken, procedures would be needed to re-establish that accountable items are consistent with declarations, including re-applying tags, seals, and applicable UIDs assigned to the item (see section 3.4.6). • The frequency and intensity of inspection activities should be consistent with ensuring the timely detection of diversion of accountable items (see section 3.2.2).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items enables diversion and/or substitution of critical components.

Step 10	Storage of Components at Dismantlement Facility	

Verification Objectives	Objectives specific to this step are to: • Establish and routinely check inventories of accountable items in storage. • Maintain chain of custody for accountable items, including through applying C&S as well as checks on the physical integrity of facilities, buildings, and storage containers.
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Notifications of an inspection and/or of events triggering a possible inspection (see section 3.1.2). • Baseline data on accountable items include seal, tag, and UID data and history of attribute/template measurements.

Inspection Approach
 	
Routine Inspection Tasks
	(10.1) If necessary, establish an initial inventory for the facility of accountable items that contain SNM.
	• Observe and do radiation measurements of item attributes to confirm consistency with declared verifiable characteristics.
	• Check accountable items against an applicable template and/or record templates to enable future integrity checks.
	• Review applicable accounting documentation and confirm tags and seals to containers and any UIDs assigned to the item.
	
	(10.2) Maintain chain of custody for accountable items (including C&S).
	• An inspection team:
	    o Checks tags, seals, and UIDs on accountable items against accounting documentation and the declared inventory;
	    o Reviews surveillance data on site and maintains permanently installed monitoring and inspection equipment.
	• Continuous remote monitoring of C&S status by the verifying entity (e.g., data from portal monitors and automated inventory monitoring systems).

Inspection Approach
 	
Ad Hoc Inspection Tasks
	(10.3) Confirm the design and integrity of storage facilities/buildings/storage containers based on design information declared by the inspected State.
	• An inspection team re-confirms the physical integrity against possible diversion and for consistency with declarations, including:
	    o Visual or other observations using agreed equipment;
	    o Measurements of physical dimensions;
	    o Comparison of laser mapping with initial (reference) maps.
	
	(10.4) If necessary, for additional confidence, confirm the absence of SNM in storage containers other than as declared and of HE in containers declared to contain SNM.
	
	(10.5) Reconfirm inventories of accountable items in storage at the facility: on a random basis, or if an agreed retention period for accountable items is exceeded.
	• To verify physical inventory (according to a statistical plan as appropriate), an inspection team:
	    o Counts items, checks tags, seals, and UIDs;
	    o Observes and measures attributes for items containing SNM to confirm consistency with declared verifiable characteristics;
	    o Checks measurements of accountable items against an applicable template;
	    o Confirms the absence of undeclared accountable items.
	
	(10.6) Monitor inter-site transfers of accountable items following guidance set out in Step 11.

Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 10, the following issue may be highlighted: • The kinds of data to be transmitted by remote monitoring equipment would be constrained and measures would be needed to ensure their security and integrity.

Potential Inspection Technologies
(technologies are further described in section 3.5)
	• For inspection approach (10.1)
	    o Seals, UIDs, RFIDs, 3D container identification and/or accelerometers;
	    o Radiation detectors for checking gamma and neutron count rates at defined positions;

	- Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies; - Muon tomography. - For inspection approach (10.2) - Seals, UIDs, RFIDs, 3D container identification and/or accelerometers; - Surveillance equipment like cameras and portal monitors. - For inspection approach (10.3) 3D laser, optical change detection, and/or container integrity assessment for initial mapping and subsequent inspections. - For inspection approach (10.4) - Gamma detectors and neutron counters for making attribute measurements by spectrometric or imaging technologies for SNM and HE; active methods necessary for absence of HEU and HE. - For inspection approach (10.5) - Equipment as for (10.2); - Radiation detectors for checking gamma and neutron count rates at defined positions; - Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies; - Muon tomography.
Assurance and Uncertainties	- Fully effective C&S on accountable items, along with confirmation of the integrity of storage areas, would offer strong assurance of their non-diversion and continued integrity. However, the risk for failure or breach of C&S cannot be excluded. If chain of custody is broken, procedures would be needed to re-establish that accountable items are consistent with declarations, including re-applying tags, seals, and applicable UIDs assigned to the item (see section 3.4.6). - The frequency and intensity of inspection activities should be consistent with ensuring the timely detection of diversion of accountable items (see section 3.2.2).
Potential Pathways for Diversion and/or Substitution	- C&S measures are defeated without timely detection. - Undetected direct access to accountable items that enables diversion and/or substitution of critical components.

Step 11

Transport of Separated Components to Other Facilities

Verification Objectives	Inspection activities at this step aim to: • Confirm chain of custody on accountable items that are transported between sites. • Ensure timely detection of any failure of chain of custody related to such movements and, if necessary, reconfirm that affected items are as declared.

Baseline Information and Arrangements	• Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.
	• Notification, within a specified period, by the inspected State of completion of the transport between sites of a consignment of accountable items, including:
	  o Originating and destination sites;
	  o Time period of transport;
	  o Data identifying each item transported;
	  o Advice of any incident or damage that may affect chain of custody measures.
	• Standing notification by the inspected State of expected duration of transport between specified sites.
	• Possible arrangements for in-situ surveillance of accountable items during transport.

Inspection Approach
 	
Routine Inspection Tasks
	(11.1) At some time prior to departure from deployed site, confirm chain of custody for accountable items that could be moved between sites.
	• An inspection team:
	  o Checks tags and seals for accountable items;
	  o Makes documentation checks.
	
	(11.2) If arrangements have been agreed, monitor accountable items during transport.
	• An inspection team:
	  o Reviews surveillance data at the receiving site;

	◦ Could arrange for surveillance measures to be applied during transport to provide additional assurance that chain of custody is maintained, and to promptly identify any problems; ◦ May apply seals to transport vehicle if additional assurance is required. ***(11.3) Confirm chain of custody for accountable items at receiving site.*** • As necessary to confirm chain of custody, an inspection team: ◦ Checks tags and seals for accountable items; ◦ Makes documentation checks; ◦ Checks that the time period over which the transfer took place is consistent with the declared transfer; ◦ Makes attribute/template measurements on randomly selected item(s).
Inspection Approach **Ad Hoc Inspection Tasks**	***(11.4) Monitor activities where containment is/may be broken and recover from any break in chain of custody*** *(see section 3.4.6).*
Potential Constraints on Inspection Activities	A general description of such constraints is at section 11.4.1. For Step 11, the following issues may be highlighted: • Information about transfers may pose a security risk. ◦ Provision of information in advance of transfer may not be agreed; ◦ Information would be limited to that needed for inspectors to carry out activities according to their mandate. • Any equipment for surveillance during transfers would be installed in anticipation of movement and must be capable of operating in isolation from an inspection team. • Any damage to containers during transport may risk exposure of proliferation-sensitive information and could pose a safety hazard.
Potential Inspection Technologies *(technologies are further described in section 3.5)*	• For inspection approach (11.1) ◦ Seals, UIDs, RFIDs, 3D container identification. • For inspection approach (11.2) ◦ Radiation rate counter in unattended mode; ◦ Seals might also be applied to transport vehicle. • For inspection approach (11.3) ◦ Seals, UIDs, RFIDs, 3D container identification. • For inspection approach (11.4) ◦ Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies; ◦ Container identification and integrity assessment.

Assurance and Uncertainties	• Good, if chain of custody is maintained. • Weaker, if there is a break in chain of custody and steps are needed to re-establish knowledge of accountable items (see section 3.4.6).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items that enables diversion and/or substitution of critical components. • Assurance of non-diversion is reduced if a significant number of accountable items are in transit and outside verification at a given time.

<table>
<tr><td>Step 12</td><td>Components in Monitored Storage</td><td>
</td></tr>
</table>

<table>
<tr><td>Verification Objectives</td><td>Objectives specific to this step are to:

Establish and routinely check inventories of accountable items in storage.
Maintain chain of custody for accountable items, including through applying C&S as well as checks on the physical integrity of facilities, buildings, and storage containers.
</td></tr>
<tr><td>Baseline Information and Arrangements</td><td>
Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1).
A negotiated facility arrangement should be in place (see section 3.1.3).
Notifications of an inspection and/or of events triggering a possible inspection (see section 3.1.2).
Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.
</td></tr>
<tr><td>Inspection Approach

Routine Inspection Tasks</td><td>(12.1) If necessary, establish an initial inventory for the facility of accountable items.

