November 2017

Phase I Summary Report:
Creating the Verification Building Blocks for Future Nuclear Disarmament

International Partnership for
Nuclear Disarmament Verification

Terminology

Throughout this report, the generic term "nuclear weapon" is used to refer to the item subject to monitoring and inspection activities. This usage is devoid of any specific technical meaning and relies on a general understanding of the term. Other products produced by the Partnership's three Working Groups use the term "Nuclear Explosive Device," or "NED," to describe the same type of item. The term "NED" was used to address specific technical considerations related to the definition of a nuclear weapon that arose during discussions among experts. In addition to these terms, readers can refer to the terms and definitions list produced by Working Group 1 as a part of its Framework Document. This document and others referenced in this report will be available on www.ipndv.org.

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Executive Summary

The International Partnership for Nuclear Disarmament Verification (IPNDV) was created as a unique public-private partnership between the U.S. Department of State, the Nuclear Threat Initiative (NTI), and more than 25 States with and without nuclear weapons. Phase I concluded with the November 2017 Plenary Meeting in Buenos Aires of senior government officials and technical experts. From its first meeting in March 2015, the Partnership broke new ground in building a diverse international program of work. Working cooperatively together, the Partners have made valuable progress in identifying the challenges associated with nuclear disarmament verification and identifying potential procedures and technologies to address those challenges.

Across its diverse participants from the policy, verification, and scientific communities, the Partnership has shared knowledge and advanced national and international thinking on nuclear disarmament verification. The "deliverables" of the Partnership's three Working Groups—"Monitoring and Verification Objectives," "On-Site Inspections," and "Technical Challenges and Solutions"—provide a strong analytic contribution to building the needed tool kit of nuclear disarmament verification concepts and capabilities. Moreover, within the Working Groups, representatives of countries both with and without nuclear weapons have brought different perspectives to bear and gained important insights from each other.

The primary focus of Phase I was the monitoring and inspection of a notional nuclear weapon dismantlement process, called the "Basic Dismantlement Scenario" (Figure 1, p. 5). It comprises Steps 6–10 of the Nuclear Weapon Dismantlement Process (Figure 2, p. 10). Those specific steps are only one part of a broader set of nuclear weapon dismantlement activities and in turn of nuclear disarmament verification.

The Partnership's decision to initially focus on nuclear weapon dismantlement was based on the recognition that dismantlement is one of the most important, complex, and technically challenging tasks of nuclear disarmament verification. Providing confidence that nuclear weapons have been dismantled as agreed is essential. Doing so successfully requires balancing the need to provide sufficient confidence that a nuclear weapon has been dismantled with the need to protect proliferation-sensitive and classified information as well as to meet safety and security requirements.

IPNDV Phase I Working Groups

Monitoring and Verification Objectives
Co-chaired by the Netherlands and the United Kingdom

On-Site Inspections
Co-chaired by Australia and Poland

Technical Challenges and Solutions
Co-chaired by Sweden and the United States

"The Partnership is an important technical exercise seeking practical cooperation between nuclear- and non-nuclear-weapon states to create a set of tools for designing and verifying a new future nuclear disarmament treaty."

Col. Marek Sobótka, Head of Nonproliferation and Disarmament Policy Division, Department of International Security Policy, Ministry of Defense, Poland

Credit: Mohamed Salih

The United Arab Emirates hosted an IPNDV plenary meeting in November 2016.

The Partnership has made a substantial contribution to understanding and finding approaches to solve this core challenge of nuclear disarmament verification.

Specifically, the Partnership's key judgment is 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.**

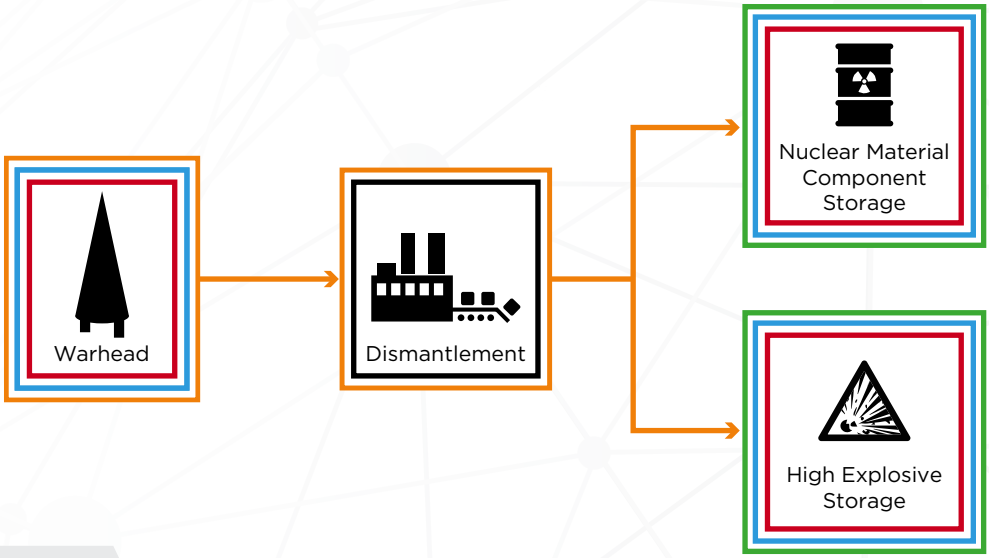
Several more specific conclusions support this key judgment and are elaborated further in this report.

As Phase I concludes, the Partners agree on the importance of building from the Basic Dismantlement Scenario to address verification issues across the entire set of steps in the process of dismantling nuclear weapons. The Partnership also identified several specific verification areas for additional analysis:

- Declarations, including within the wider nuclear disarmament process and as complements to more specific monitoring and inspection of nuclear weapon dismantlement
- Data handling requirements across the inspection process
- Information barrier technologies
- Technologies enabling measurements of Special Nuclear Material (SNM) and High Explosives (HE), as well as the development of nuclear weapon templates
- Testing and exercising potentially promising technologies and procedures

Taken together, these form a roadmap of next steps for the Partnership.

Figure 1: IPNDV Basic Dismantlement Scenario



Monitoring Options

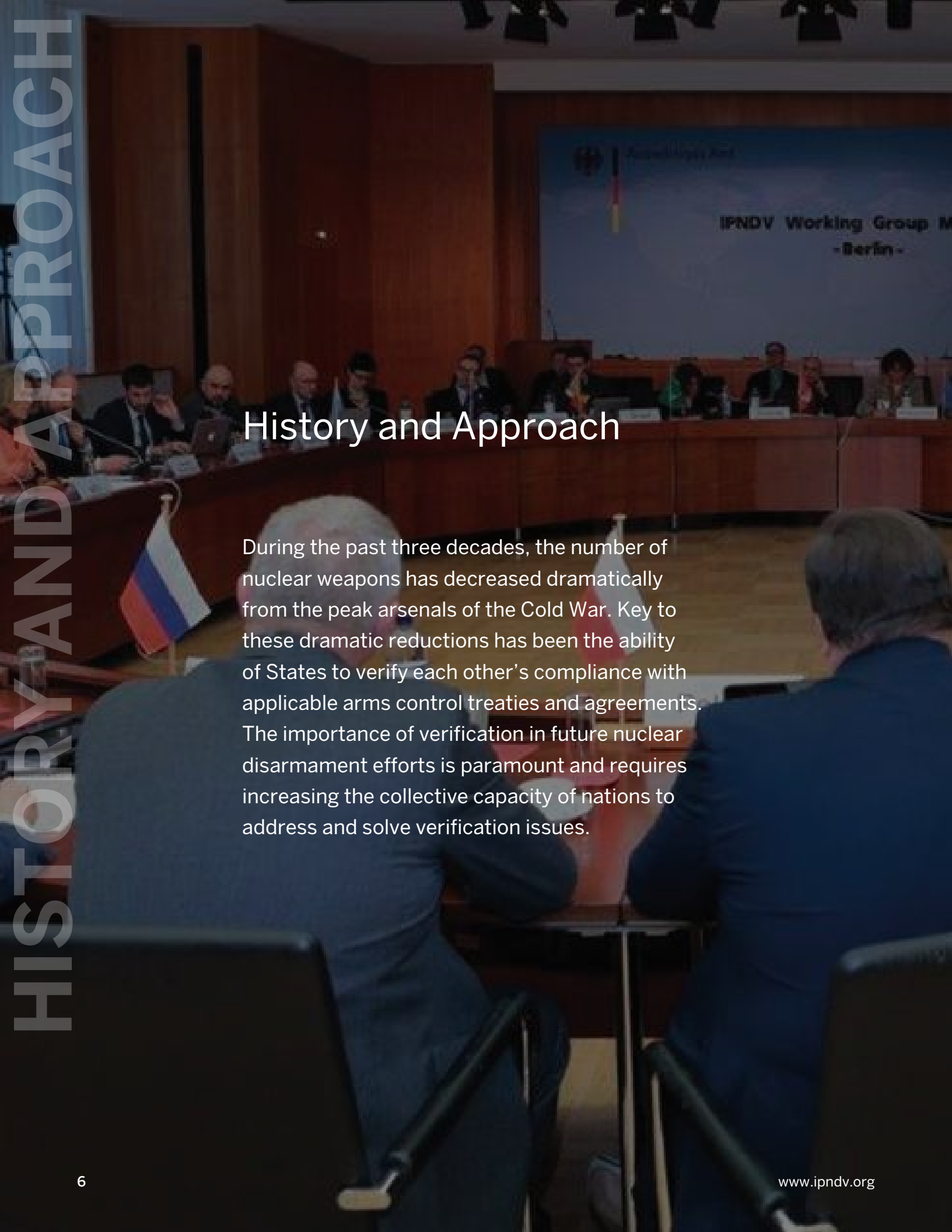
- Declarations and Inspections
- Measurements*
- Chain of Custody
- Temporary Monitored Storage (Until Next Stage of Dismantlement Disposal)

*This could include:
- Presence of Pu/HEU/Explosives
- Absence of Nuclear or Explosive Material
- Isotopic Composition
- Minimum Mass

Note: Access to the dismantlement facility will be restricted in order to ensure no sensitive or classified information is revealed. The black box around the dismantlement facility illustrates that there will be no access during the dismantlement phase.