Observe and measure item attributes (mainly radiation measurements) to confirm consistency with declared verifiable characteristics.
Record templates to compare against matching items, and/or to enable future integrity checks.
Review applicable accounting documentation and confirm tags and seals to accountable items, including any UIDs assigned to the item
Establish C&S over accountable items.

(12.2) Maintain chain of custody for accountable items (including C&S).

An inspection team:

Checks tags, seals, and UIDs on accountable items against accounting documentation and the declared inventory;
Reviews surveillance data on site and maintains permanently installed monitoring and inspection equipment.

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	• Continuous remote portal monitoring and use of other C&S status by the verifying entity (e.g., data from portal monitors and automated inventory monitoring systems). ***(12.3) Confirm the design and integrity of storage facilities/buildings/storage containers based on design information declared by the inspected State*** • An inspection team re-confirms the physical integrity against possible diversion and for consistency with declarations, including: o Visual or other observations using agreed equipment; o Measurements of physical dimensions; o Comparison of laser mapping with initial (reference) maps. ***(12.4) Routinely confirm inventories of accountable items in storage at the facility.*** • To re-verify physical inventory (according to a statistical plan as appropriate), an inspection team: o Counts accountable items and checks tags, seals, and UIDs on the items against applicable accounting documentation and the declared inventory; o Observes and measures item attributes to confirm consistency with declared verifiable characteristics; o Checks accountable items against an applicable template; o Confirms the absence of undeclared accountable items.
Inspection Approach **Ad Hoc Inspection Tasks**	***(12.5) Monitor inter-site transfers of accountable items following guidance set out in Step 11.*** ***(12.6) Monitor activities where containment is/may be broken and recover from any break in chain of custody*** *(see section 3.4.6).*
Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 12, the following issue may be highlighted: • The kinds of data to be transmitted by remote monitoring equipment would be constrained and measures would be needed to ensure their security and integrity.
Potential Inspection Technologies *(technologies are further described in section 3.5)*	• For inspection approach (12.1), (12.2), (12.4), and (12.6) o Seals, UIDs, RFIDs, accelerometers; o Surveillance equipment like cameras and portal monitors; o Radiation detectors for checking gamma and neutron count rates at defined positions;

	o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies; o automated inventory monitoring systems; o Muon tomography; o Calorimetry. • For inspection approach (12.3) o 3D laser, optical change detection, and/or container integrity assessment for initial mapping and subsequent inspections; o Seals, surveillance equipment like cameras.
Assurance and Uncertainties	• A history of observations, as well as attribute and template measurements of an item prior to receipt at the facility would add useful assurance that the item is consistent with declarations. If not available, attribute measurements on all accountable items is needed. If template techniques are available to enable comparison between items of the same model, stronger assurance could be achieved. • Fully effective C&S on accountable items, along with confirmation of the integrity of storage areas, would offer strong assurance of their non-diversion and continued integrity. However, the risk for failure or breach of C&S cannot be excluded. If chain of custody is broken, procedures would be needed to re-establish that accountable items are consistent with declarations, including re-applying tags, seals, and applicable UIDs assigned to the item (see section 3.4.6). • The frequency and intensity of inspection activities should be consistent with ensuring the timely detection of diversion of accountable items (see section 3.2.2).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items that enables diversion and/or substitution of critical components. • Items could be mis-declared by the inspected State.

Step 13	Transport of Components to Disposition Facilities	

Verification Objectives	Inspection activities at this step aim to: • Confirm chain of custody on accountable items that are transported between sites. • Ensure timely detection of any failure of chain of custody related to such movements and, if necessary, reconfirm that affected items are as declared.

Baseline Information and Arrangements	• Baseline data on accountable items already under verification include seal, tag, and UID data and history of attribute/template measurements.
	• Notification, within a specified period, by the inspected State of completion of the transport between sites of a consignment of accountable items, including:
	    o Originating and destination sites;
	    o Time period of transport;
	    o Data identifying each item transported;
	    o Advice of any incident or damage that may affect chain of custody measures.
	• Standing notification by the inspected State of expected duration of transport between specified sites.
	• Possible arrangements for in-situ surveillance of accountable items during transport.

Inspection Approach
 	
Routine Inspection Tasks
	(13.1) At some time prior to departure from deployed site, confirm chain of custody for accountable items that could be moved between sites.
	• An inspection team:
	    o Checks tags and seals for accountable items;
	    o Makes documentation checks.
	
	(13.2) If arrangements have been agreed, monitor accountable items during transport.
	• An inspection team:
	    o Reviews surveillance data at the receiving site;
	    o Could arrange for surveillance measures to be applied during transport to provide additional assurance that chain

	of custody is maintained, and to promptly identify any problems;
	    o May apply seals to transport vehicle if additional assurance is required.
	
	(13.3) Confirm chain of custody for accountable items at receiving site.
	• As necessary to confirm chain of custody, an inspection team:
	    o Checks tags and seals for accountable items;
	    o Makes documentation checks;
	    o Checks that the time period over which the transfer took place is consistent with the declared transfer;
	    o Makes attribute/template measurements on randomly selected item(s).

Inspection Approach **Ad Hoc Inspection Tasks**	***(13.4) Monitor activities where containment is/may be broken and recover from any break in chain of custody*** *(see section 3.4.6).*

Potential Constraints on Inspection Activities	A general description of such constraints is at section 13.3.1.
	For Step 13, the following issues may be highlighted:
	• Information about transfers may pose a security risk.
	    o Provision of information in advance of transfer may not be agreed;
	    o Information would be limited to that needed for inspectors to carry out activities according to their mandate.
	• Any equipment for surveillance during transfers would be installed in anticipation of movement and must be capable of operating in isolation from an inspection team.
	• Any damage to containers during transport may risk exposure of proliferation-sensitive information and could pose a safety hazard.

Potential Inspection Technologies
(technologies are further described in section 3.5)
	• For inspection approach (13.1)
	    o Seals, UIDs, RFIDs, 3D container identification.
	• For inspection approach (13.2)
	    o Radiation rate counter in unattended mode;
	    o Seals might also be applied to transport vehicle.
	• For inspection approach (13.3)
	    o Seals, UIDs, RFIDs, 3D container identification.
	• For inspection approach (13.4)
	    o Gamma detectors and neutron counters for making attribute and/or template measurements by spectrometric or imaging technologies;
	    o Container identification and integrity assessment.

Assurance and Uncertainties	• Good, if chain of custody is maintained.

	• Weaker, if there is a break in chain of custody and steps are needed to re-establish knowledge of accountable items (see section 3.4.6).
Potential Pathways for Diversion and/or Substitution	• C&S measures are defeated without timely detection. • Undetected direct access to accountable items that enables diversion and/or substitution of critical components. • Assurance of non-diversion is reduced if a significant number of accountable items are in transit and outside verification at a given time.

Step 14	Disposition of Components	

Verification Objectives	Inspection activities specific to this step aim to confirm: • Routinely check inventories of accountable items in storage for consistency with declarations; • Maintain chain of custody for accountable items, by applying C&S, and by checking the physical integrity of facilities, buildings and storage containers; • Verify that all SNM entering the disposition process is contained in material or items declared as the output from the 14-Step Dismantlement Process. *This paper does not address disposition of non-SNM bearing components.*
Baseline Information and Arrangements	• Declarations on sites and facilities, and on a program to verifiably reduce weapons numbers (see section 3.1.1). • A negotiated facility arrangement should be in place (see section 3.1.3). • Notifications of an inspection and/or of events triggering a possible inspection (see section 3.1.2). • Baseline data on accountable items under verification include seal, tag, and UID data and history of attribute/template measurements.

Inspection Approach
 	
Routine Inspection Tasks
	(14.1) Monitor receipts of accountable items following guidance set out in Step 13.
	
	(14.2) If necessary, establish an initial inventory for the facility of accountable items that contain SNM.
	• An inspection team:
	    ○ Observes and measure item attributes to confirm consistency with declared verifiable characteristics;
	    ○ Checks accountable items against an applicable template;
	    ○ Reviews applicable accounting documentation and confirm tags and seals to containers and any UIDs assigned to the item.

(14.3) Maintain chain of custody for accountable items (including C&S) at disposition facility prior to disposition.