This chart describes the basic dismantlement scenario, indicating monitoring options, addressed in Phase I. The objectives were to (1) ensure chain of custody of the nuclear warhead (from the agreed point prior to dismantlement) until both the explosive and nuclear material are in temporary monitored storage; (2) confirm the warhead meets the agreed characteristics; (3) confirm the dismantlement of the warhead; and (4) ensure the nuclear (and explosive) material remain within temporary monitored storage until the next stage of the dismantlement (or disposal) process.

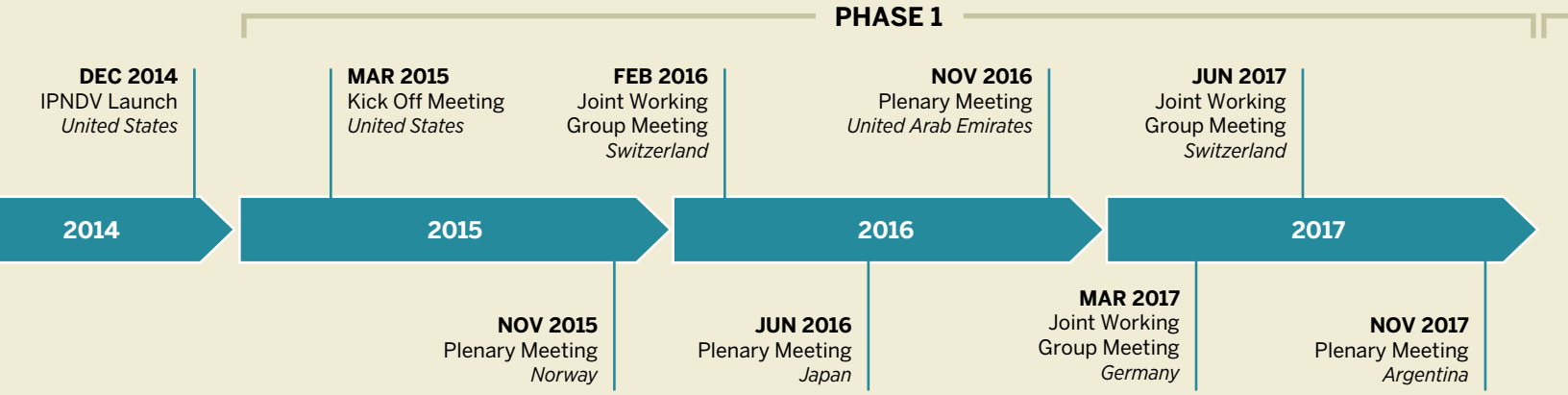
The Partnership's success reflects the commitment of all the countries, their experts, and the senior government officials who participated. It also is the result of the hard work and creative thinking of the co-chairs of the Partnership's Working Groups as well as of the participants of those groups and their colleagues at home. They deserve thanks—both for their work in Phase I and for their ongoing contributions. With continuing international support and commitment, the Partnership has and will continue to make a substantial contribution to creating the verification building blocks of future nuclear disarmament.



History and Approach

During the past three decades, the number of nuclear weapons has decreased dramatically from the peak arsenals of the Cold War. Key to these dramatic reductions has been the ability of States to verify each other's compliance with applicable arms control treaties and agreements. The importance of verification in future nuclear disarmament efforts is paramount and requires increasing the collective capacity of nations to address and solve verification issues.