- An inspection team:
  - Checks tags, seals, and UIDs on accountable items against accounting documentation and the declared inventory;
  - Reviews surveillance data on site, and maintains permanently installed monitoring and inspection equipment;
  - Continuous remote monitoring of C&S status by the verifying entity (e.g., data from portal monitors and automated inventory monitoring systems).

(14.4) Confirm the physical integrity of the disposition process against possible diversion and for consistency with declarations.

- The inspection team confirms the physical integrity of the dispositions process against possible diversion and for consistency with declarations, including:
  - Visual or other observations of the integrity of processing buildings and equipment, including continuous remote monitoring (e.g., portal monitors);
  - Visual observations and low-resolution measurements of the process to check consistency with declarations.

(14.5) **Confirm that all SNM in items entering the disposition process is contained in material or items declared as the output from the process.**

- Based on which of the three categories the material will be classified, the inspection tasks and techniques will differ, as follows:
  1. **Non-explosive military use (e.g., naval reactors).** Item will be verified using non-destructive assay (NDA) techniques before it enters into the non-explosive military stream and then again once it is retired from use, under a detailed framework that would be developed to implement Article 14 of the Model Comprehensive Safeguards Agreement (INFCIRC/153) dealing with use of “nuclear material which is required to be safeguarded thereunder in a nuclear activity which does not require the application of safeguards under the Agreement.”
  2. **Civilian use.** International Atomic Energy Agency (IAEA) safeguards, or equivalent provisions, will apply and verification would involve confirming type and quantities of nuclear material in declared items. If

		information such as type and quantity of SNM was provided before processing, this information can be used to ensure no diversion has taken place through the use of NDA techniques. If no information was provided by the State, in-situ measurements may be possible. *3.* **Storage or disposal (with or without down-blending).** The tasks and techniques will differ depending on information available before and after entering the dispositioning facility, as follows:

Information Pre-Processing	***Information Post-Processing***	***Tasks and Techniques***
Not provided	*Not provided*	*Use tags, seals, UIDs with routine verification to ensure that the integrity of storage site as well as that C&S measures have not been compromised.*
Not Provided	*Provided*	*Perform measurements to confirm material and then use tags, seals, and UIDs —in-situ measurements may be possible on item to confirm absence of diversion.*
Provided	*Provided*	*Perform measurements to confirm material —in-situ measurements may be possible on item*

				to confirm absence of diversion.	

Inspection Approach **Non-Routine Inspection Tasks**	***(14.6) Confirm the design and integrity of storage facilities/disposition buildings/storage containers for accountable items based on design information declared by the inspected State.*** An inspection team re-confirms the physical integrity against possible diversion and for consistency with declarations, including: • Visual or other observations using agreed equipment; • Measurements of physical dimensions; • Comparison of laser mapping with initial (reference) maps.
Potential Constraints on Inspection Activities	A general description of such constraints is at section 3.3.1. For Step 14, the following issues may be highlighted: • The kinds of data to be transmitted by remote monitoring equipment would be constrained and measures would be needed to ensure their security and integrity. • Information on type and quantity of SNM in post-processed declared items may be considered sensitive by the inspected State. • Process design information may be considered sensitive by the inspected State.
Potential Inspection Technologies	*Further work to be done, possibly in IPNDV Phase III.*
Assurance and Uncertainties	• Fully effective C&S on accountable items, along with confirmation of the integrity of storage areas, would offer strong assurance of their non-diversion and continued integrity. However, the risk for failure or breach of C&S cannot be excluded. • Significant issues remain to be addressed for ensuring that all SNM in items entering the disposition process is contained in material or items declared as the output from the process. Checks on the physical integrity of the disposition process against possible diversion can probably provide only limited assurance.
Potential Pathways for Diversion and/or Substitution	• Items could be mis-declared by the inspected State. • C&S measures are defeated without timely detection. • Undetected direct access to accountable items or SNM from them enables diversion.

Part 3. Cross-Cutting Issues

3.1. Baseline Arrangements and Information for Inspections

3.1.1. Declarations

A country undertaking dismantlement would submit various declarations to a verification entity. Such declarations would set out an anticipated program of activities against which compliance could be judged. To facilitate planning of verification activities, the program could specify one or more campaigns during which a certain number of nuclear weapons is to be dismantled.

Other declarations and notifications would be provided to facilitate inspection activities. In its Phase I, IPNDV considered declaration and notification requirements for Steps 6–10 (see Chapter 2 of Deliverables Four, Five, and Six). Declaration requirements for all 14 steps would be similar but wider in scope. These can be summarized as including declarations/notifications covering:

- All facilities where NEDs/components will be handled, stored or processed;
- Containers for storage and/or transport of NEDs/components;
- The status of each accountable item, including location in storage, verifiable characteristics.

For Steps 2–8, an accountable item is a NED, which can be expected to be presented to inspectors inside a closed container. For later steps, an accountable item could include one of the following from a dismantled NED, presented in a closed container:

- SNM;
- HE;
- Other weapon components.

3.1.2. Operational Notifications

Operational notifications would also be required, for example for the verifying entity to inform an inspected State of an impending inspection, or for a State to inform the verifying entity of an event that may trigger the need for an inspection. The details of notification data may require protection from access by third parties and should be transmitted using secure means.

- A notification by the inspected State to the inspecting entity of an event could include:
    - Date/time of planned event;
    - Location of planned event, identified using the most current facility diagram;

    - Identifying information on the accountable item(s) involved (type/number/UID).

- A notification by the inspecting entity to the inspected State of an inspection could include the following information:
    - Notification of intent to conduct inspection;
    - Arrival information at the Point of Entry;
    - Inspection team composition;
    - Any request for special assistance (e.g., special dietary, medical, or religious considerations; unique communications requirements, etc.).

3.1.3. Facility Arrangements

It is likely that the requirements of a verification agreement will apply at sites and facilities of varying design, even where facilities may carry out the same function in the dismantlement process. To implement the provisions of a verification agreement effectively, and in a non-discriminatory way, a site-specific facility arrangement would be negotiated. Such an arrangement would set down parameters for the conduct of inspections, including details of the access inspectors require during inspections, along with managed access measures to prevent the disclosure of sensitive information.

A facility arrangement would record relevant information about the site, and each facility on it where verification activities may take place. An arrangement would include some details on the layout of relevant buildings and structures.

Assurance that accountable items have not been diverted or interfered with will rely heavily on effective C&S. A facility arrangement would address the design of C&S systems to be used, as well as measures to ensure the integrity of relevant buildings and storage containers.

The detail to be included in a facility arrangement could vary considerably, depending on the complexity of the facility and of the verification measures to be applied at it.

3.1.4. Containment and Surveillance and Facility Design

Through familiarization and planning visits at each site and building, inspectors initially receive, and during subsequent visits, make observations and measurements to confirm declared site and building diagrams and storage container designs and check relevant parts of buildings to ensure integrity against diversion. The inspecting entity and inspected State develop site-specific arrangements for C&S of accountable items, including through use, where appropriate of tags, seals, portal monitors, and cameras. Inspection equipment would include such C&S equipment, as well as equipment for tasks such as measuring physical dimensions as well as equipment for recording findings.

3.2. A Systems Approach to Verification

3.2.1. A Systems Approach

When approaching a complex system, involving many diverse elements and comprising intricate interconnections and influences, engineers look towards devising a systematic approach to understand it in totality. A systems approach is used to design a methodology that can take into account internal and external factors, clearly identify the stakeholder needs, and helps set priorities for a particular system.

Systems approaches are not new to verification. Inspired by the recent development and implementation of State-level approaches by the IAEA, applying a systems approach to the complex issue of nuclear disarmament verification might help to formulate an objective, standardized, transparent, and reproducible framework, that can be well-documented, so that stakeholders can confidently use it to identify and address gaps in disarmament verification capabilities and approaches. Such a framework could also drive the development of new research and development directions.

Each country has a specific and unique set of characteristics of its nuclear program that will influence how verification approaches can and should be applied. For example, the degree of separation between the civilian and military sectors is highly variable in different States. The scale of the facilities in a State's nuclear enterprise also varies. Some facilities are large, complex and energy intensive, while other activities (e.g., weaponization research and development) can be accomplished with fewer resources and a smaller footprint. Effective system-wide confidence must address the requirements for the protection of proprietary information in civilian facilities and national security information in military facilities, while not creating gaps that fundamentally reduce the level of confidence in the whole system in ways that are not politically acceptable. The verification approach for different countries, therefore, should not be "one-size-fits-all," although the verification objectives and confidence levels must be the same for all parties to an agreement. An example of this might be that a treaty may not designate how many person-days of inspection are required but rather say that each relevant facility is subject to the same number of on-site visits. This would mean that a country with a smaller complex would not have as many annual person-days of inspection as a country with a more extensive infrastructure to meet same verification objectives.

3.2.2. Role of a Physical Model

The physical model of a nuclear fuel cycle, as defined in the IAEA Glossary, is

> a detailed overview of the nuclear fuel cycle [...], identifying, describing and characterizing every known technical process for converting nuclear source material to weapon usable material, and identifying each process in terms of the equipment, nuclear material and nonnuclear material involved. The physical model is used by the

> IAEA, inter alia, for acquisition path analysis […] and for safeguards State evaluations […].[13]

The nuclear fuel cycle is defined as "a system of nuclear installations and activities interconnected by streams of nuclear material."

The physical model has become an integral part of the State evaluation process in the IAEA Department of Safeguards, including the development and update of State-level safeguards approaches. It serves as reference document on the nuclear fuel cycle, guides the analysis of open source information (including nuclear-related trade data) and provides the basis for conducting an acquisition path analysis (APA). The physical model helps to identify proliferation indicators and to prepare verification activities.

Based on the lessons learned from using a physical model in IAEA safeguards, a systems approach might provide a generic and structured approach to the complex and sensitive issues in disarmament verification. A systems approach including a physical model could help design a transparent State-level systems framework to define verification objectives, processes, and timescales for an effective verification regime based on the strategic goals of a given disarmament treaty. Similar to applying APA in the context of State-specific safeguards approaches, a physical model could provide the basis for finding signatures of what States are doing, identifying and assessing cheating pathways in the disarmament process, specifying and prioritizing State-specific verification goals, and identifying verification measures to address the verification goals.

In order to develop a physical model in the context of disarmament verification, one of the questions to be addressed is how to formalise the model. Although the physical model in IAEA safeguards only focuses on nuclear material and related processes within the civilian nuclear fuel cycle, the physical model to be used in the context of nuclear disarmament verification may need to cover production, deployment, dismantlement, and disposition of nuclear weapons, depending on the scope of an agreement. There are different options for extending the physical model in this regard.

One option would be to combine civilian nuclear fuel cycle, military nuclear fuel cycle and the nuclear weapons' complex in one model.

Another option would be to use different separate physical models for (a) the civilian nuclear fuel cycle, (b) the military nuclear fuel cycle, both focusing on nuclear material only, and (c) the nuclear weapons' complex including production, deployment, dismantlement and disposition. The three models could then be connected via the potential flow of nuclear material in between the three models.

If the physical model of the nuclear weapons' complex would be based on the 14 steps, technically plausible cheating pathways among the 14 steps could be identified and assessed and prioritised in terms of their attractiveness to the respective State. The attractiveness of any

[13] *IAEA Safeguards Glossary 2001 Edition*, International Verification Series, No. 3, https://www.iaea.org/sites/default/files/iaea_safeguards_glossary.pdf.

cheating pathway may not only depend on technical and/or financial constraints, but also on non-technical factors (strategic considerations). A systems concept would support integrated analysis of varied information, encompassing State-declared information, international technical monitoring data, information obtained by national technical means, open source and trade information, and diplomatic consultations. With ever-greater capabilities to record and share vast amounts of data, mechanisms to systematize and integrate a wide range of information are increasingly being explored by governments, the private sector, and citizens. These capabilities can be applied to verification of existing treaty-specific commitments but might also help to highlight places in the system where transparency would yield the greatest benefit.

3.2.3. Frequency of Inspection Activities

The technical needs to establish confidence in continuity of knowledge, chain of custody, or material/item identification are based on the type of activity or conduct of the inspected State. However, viewing the dismantlement process as an interconnected system, defining measurement, or monitoring requirements will not be done by looking at any one step in isolation.

The disarmament verification process comprises several steps and it must be decided whether at any step a verification activity has to be performed. There may be good reasons to repeat measurements. These reasons might include engagement for the inspectors, deterrence for the inspected, the time that a declared item has stayed static in any step within the process or since a previous measurement was taken, and the overall political context (e.g., messaging/signaling to policymakers and legislators). However, there may be also good reasons to perform measurements on a random basis in order to better balance efficiency and effectiveness. When viewing the 14 steps as a whole system, it is important to know why we recommend a process/procedure and what the trade-offs for implementation would be, remembering that more is not always better.

For example, one could design a system in which seals are placed at every possible vector along a diversion pathway even if that means there are multiple seals along each diversion pathway. Although this might increase overall confidence if there is no indication of tampering, that is unlikely. When taking into account failure rates and the probability of false positives, the more seals that are placed, the more uncertainty there might be. Or, to use a separate metric, the more human and financial resources will be needed to resolve questions and reduce uncertainties. Similarly, taking repeated intermediate measurements (such as inventory verification) introduces additional measurement uncertainties outweigh the confidence gained by more measurements. These are examples where a deliberate assessment is needed to allocate time and effort across the steps rather than taking a “more is more” approach to monitoring measures.

Some inspection activities have value for political confidence-building even when they don’t add to the technical verification conclusions. For example, political confidence in monitoring may be increased by distributing tasks throughout the dismantlement process. When verification activities involve calculated uncertainty, as are inherent in some measurements, taking multiple measurements at every step along the process actually decreases overall technical conclusions of the verification system, i.e., also lowers the verification effectiveness. Efficiency and technical effectiveness are essential, but they are not the only objectives of a verification regime. It is important, therefore, to be clear when the regime might include a monitoring step for a technical purpose and when it is serving another objective.

3.3. Common Constraints for Inspections

3.3.1. Constraints on Inspection Activities

The highly sensitive nature of nuclear weapons and related facilities will necessarily constrain the kinds of inspection activities that could be conducted at each of the 14 steps. Much of the work of IPNDV focuses on the design of verification solutions that can work with these constraints. Constraints will vary from step to step and from site to site; however, generic issues are outlined here.

- To protect proliferation-sensitive information, constraints on physical and visual access to a NED would be required. The use of additional protective clothing may be required to prevent particles adhering to inspectors' clothing. Limitations, like information barriers, will be placed on verification equipment, which could measure or record proliferation-sensitive information.
- Effective verification will require inspectors to have some knowledge of the design of facilities and containers in which NEDs or components are stored or handled. However, concerns may arise over inspectors gaining a full understanding of and therefore being able to pass on information regarding security arrangements at a site, or inherent in the design of buildings or building access requirements. Similar concerns might also arise in relation to elements of the design and construction of containers. The precise location of NEDs may also be sensitive. Careful negotiation will be required to meet verification objectives while protecting national concerns.
- Security of NEDs or their components is likely to be particularly sensitive during transportation outside controlled sites. Without the layers of physical security present in a fixed facility, there will be a high level of sensitivity regarding security information on transport containers, vehicles, routes, and timings.
- Safety procedures would apply to protect inspectors and inspected State personnel. This may limit the number of inspectors able to access a location and the duration of such access. Particular inspection activities would need to be carried out by site personnel under the instruction of inspectors.
- Restrictions may be required on the proximity of inspectors to explosive materials, the number of personnel within an explosive building, clothing, footwear, and other

measures to manage static discharges. The design and use of electronic equipment would also be subject to explosive safety requirements.

- The design and use of inspection equipment will need to avoid the unplanned exposure to inspectors of sensitive information. If sensitive information needs to be provided to inspectors, further security measures will be needed to ensure it is used only as has been agreed.
- The kinds of access available to inspectors would need, in most cases, to be pre-negotiated and included in a facility arrangement document.

As stated in the results of IPNDV Phase I, the direct visual observation of a NED or its components, for example during maintenance, would pose a serious risk for exposure of proliferation-sensitive and national security sensitive information, and must be avoided. Measurement techniques applied by inspectors must also be designed to avoid the exposure of such information. In that case, inspectors would only have access to the NED when inside a closed container or, after dismantlement, to closed containers containing the various components.[14]

An information barrier is a system designed to prevent the release of classified or sensitive information while allowing meaningful measurements to be performed on nuclear weapons and/or sensitive items. This can be accomplished by using a combination of hardware, software, and administrative controls, but it must satisfy two requirements: (a) the information barrier must provide inspectors with the confidence that the unclassified output is reproducible and accurately represents the classified input; and (b) the inspected State must have confidence that the sensitive information is not released to the inspectors. After passing through an information barrier, the results of a classified, sensitive, or proprietary measurement should be reported as an unclassified result. One such option is to have the result reported as a binary (pass or fail) result with respect to predetermined criteria.