TIMELINE

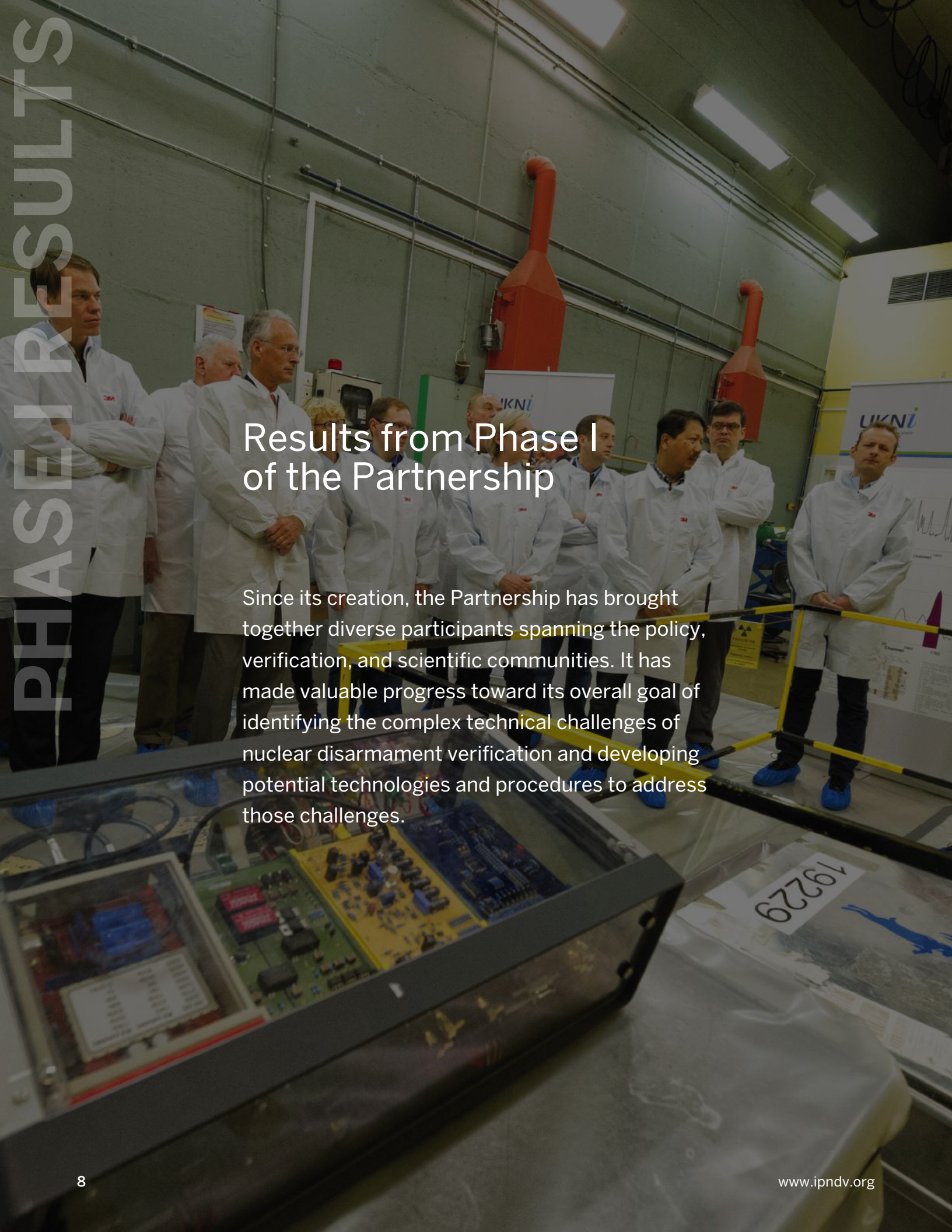


In the latter half of 2013, officials of the U.S. Department of State began to consider how to create an informal, multinational consortium of countries to investigate and search for the technical and procedural solutions to nuclear disarmament verification.

In 2014, NTI completed a two-year study of global nuclear disarmament verification. A key recommendation from NTI's *Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks* series was that "the international community must now work to build and sustain a global cadre of verification experts." The NTI report emphasized that countries "both with and without nuclear weapons should join international verification efforts to make them more effective and build confidence." Having developed independently up to that point, the two efforts converged, becoming a public-private partnership between the U.S. Department of State and NTI.

In December 2014, the U.S. Department of State announced that the U.S. government would lead the Partnership, in cooperation with NTI. More than 25 countries are now taking part in this ongoing effort.

The Partnership established three technical Working Groups for its first phase of work. These groups addressed specific focus areas and met multiple times during each year to conduct their work. The groups reported their progress to annual plenary meetings that brought together senior government officials and technical experts to monitor the progress of the Working Groups, discuss common themes and challenges, and increase the understanding of other relevant research that may inform the overall work of the Partnership. The Partnership's work has built on the U.S.-Russia monitoring and verification experience, as well as the joint U.S.-UK technical cooperation on nuclear disarmament verification and the UK-Norway Initiative on Nuclear Warhead Dismantlement Verification.



Results from Phase I of the Partnership

Since its creation, the Partnership has brought together diverse participants spanning the policy, verification, and scientific communities. It has made valuable progress toward its overall goal of identifying the complex technical challenges of nuclear disarmament verification and developing potential technologies and procedures to address those challenges.

"[The IPNDV] has provided a very good space" for dialogue between nuclear- and non-nuclear-weapon states [and] "is very welcome."

María Antonieta Jáquez, Deputy Director-General for Disarmament, Ministry of Foreign Affairs, Mexico (Arms Control Today)

The Partnership's three Working Groups have been central to its contribution to broadening understanding of the complexities of nuclear disarmament verification:

- **Working Group 1: Monitoring and Verification Objectives**, co-chaired by the Netherlands and the United Kingdom
- **Working Group 2: On-Site Inspections**, co-chaired by Australia and Poland
- **Working Group 3: Technical Challenges and Solutions**, co-chaired by Sweden and the United States

Each of these Working Groups has brought together experts and officials drawn from across the Partner countries. Working Group participants were often supported by colleagues at home. Together, the Working Groups produced more than 50 analytic working papers across their respective areas of concern. Each Working Group set out its key findings in written reports, or "deliverables," of its work. (Summaries of these findings are included below, and a complete list of the deliverables is included on pp. 35–36 of this report.)