Although an information barrier ensures that classified or sensitive information collected for a given measurement is not released, its use introduces an additional complexity where both the inspected State and inspectors must trust that the information barrier system is not performing any task other than its intended one (i.e., they must be able to certify and authenticate[15] the system, as one would have to do with all monitoring equipment). Therefore, the information barrier hardware, software, and/or administrative controls must be designed to facilitate inspection. Trust in the system can be facilitated in a number of ways, including joint development between the inspected State and monitoring parties or entity to ensure full understanding of the features included, simple hardware and software to ensure that the functionality is fully transparent.

[14] In its Phase I, IPNDV considered in additional detail the constraints likely to verification for Steps 6–10 (see Chapters 14 and 15 of the Working Group 2 deliverable).
[15] Principles on certification and authentication of inspection equipment can be found in Chapter 10 of the document of deliverables 4, 5, and 6 for IPNDV's Phase I.

Design information about a storage facility or buildings will need protection consistent with physical security requirements of these sites. This may limit the kinds of information to which inspectors have access; however, it will be necessary (e.g., as part of a facility arrangement) to determine a set of facility-specific design information that will adequately allow for conduct of monitoring and inspection activities. More sensitive information could be retained on-site under dual seal. Site security requirements must be taken into account when designing monitoring and inspection activities to avoid impeding verification.

Inspection procedures will need to take into account the design of containers for accountable items, including to:

- Avoid any effect on measurement techniques that may cause inconsistency;
- Prevent undetected access to its contents;
- If technically feasible, leverage uniquely identifiable characteristics of the container itself to add assurance about the identity and/or integrity of the accountable item.

It could be in the interest of the inspected State to have a set of standard containers for each type of item (e.g., warhead) that does not deviate from one container to the other, at least not to such an extent that the discrepancies could affect radiation measurements enough to cause failure of a template matching test.

3.4. Inspection Methodology Issues

3.4.1. Types of Nuclear Weapons

An analysis of the verification process of the dismantlement of nuclear weapons should comprise all types of such weapons.

The nuclear explosive component of a nuclear weapon by definition has three main components:

- SNM (based on design; can vary, but usually contains fissile material like weapons grade ${}^{235}_{92}U$; ${}^{239}_{94}Pu$);
- HE (chemical component, minimum detonation velocities range usually from 6,900 m/s to 10,100 m/s. HE can vary from Trinitrotoluene (TNT) to Octanitrocubane (ONC). The HE to be used for munitions have to have a low level of shock sensitivity and friction sensitivity to allow the storage of the nuclear weapon;
- Other components and materials used (based on design, which may also be sensitive and require special handling).

A nuclear weapon is designed to be delivered to a target by a particular delivery system. These delivery systems can be categorized as follows:

(a) Air-launched;

(b) Surface-launched[16];
(c) Sub-surface launched;
(d) Other types of deployment.

Dismantlement verification activities could start at different steps based on the type of delivery system involved (Step 1 or 2).

Air-launched nuclear weapons consist of the following types:

- Guided or unguided missiles;
- Gravity bombs.

Commonly, these types of nuclear weapons are stored in a WSA within the confines of a military installation. In such cases, the verification of the dismantlement of these nuclear weapons most likely starts at Step 2.

Surface launched nuclear weapons consist of the following main categories:

- Missiles (e.g., cruise, ballistic, other);
- Artillery shells;
- Depth charges;
- Naval mines.

Missiles can have nuclear weapons mated or not depending on the function. To ensure the deterrence capability of the missiles, nuclear weapons are usually mated on the delivery vehicle. These warheads can be singular or multiple. The procedures for de-mating these warheads will depend largely on the design of the missile's launcher. For instance, a missile in a below-ground silo type launcher may have different procedures than those for an above-ground launcher. After the nuclear weapon is de-mated from the missile, it will likely be transported to a WSA located at a nearby military facility. The dismantlement verification for this case probably starts at Step 1. Some missiles and other similar systems are not normally mated with a nuclear weapon, so the start of the dismantlement verification process could start at the associated WSA (Step 2).

Nuclear artillery shells are most likely to be stored at the associated WSA (Step 2).

Surface-launched Cruise Missiles and other similar systems are normally stored and deployed in a launch canister either on a ship or in a WSA. In either case, the de-mating of nuclear weapons from these missiles will be done at the associated WSA.

Sub-surface nuclear weapons consist of the following:

- Submarine launched or other missiles;
- Torpedoes;
- Naval mines.

[16] Ground-launched or sea-launched.

These weapons can be deployed on operational submarines. Dismantlement verification for these systems may be the most challenging due to the nature of submarine design, the type and size of the associated missile, and the potential weather challenges. Depending on the system, the de-mating process could begin on the submarine (Step 1) or the missile may be removed from the submarine and transported to a nearby storage facility to begin the de-mating process. Subsequently the nuclear weapon is moved to its associated WSA (Step 2). The missiles based on some submarines can have single or multiple warheads.

Other nuclear weapons may include:

- Special demolition munitions with nuclear materials;
- Nuclear landmines

These weapons are not mated to a delivery vehicle nor are they fired from artillery pieces and are typically stored in a WSA.

The starting point of the dismantlement verification process largely depends on the delivery system.[17] The outcome of the dismantlement process should be the same for all nuclear weapons, regardless of whether it was originally mated to a delivery vehicle stationed on a military installation, or in a storage facility.

3.4.2. Measurements to Check That an Item Is as Declared

Attribute Measurements

Various measurements can be used to determine if suitably chosen attributes of an object are consistent with what it has been declared to be. However, direct access by inspectors to data revealing attributes of an object that has been declared to be a NED (or SNM or HE from a NED) may of course be problematic. Radiation signatures will in all likelihood be behind an information barrier, especially if they are anywhere near the detailed kind that could in itself give high confidence that an object contains a NED.

To verify that the object has the characteristics of a NED, the intrinsic nuclear properties would have to be used. The signatures then consist of radiation, and due to the shielding involved only neutrons and high-energy photons will be detected outside the NED (and its container). These radiation signatures could either be emitted spontaneously or induced from within the item itself (passive methods), or as a reaction to applied radiation from the outside (active methods). Active methods would generally be more problematic from a safety perspective but could have greater efficacy for verifying the presence of SNM or HE. Some radiation would give confidence that the object contains fissile material, whereas other radiation could indicate presence of other relevant materials such as HE.

[17] Depending on the scope and circumstances of a treaty, at its entry into force NEDs and other accountable items will likely be present also at steps further along the dismantlement process.

Template Measurements

In addition, measurements may be devised so as to compare, from one measurement ("template") to another, measured signatures of, for example emitted radiation that are complex and specific enough to serve as a "fingerprint" of an object or class of objects, but that do not reveal detailed information on any physical attributes. Such template matching could be used in two different ways: either as a way to verify that the object in question is the same one as before (UID), or to gain assurance that the object has the same kind of characteristics as stipulated in a so-called "golden template." The signatures used can be intrinsic and/or extrinsic and can be used for the NED and/or the container storing the NED. An example of an externally applied signature would be a reflective particle tag. This tag creates a complicated pattern of reflected light and can thus function as a UID.

Intrinsic signatures fall into two different categories: signatures related to nuclear properties of the object, and signatures related to microscopic material structural properties of the object. To match signatures that the object has the characteristics of a NED, the same intrinsic nuclear properties—and limitations—as discussed for attribute measurements apply. With the template method, different items have to match each other, so factors such as ageing need to be considered. Although ageing of a nuclear warhead could change the passive gamma spectrum, this could possibly be mitigated by carefully selecting the relevant energy bins in the photon spectrum; for neutrons, the ageing will not generally alter the template in any drastic way.

In the second category, the microscopic properties of the outermost material region are examined to produce a UID. This is based on the fact that, at the microscopic level, local properties like the crystalline structure and defects within it, etc., make a signature that is irreproducible if tampered with. Technologies use acoustic, electromagnetic, or optical principles, and measure the response of the material.

Considerations

Because the application of attribute/template measurements would be resource intensive, accountable items for which such techniques are applied during a given inspection could be randomised, but may have to be designed to work through all accountable items over time. Depending on the scope of a verification agreement, there may be measures to identify the presence of any undeclared items at declared facilities.

For both attribute and template measurements, measurements of uranium will be more challenging than for plutonium. Verifying the presence of uranium and HE is in particular more likely to be conclusive post-dismantlement. Optionally, and if additional managed access measures are agreed, higher quality attribute measurements could be made on SNM during Step 8 (dismantlement). Such measurements, performed behind an information barrier, could be designed so that bare weapons components would not leave the dedicated dismantlement area and would remain shrouded for any inspector. The detectors would be outside the dedicated dismantlement area.

3.4.3. Verifying the Absence of a NED or SNM at a Location

Inspection measures applicable to the 14-Step Process focus on confirming that dismantlement-related activities do in fact take place as declared. In the main, this requires inspectors to confirm the presence of a NED, and after dismantlement, of its SNM, HE, and other components.

However, inspectors may also need to carry out activities that test for the absence of a NED or its sensitive components at certain places. In nuclear dismantlement, the essential step is the separation of SNM and HE. In that step it will be necessary to confirm the absence of SNM in material streams that are declared not to contain it, and to confirm the absence of HE in the material stream that contains SNM. Absence measurements could be made using techniques that pose a much lower risk for the exposure of sensitive information. In section 3.4.4, a practical approach to absence measurements for NED dismantlement is described.

At other steps inspectors also could check gamma and neutron count rates to confirm that no "nuclear object" is present in a certain area or NED storage container. Such a measurement would help confirm the correctness of a State's declaration about activities at the location and may be part of a set of measures to ensure that a location is not being used for diversion of SNM.

Thus, measurements to confirm the absence of a nuclear object can also contribute to verifying the completeness of declarations that a State may make as well as the correctness of declarations.

3.4.4. Use of Presence and Absence Measurements to Decide upon Ending the Monitoring of HE and Non-SNM Weapons Components

At Step 8 of the 14-Step Process, the crucial activity in NED dismantlement takes place: separation of SNM from HE. This dismantlement results in various product streams. Some streams include materials that need to be accounted for; their disposition needs to be verified, and they remain under chain of custody. Other product streams could be exempted from the chain of custody, after definitive proof that the declaration is correct. Thus, various complementary analyses are required, to prove the presence and absence, respectively, of sensitive materials (i.e., SNM and HE).

It is assumed here that, for any single NED, Step 8 results in three (declared) types of product streams, and that products from all three are (for non-proliferation reasons) in containers:[18]

1. Containers with SNM (and without HE);
2. Containers with HE (and without SNM);

[18] Absence measurements on empty containers need to be performed both before they enter the dismantlement area (Step 8) and after they have left it.

3. Containers with neither SNM nor HE (various materials, some of which may be radioactive[19]).

The containers holding SNM[20] may include some shielding material (both for criticality safety and for radiation protection). Such shielding material must be taken into account when developing procedures and technologies for absence measurements. Containers in product stream 2 and containers without radioactive materials in product stream 3 do not require shielding for safety purposes; containers with radioactive materials in product stream 3 may require shielding.[21] Therefore, the containers used for product stream 2 and for (a part of) product stream 3 do not introduce additional difficulties regarding detection limits for SNM.

An inspection approach to confirm that the three product streams separately contain SNM and HE could use the following measurement methodology for each declared container. First, perform an initial check to confirm absence of SNM (including active measurements to confirm absence of HEU).

- If no SNM is present, the container is confirmed to be either of type 2 (container with HE and no SNM), or type 3 (container with neither SNM nor HE).
- If SNM is present, an additional active neutron interrogation measurement is required to confirm absence of HE. If HE is absent, dismantlement is confirmed, and the container is type 1 (container with SNM and no HE). If HE is present, dismantlement is not confirmed, and additional measurements are required.

Additional confidence of verification of absence SNM in product streams 2 and 3 can be achieved in two phases:

(a) An initial check of absence following dismantlement in Step 8;

(b) A supplementary confirmation of absence at Step 10 (possibly later steps also).

The initial check in the dismantlement step serves to detect potential diversion of individual components of the NED “immediately” after dismantlement. From a practical point of view, diversion of very small masses of these materials may not be attractive. Further research may be required to set the detection limits which are required[22] for confirming the absence of SNM and HE in this initial check.

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[19] These materials may include a neutron generator or initiator, metals, and various high-Z and low-Z materials; product stream 3 may contain radioactive materials, but not ^{233}U, HEU, or ^{239}Pu.

[20] If there are multiple containers necessary for the SNM (e.g., for criticality reasons) or if there are containers with other components that need continued monitoring like SNM, the principles discussed in this paper for SNM are also applicable for these extra containers.

[21] The containers holding radioactive materials in product stream 3 may require shielding for radiation protection reasons.

[22] The choice of detection technologies and the setting of detection limits may depend on practical conditions under which the analyses will be performed.

In the storage of components at the dismantlement facility (Step 10)[23] the absence of SNM can be confirmed with long-term measurements on large numbers of containers from product streams 2 and 3, thereby minimizing detection limit problems. At this step, a stationary measurement system with optimized radiation protection precautions[24] can be envisaged. This confirmation may be especially important for containers in product stream 3 that hold radioactive materials that may require shielding. A suitable measuring time has not been established. After this confirmation, the containers with HE (product stream 2) can be transported[25] to a combustion site and burned. This ends the chain of custody for HE. Similarly, a part of the containers from product stream 3 (various materials) can be transported to a mechanical destruction site and destructed. Thereafter, chain of custody ends. If there are containers in product stream 3 that hold radioactive materials, these have to be addressed according to the national radiation protection and nuclear waste regulations. Thereafter, chain of custody ends.

3.4.5. Verification of Dismantled NED Components Other Than SNM or HE

Inspection approaches described in this document for Step 8 of the 14-Step Process focus on the presence and separation of SNM and HE. Measurements on other non-nuclear components removed from a NED play no role (except to confirm the absence of SNM). It is possible, however, that additional assurance that the dismantled item was a NED might be obtained through measurements to look for evidence of material changes and activation products indicative of prolonged exposure to neutron fluence from plutonium. A disposition processes that sanitizes the parts through physical destruction means (e.g., chopping, crushing, shredding, etc.) may make it possible for inspectors to make such measurements and gain additional confidence that a dismantled item was a NED.

Further research will be needed to examine whether such an inspection methodology is feasible and to confirm that it would not put proliferation-related or national security information at risk.

3.4.6. Recovery from a Gap in, or Failure of, Containment and Surveillance on an Accountable Item

As used in this paper, the term “containment and surveillance” includes measures to detect any unauthorised access to accountable items that pose a risk for diversion from monitoring under a verification agreement, or for interference with the item’s integrity (e.g., replacement of the item with a counterfeit). Inspectors should investigate any loss of C&S measures and, where appropriate, gather information to enable a determination on whether provisions of a verification agreement may have been breached.

[23] In principle, the confirmation of absence could also take place in Step 12 or Step 14, if there are plausible practical, logistical or measurements (e.g., use of technologies that may cause stability problems with SNM and/or with HE) considerations. The chain of custody must then be maintained up to and including Steps 12 or 14.
[24] This may be obligatory if active photon or neutron interrogation technologies need to be applied.
[25] Chain of custody aspects: bookkeeping at sending and at receiving addresses, and intact seals.

C&S will have a central role in maintaining continuity of knowledge about (and thus chain of custody over) each accountable item. Thus a loss of C&S, including for inadvertent reasons, may undermine confidence gained from observations and measurements that have previously been made of one or more accountable items, and additional steps would be needed to recover at least some of that knowledge and to reapply chain of custody. There may also be circumstances in which a State needs to break a container seal (e.g., to carry out maintenance). Additional steps may be needed in that case also.

If there are indications of a loss of C&S (e.g., a damaged seal), inspectors could:

- Investigate the cause of the loss;
- Observe and measure item attributes to confirm consistency with declared verifiable characteristics;
- Check accountable items against an applicable template;
- Review applicable accounting documentation;
- Re-apply tags and seals to containers and other potential accountable items, and/or including any UIDs assigned to the item.