The result is a significant growth in knowledge and expertise among participants, their governments, and the global community on the challenges of verification of nuclear disarmament and potential solutions to address those challenges.

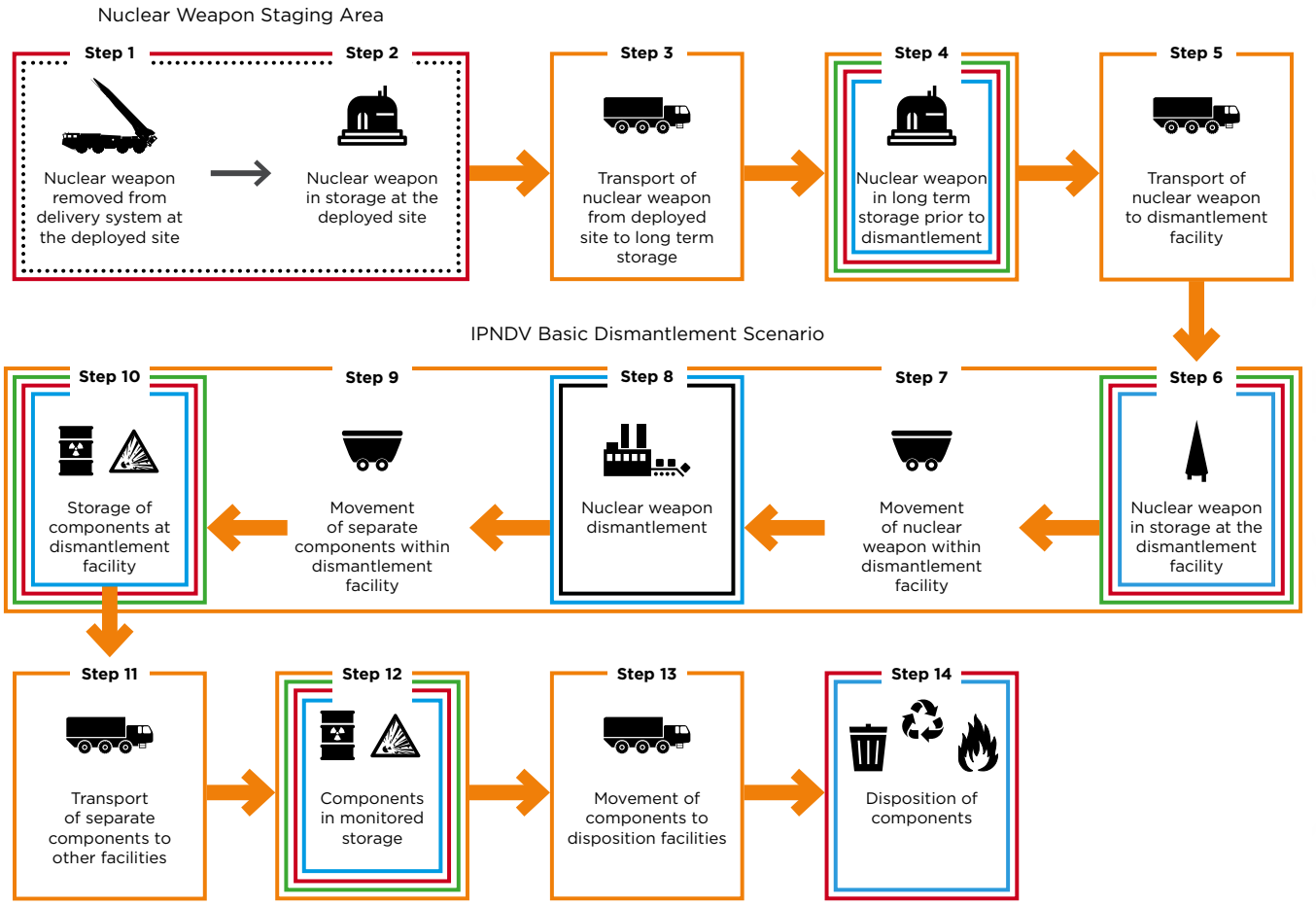
Moreover, the Partnership has emphasized and demonstrated collaboration among States with and without nuclear weapons. All have gained from the perspectives and unique insights of each other. This demonstrated collaboration in addressing challenges and finding solutions provides a model for continued and broader multilateral cooperation on nuclear disarmament issues.

The Partnership's 14-Step Analytic Framework for Dismantling Nuclear Weapons

In addressing verification challenges, the Partnership developed a 14-step analytic framework of dismantlement-related activities under a future nuclear disarmament agreement. Depicted in Figure 1, this framework entails a series of specific steps, with associated monitoring/inspection options. The Partnership also developed a set of principles for nuclear

Figure 2: Key Steps in the Dismantlement Process

Monitoring and Verification Activities, as Identified by the IPNDV, for Key Steps in the Process of Dismantling Nuclear Weapons



*We make the assumption that there will be declarations at each step in the process.

disarmament verification, including effectiveness, confidence-building, and non-proliferation.