If the inspected State needs to break a container seal (e.g., to carry out maintenance) it notifies the verifying entity. In that case, an inspection team:

- Monitors movement of items, equipment, and material in and out of a dedicated area to ensure non-diversion of nuclear material;
- Re-applies tags and seals to containers and other potential accountable items, including any UIDs assigned to the item, and/or
- On a random basis:
    - Observes and measures item attributes to confirm consistency with declared verifiable characteristics;
    - Checks accountable items against an applicable template and/or record templates to enable future integrity checks.

Even after completing procedures such as those mentioned, the value of prior observations and measurements made by inspectors with respect to an accountable item would be degraded. The impact on confidence in verification could be significant, especially if the gap or failure occurs later in the 14-Step Process. If a significant number of accountable items was affected, additional measures may be needed to rebuild confidence. To avoid such problems, the design and implementation of robust C&S measures will be important.

3.4.7. Inventory Monitoring Methods

An inventory monitoring system[26] could be designed to continuously track and monitor accountable items within a storage facility to ensure that, should there be a failure of any monitoring equipment, the inspecting entity would have prompt notification and any loss of continuity of knowledge would be limited. Remote access to information from portal monitors and other monitoring equipment also could be useful.

3.5. Descriptions of Potential Inspection Technologies

IPNDV has identified a range of technologies that might be used for verification of NED dismantlement. The specific selection of technology for a given scenario would be highly influenced by the details of that scenario. There are several considerations that may constrain the selection of technologies:

- As discussed in section 3.3, many measurement techniques expose sensitive information about the object being measured without some form of information barrier. Generally, if a measurement technique applied to a NED or its components is considered for use in a way that reveals size, mass, shape, or material composition (e.g., many radiation-based spectrometric or imaging methods), a suitable form of information barrier would need to be considered. The same applies if a technique relies on comparison to some form of library of known features of materials (e.g., some HE identification methods).
- Any equipment used in the vicinity of a NED would need to be certified by the inspected State to ensure that it meets safety requirements and will not expose sensitive information. Inspectors would need to authenticate the equipment to ensure that it performs in accordance with its expected functionality. Certification and authentication would need to be maintained over time. Especially for complex equipment, such as that incorporating an information barrier, the certification and authentication processes present a considerable challenge.
- To assure an inspected State that equipment making measurements on a NED is not misused, it could be expected that the equipment would be operated by inspected State personnel under close instruction by inspectors.
- Some measurement techniques use active probing, i.e., they depend on irradiation by an external source of the interrogated object to create signatures that can be observed. Such techniques may significantly complicate any safety assessment for use in a dismantlement verification context. Active probing techniques usually are affiliated with high intensity radiation fields. Thus, radiation protection regulations may also restrict their applicability at some locations.

[26] E.g., refer IAEA-SM-367/17/03, D. Mangan et al. "Trilateral Initiative Inventory Monitoring Systems for Facilities Storing Classified Forms of Fissile Material," https://www-pub.iaea.org/MTCD/publications/PDF/ss-2001/PDF%20files/Session%2017/Paper%2017-03.pdf.

Addressing these considerations may require considerable efforts before a technology may be used in a given dismantlement verification function, even though the technology may in itself be readily available and in wide use elsewhere. Depending on the technology and the intended function, these efforts could include, inter alia, development of suitable information barrier systems, development of certification and authentication measures for hardware and software and modifications to user interfaces and modes of operation to facilitate inspector monitoring where inspected State personnel operate the equipment. For most technologies identified, IPNDV assesses the "generic" technology readiness level as quite high (only a few are below the 7–9 range on a 9-step scale). In many cases, however, the assessed readiness for use in a dismantlement verification context is considerably lower (typically in the 3–6 range).

Other considerations influencing the use of technologies are practical ones, such as measurement times and physical size of equipment. Again, the impact often depends on details of specific scenarios, but where possible the selection of technologies listed for tasks broadly reflects such considerations as well.

Although factors such as those discussed above may make an individual measurement technique very complex to implement, a verification system may be designed to make use of alternative, most often multiple techniques and measures in a way that offers the required assurance. For example, a detailed attribute measurement may be impossible given restrictions to protect sensitive information, but it may be possible to replace it by a combination of less detailed attribute measurements, chain of custody measures and measurements designed to verify absence rather than presence of sensitive components. Measurements to verify absence of a NED or its components can be easier to implement because the object exposed to measurement does not have properties that the measurement technology is designed to reveal. Examples of such considerations are found in section 3.4.

The following are short descriptions of potentially applicable methods and technologies. All Technology Working Group papers referred to below can be found at the IPNDV website, https://www.ipndv.org/learn/dismantlement-interactive/.

3D Laser Change Detection System. 3D laser system used to measure a room that enables inspector to identify changes between two inspections in the 3D geometry of a facility and the installed equipment. Can be used to verify design information, verify the absence of undeclared changes, detect movement of containers and for containment verification; could be a fixed system that remains installed or portable system that is brought in for each inspection. For more information on this technology, see Technology Working Group paper "CoC1—3D Facility Verification and Change Detection."

Accelerometers. Sensors that can indicate whether an object of interest has moved or mechanically manipulated; can provide continuous monitoring and triggering. Battery lifetime a potential limitation (can run for years but not indefinitely). Could be applied to the outside of the container to monitor movement of container; if it cannot be applied to a container could be applied to mechanical structures. Consider security implications (e.g., knowledge of route could be considered sensitive). For more information on this technology, see Technology Working Group papers “CoC4—Accelerometers.”

Automated Inventory Monitoring System. The primary functions of such a system is to track item locations during storage and movements within a facility and to monitor item integrity. For example, RFID devices, Portal Monitors and/or Accelerometers feed real-time data into the system.

Calorimetry. Measurement of thermal power output of nuclear material; possibly used to confirm the presence of Pu or U if SNM separated into elements. Cannot detect U in the presence of Pu. May need an information barrier, depending on measurement time, as mass of material can be determined if isotopic information is also available. For more information on this technology, see Technology Working Group paper “NM1—Calorimetry.”

Container Identification and Integrity Assessment. Laser (or other electromagnetic), acoustic or optical system that performs a high-accuracy measurement of the unique surface structure of a container to fingerprint and identify the item. Can be used to monitor NED and NED component containers as well as monitoring equipment enclosures. Depending on the scenario, can be used for identification, authentication and tamper indication, but each use case requires specific development. For more information on this technology, see Technology Working Group papers “CoC7—Container Integrity Assessment,” “CoC2—3D Identification and Containment” and “WG6-CoC1—Non-Contact Laser Interferometry.”

Gamma and Neutron Counting, Spectroscopy and Imaging. These technologies will measure gamma and/or neutron emission rates on the item (NED and/or components) for attribute, template or absence purposes. They include simple counting as well as spectrometric or imaging methods and could be either passive or active (i.e., depending on an external source of radiation to produce a response in the interrogated object). Specific examples include passive gamma or neutron counting, nuclear resonance fluorescence (an active gamma method), active neutron methods to measure response of both fissile and non-fissile material. For more information on these technologies, see Technology Working Group papers “NM2—High Resolution Gamma-Ray Spectroscopy (HRGS),” “NM3—Gamma-Ray Imaging,” “HENM1—Nuclear Resonance Fluorescence,” “NM4—Passive Neutron Counting,” “NM6—Active Neutron Interrogation,” “NM5—Pulsed Neutron Interrogation,” “NM7—Fast Neutron Imaging,” “NM9—Radiation Templates,” and “WG6-NM1—Detection Sensitive Neutron Detector.”

Muon Tomography. Density imaging using cosmic muons, which are preferentially scattered by heavier elements. Muon tomography does not have the sensitivity to identify the exact mass. Depleted U cannot be distinguished from HEU or Pu. May need an information barrier if a high-resolution image is obtained. For more information on this technology, see Technology Working Group paper “NM8—Muon Tomography.”

Nuclear Quadrupole Resonance (NQR). Detection and identification of bulk HE by excitation of select nuclei using radio waves and comparison to known spectra. Requires suitable containers; e.g., will not work with metallic containers. For more information on this technology, see Technology Working Group paper “HE3—NQR Explosive Identification System.”