Within this 14-step framework, the primary focus of Phase I was on the monitoring and inspection of nuclear weapon dismantlement (Steps 6–10 of Figure 2), or what the Partnership labeled the "Basic Dismantlement Scenario."

This scenario guided the Working Groups and was the basis of a one-day Walkthrough Exercise as Phase I drew toward its conclusion. In that Exercise, participants explored the application of technologies and procedures identified by the Working Groups to carry out the monitoring/inspection tasks needed to provide confidence that a nuclear weapon is dismantled as declared.

At the March 2017 meeting in Berlin, Ambassador Susanne Baumann, German Deputy Commissioner for Arms Control and Disarmament, participated in Working Group discussions.

In Phase I, the Partnership's decision to concentrate on the Basic Dismantlement Scenario and then build out the set of steps in the nuclear weapons dismantlement process was based on the recognition that verification of dismantlement of a nuclear weapon is one of the most important, complex, and technically challenging aspects of nuclear disarmament verification. Providing confidence that nuclear weapons have been dismantled as agreed is an essential task. Nuclear weapon dismantlement also clearly presents the issue of how an Inspected State can cooperate to build confidence that a nuclear weapon has been dismantled as declared and at the same time, continue to protect proliferation-sensitive and otherwise classified information as well as meet safety and security requirements related to handling and storing nuclear weapons.

The Partnership's Basic Dismantlement Scenario assumed that to protect proliferation-sensitive and other classified information, as well as for safety and security reasons, the nuclear weapon would be presented for inspection in a sealed container and that inspectors would not be able to observe directly the dismantlement of the nuclear weapon. For similar reasons, inspection activities, use of containment and surveillance to ensure the integrity of sites subject to inspection, and measurement techniques were sometimes limited. At the same time, the Partnership assumed that the Inspected State would comply fully and cooperatively with the provisions of the disarmament agreement and the requirements related to safety, security, and proliferation-sensitive information.

Key Judgment

Based on the Working Group results and the Walkthrough Exercise, the Partnership's key judgment is 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*

"Being a group from five continents, participants come from different backgrounds and bring different disarmament philosophies to the discussions. But all agree that effective verification is a key feature of any successful arms control agreement."

Ambassador Michael Biontino, Permanent Representative to the Conference on Disarmament, Federal Republic of Germany

safety, security, non-proliferation, and classification concerns in a future nuclear disarmament agreement. Several more specific conclusions support this key judgment that multilaterally monitored nuclear weapon dismantlement can be done.

As elaborated by Figure 3, there are established inspection technologies and procedures that could be applied to build confidence in the chain of custody of containerized nuclear weapons and their component Special Nuclear Material (SNM) and High Explosives (HE) throughout the core dismantlement process—from storage of a nuclear weapon at a dismantlement facility (Step 6) through its dismantlement (Step 8), to the temporary storage of separated SNM and HE components (Step 10). Their use would provide assurance against any diversion or tampering with the nuclear weapon and its components as the dismantlement process proceeds. However, some important safety, security, and classification issues also were identified that would affect the specific technologies and approaches used to ensure chain of custody.

Multiple technology options also were identified to permit measurement for the presence of SNM in sealed containers, both prior to and after dismantlement. Again, the purpose would be to build confidence that a nuclear weapon is being dismantled. Using information barriers was seen to be essential for SNM measurement in order to protect proliferation-sensitive and classified information. Regarding these information barriers, promising technologies and concepts exist, but more work is needed to turn those concepts into workable systems. For technical and safety reasons, greater confidence will be attainable in measurements to confirm the presence of plutonium than are attainable in measurements to confirm the presence of uranium in the nuclear weapon container. Technology options also were identified that would show that HE could be present in a nuclear weapon/HE container—but sensitivity is limited, and it is more challenging to confirm the presence of HE than to do so for SNM. Across all these technologies, the options so far identified still need to be validated in practical situations.

IPNDV participants have presented the Partnership's mission, goals, and progress at meetings around the world, including at a United Nations First Committee side event on nuclear disarmament verification in October 2017.

In turn, inspection technologies and procedures can be implemented to meet the requirement to ensure the integrity of those areas within a dismantlement facility associated with initial storage before dismantlement, actual weapon dismantlement, and temporary storage of SNM and HE components after dismantlement. The use of these technologies and procedures would need to comply with the limits set by safety and security, and the need to protect proliferation-sensitive and nationally sensitive information. But taken together, these technologies and procedures would be sufficient to provide confidence that a nuclear weapon/SNM and HE components are not removed or moved without being authorized or observed.

The analyses of the Working Groups as well as the results of the Walkthrough Exercise make clear that some residual verification uncertainties will be unavoidable in meeting the monitoring and inspection requirements at different points in the dismantlement process. The challenge is to manage and reduce those uncertainties at different steps in that process in order to provide assurance that a nuclear weapon has been dismantled. The verification of nuclear weapon dismantlement needs to be viewed as the result of many separate, mutually reinforcing, and cumulative activities over time. Used in an overall system, those activities can reduce uncertainties and provide meaningful confidence in the dismantlement process.