Optical Change Detection Systems. Optical system used to detect changes in configuration between two inspections. Changes in lighting may trigger a configuration change determination. Can be used to verify design information, verify the absence of undeclared changes, detect movement of containers and for containment verification; could be a fixed system that remains installed or portable system that is brought in for each inspection. For more information on this technology, see Technology Working Group paper "CoC8—Optical Change Detection."

Portal Monitors. Non-spectroscopic radiation portal monitor used to detect movement of radiation emitting device into or out of an area. Shielding will affect the measurement; susceptible to background levels. Could be used to confirm presence of radiation emitting device and can act as a trigger for other surveillance systems. For more information on this technology, see Technology Working Group paper "CoC5—Radiation Detection."

Radiation Detection for Unattended Monitoring. Radiation intensity (i.e., non-spectroscopic) measurements to monitor changes in the radiation environment. For more information on this technology, see Technology Working Group paper "CoC5—Radiation Detection."

Radiation Sweeping. For absence measurements to establish CoC in a well-defined area. Sensitivity of the detector must be checked and adequate for the CoC requirements. For this generic low-resolution detector type, there is no Technology Working Group paper, as a large number of suitable gamma and neutron detectors are commercially available.

Radiation-Hardened Radiofrequency Identification (RFID). Devices that can be used to assign a unique ID to a container using radiofrequencies; RFID-based devices range from very simple, passive systems to complex, active systems integrating other sensor information. Active systems are battery powered and have a limited lifetime. Active systems would have to meet safety and security requirements. For more information on this technology, see Technology Working Group paper "CoC9—Radio Frequency Identification."

Raman. Detection and identification of bulk or trace HE by comparison of vibrational, rotational, and other low frequency modes of a molecular system to known spectra. Depends on optical contact (e.g., HE stored in a semi-transparent container). For more information on this technology, see Technology Working Group paper "HE4—Raman Explosive Identification System."

Tamper Indicating Devices (TID)/Seals. Various devices that can be used to indicate if a container or room has been opened or tampered with. Containers need to be conducive to application of a seal or tamper indicating device. Examples include adhesive and loop seals/TIDs. For more information on this technology, see Technology Working Group paper "CoC6—Tamper-Indicating Seals and Enclosures."

Unique Identifier (UID). A unique identifier (UID) is a fingerprint or signature of an item that is difficult to counterfeit or transfer from one item to another without detection. UIDs may be applied to the item, such as visual tags or labels or RFID-based devices (see below). UIDs may also be intrinsic to the item (e.g., crystalline structure of metal or composite material at a specific location). For more information on UIDs, see Technology Working Group paper "CoC10—Unique Identifiers."

X-Ray Based Methods. Interrogation of material properties like shape, location, effective atomic number, density, mass, type and crystallographic properties through irradiation of material with x-rays and detection of scattered and/or transmitted radiation. Exact identification of HE requires a material library. X-rays can penetrate low-density materials and so these methods may be used where HE is obscured, unless this is achieved by high-density materials. For more information on these technologies, see Technology Working Group papers "HE5—X-Ray backscattering imaging," "HE6—X-Ray Diffraction" and "HE1—X-Ray Computed Tomography"

3.6. Inspection Findings and Compliance Assessment

3.6.1. Information to Be Reported by Inspectors

Inspection reports should include information to provide a factual accounting of the conduct of the inspection, such as a description of activities carried out by inspectors, a listing of the accountable items inspected, and a description of any problems encountered. For each accountable item that was an object of inspection, the inspection team documents events associated with the item against the records provided by the inspected State (e.g., the UID) identifying information related to any tags and seals that were applied, updated facility diagrams, negotiated facility arrangements, and any concerns noted during the inspection.

Anomalies found during the inspection (such as measurements that deviate beyond an acceptable range, or gaps in video recordings) are also recorded by the inspectors, along with any comments from the inspected State on those anomalies. Such an inspection report can serve to demonstrate that relevant functional objectives of an inspection have been met and to enable planning of future inspections. Although information and data on individual accountable items may be held on-site, reports may include summary information on facility design and layout as well as numbers of NEDs that have been subject to inspection. IPNDV can develop this analysis further in its future work.

Compliance judgements are not part of the inspection process. An inspection report will only provide findings, including any anomalies or information gaps.

3.6.2. Treatment of Inspection Results and Dispute Resolution

Various approaches could be used for recording and retaining information collected during an inspection. In one model, an inspection team submits its report for analysis by the staff of a verification entity. The entity would provide summary information to all parties to the verification agreement where there is no indication of non-compliance. If there are indications of non-compliance, additional details would be provided to a compliance body. The advantage of this model is that it allows for increased transparency by inspected States, as the results of inspection activities would normally have only limited distribution. This approach is similar to that taken by the IAEA with respect to NPT safeguards.

A second approach is based on the verification regime for the Comprehensive Nuclear-Test-Ban Treaty. In this approach the inspection data are collected and are given to all parties. The advantage of this model is that by giving the data to all, full transparency, and therefore confidence, is gained by all parties and not just the verification entity. A potential downside of this model is the relatively wide distribution of inspection reports. As a result, in a verification agreement or during an inspection itself, the potential inspected States may try to impose a greater degree of control on the inspectors as to what data can be collected. This may impact the effectiveness of the verification and the confidence that can be gained by those who review the data.

Given the fact that nuclear disarmament will require a high degree of confidence across a wide range of States, how transparency, confidentiality, and confidence can be balanced will be critical to successful verification.

A verification regime should include mechanisms to resolve disputes between its parties. Where anomalies or gaps in information lead to disagreement, a robust dispute settlement mechanism is necessary to provide continued assurance in the verification process, both to any independent authority and other States participating in the disarmament regime. A mechanism should be available for the inspected State to explain an anomaly, or to resolve differences in assessments in the inspection report. Possible options for such mechanisms are addressed by IPNDV in its Phase I (see Chapter 13 of Deliverables Four, Five, and Six).

3.6.3. Use of National Technical Means or Open Source Data

Information from national technical means of verification or from open sources is already embedded in arms control agreements and could have a role in verification of NED dismantlement, subject to the terms of a verification agreement. For example, in certain circumstances satellite observations might provide additional information about the location of some accountable items.

3.7. Terms and Abbreviations Used in This Document

	accountable item	A discrete item that is monitored and tracked in accordance with the terms of a verification agreement. In the context of verified NED dismantlement, it would normally refer to a containerised NED or components.
	Air-Launched Cruise Missile	See section 3.4.1.
	attribute measurement	A measurement of intrinsic properties of an accountable item (as specified by a verification agreement) to check that it is consistent with the kind of item it has been declared to be. See section 3.4.2.
C&S	containment and surveillance	Use of equipment like cameras and portal monitors, container identification, and integrity assessment technologies to detect unauthorized access to accountable items.
	dismantlement area	A "black-box" room or cell in a dismantlement facility in which a NED is disassembled by separating SNM from HE.
HE	high explosive	Refers to the chemical explosive component of a NED.
	information barrier	A system designed to prevent the release of classified or sensitive information while allowing meaningful measurements to be performed on nuclear weapons and/or sensitive items. See section 3.3.1.
	Intercontinental Ballistic Missile	See section 3.4.1.
IPNDV	International Partnership for Nuclear Disarmament Verification	
NED	nuclear explosive device	A generic term for an object containing SNM and HE that is capable of producing a nuclear yield. IPNDV uses the term NED to refer to an object that is removed from a missile or other delivery system at Step 1 of the 14-Step Process and dismantled in following steps.
RFID	Radio-Frequency Identifier	See section 3.5.
SLBM	Submarine-Launched Ballistic Missile	See section 3.4.1.

SLCM	Sea-Launched Cruise Missile	See section 3.4.1.
SNM	Special Nuclear Material	Refers to nuclear material contained, in or removed from, a NED. Its specification corresponds with *special fissionable material* as defined in Article XX of the IAEA Statute.
TID	Tamper Indicating Device	See section 3.5.
UID	Unique Identifier	See section 3.5.
WSA	Warhead/Weapon Storage Area	A storage are for NEDs associated with an operational military base.

About the International Partnership for Nuclear Disarmament Verification

The International Partnership for Nuclear Disarmament Verification (IPNDV), through a unique public-private partnership between the U.S. Department of State and the Nuclear Threat Initiative, brings together more than 25 countries with and without nuclear weapons. In this ongoing initiative, the partners are identifying challenges associated with nuclear disarmament verification, and developing potential procedures and technologies to address those challenges. Learn more at www.ipndv.org.