Prior negotiation and codification of procedures is key to lowering the risk of unplanned disclosure of sensitive information. The Partnership also identified and explored key activities on the part of an Inspected State that would need to be carried out to support the monitoring and inspection process. Examples include maintaining a system of Accounting and Control (including nuclear dismantlement activities); making an initial dismantlement declaration (including information necessary for monitoring/inspection); and developing specific facility agreements to cover areas within the facility subject to inspection (including procedures for managed access by inspectors).

Figure 3: Potential/Tasks and Options for Monitoring/Inspection of Nuclear Weapon Dismantlement

Step 6: Nuclear Weapon in Temporary Storage at Dismantlement Facility

Step 6a: Arrival

Monitoring/inspection tasks:*

- Confirm item declared is a nuclear weapon
- Apply chain of custody technologies/procedures during temporary storage and for onward inspection process
- Ensure integrity of storage area

Technologies/procedures options:

- Use of unique identifiers, tags, and seals on containerized nuclear weapon
- Checking Inspected State declarations, documentation, and records
- Inspections, containment and surveillance, portal monitoring technologies to verify design and ensure no unauthorized removal or tampering within the designated area

Step 6b: Initial measurement

Monitoring/inspection tasks:

- Confirm item is a nuclear weapon
  - Measure for presence of Special Nuclear Material (SNM) and of High Explosives (HE)
  - Other, complementary inspection activities

Technologies/procedures options:

- Multiple technology options—easier for plutonium than uranium; easier to detect presence of SNM than HE
- Use of information barrier essential to protect proliferation-sensitive/classified information
- Use of nuclear weapon "templates"
- Physical measurements of container
- Checking records/documentation

Step 7: Movement in Facility

Monitoring/inspection tasks:

- Sustain chain of custody

Technologies/procedures options:

- For security reasons, no visual observation by inspectors of actual transport of the nuclear weapons
- At this step, inspectors rely on chain of custody procedures applied in 6a, then rechecked at 8a

*** Inspected State Tasks-Dismantlement Assumptions and Definitions**

Inspected State would seek to demonstrate compliance within applicable safety, security, and non-proliferation requirements; ensure no proliferation-sensitive or classified information is revealed while providing other inspection-relevant information as provided for by an implementing agreement; facilitate Inspection Team activities in accordance with applicable agreements; and ensure the safety of personnel.

Assumptions: nuclear weapon/components presented for inspection in sealed containers; no direct observation of dismantlement by inspectors to avoid revealing weapon design information

Chain of custody: confidence that containerized nuclear weapon not diverted or tampered with at any step

Integrity of storage: confidence that containerized nuclear weapon/SNM or HE cannot leave area subject to inspection unobserved

Information barrier: technology to protect sensitive information while still providing "green light/red light" as to presence of inspection-relevant information

Nuclear weapon template: technical "snapshot" measuring specific characteristics/dimensions of the nuclear weapon

Step 8: Nuclear Weapon Dismantlement

Step 8a: Entry of nuclear weapon into dismantlement area	Step 8b: Exit from dismantlement area (after dismantlement)
Monitoring/inspection tasks: • Ensure unbroken chain of custody • Ensure integrity of dismantlement area so that nuclear weapon/SNM or HE cannot leave area unobserved	**Monitoring/inspection tasks:** • Ensure onward chain of custody of SNM/HE containers after exit • Measure SNM/HE containers exiting area to confirm SNM/HE • Confirm no remaining SNM/HE or weapon in dismantlement area—and no unauthorized removal • Other inspection activities
Technologies/procedures options: • Inspections, containment, and surveillance technologies to verify design and ensure no unauthorized removal or tampering with area • Portal monitoring of entry-exit to dismantlement area • Use of radiological/HE detection equipment to detect presence of SNM/HE in the dismantlement area	**Technologies/procedures options:** • Same as 6a (chain of custody, integrity of area) • SNM/HE—same as 6b but added techniques given nuclear weapon now dismantled • Portal monitoring of entry-exit • Re-inspect with radiological/HE detection equipment to ensure absence of any remaining SNM/HE in dismantlement area • Use of nuclear weapon "templates"

Step 9: Movement in Facility

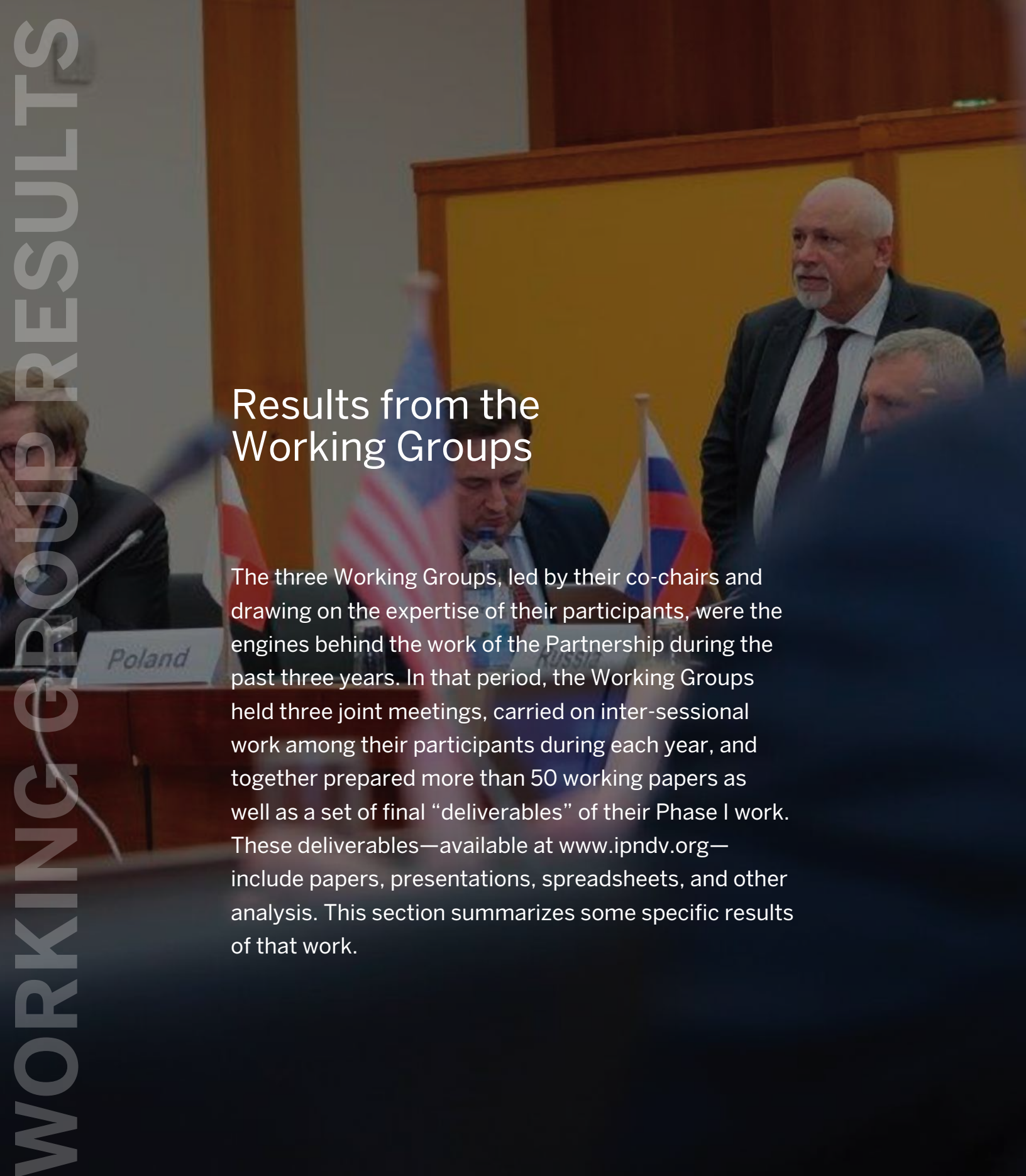
Monitoring/inspection tasks:
- Sustain chain of custody

Technologies/procedures options:
- For security reasons, no visual observation by inspectors of actual transport of the nuclear weapons
- At this step, inspectors rely on chain of custody procedures applied in 8b, then rechecked at 10

Step 10: Temporary Storage of Separated SNM/HE Containers and Longer-Term Monitoring

Monitoring/inspection tasks:
- Confirm unbroken chain of custody on exit from dismantlement area to temporary storage
- Ensure integrity of storage building with containerized SNM/HE
- Provide confidence SNM/HE remain in temporary storage until moved in accordance with agreement—periodic SNM/HE measurements

Technologies/procedures options:
- Same as 6a and 8b (chain of custody, integrity of area)
- Ad hoc/routine on-site inspections
- SNM/HE measurement same as 8b



Results from the Working Groups

The three Working Groups, led by their co-chairs and drawing on the expertise of their participants, were the engines behind the work of the Partnership during the past three years. In that period, the Working Groups held three joint meetings, carried on inter-sessional work among their participants during each year, and together prepared more than 50 working papers as well as a set of final "deliverables" of their Phase I work. These deliverables—available at www.ipndv.org—include papers, presentations, spreadsheets, and other analysis. This section summarizes some specific results of that work.

Credit: Ralph Alswang

The first IPNDV plenary was held in March 2015 and hosted by the United States. There, participants began to lay the framework for the first phase of the initiative.

Working Group 1: Monitoring and Verification Objectives

Verification efforts in the context of existing agreements have largely focused on delivery vehicles, not on the nuclear warheads themselves. To inform their work, the Partners were briefed on the efforts that previously have considered aspects of nuclear disarmament verification: the joint U.S.-UK technical collaboration on nuclear disarmament verification and the UK-Norway Initiative on Nuclear Warhead Dismantlement Verification. During a plenary meeting in Oslo, the Partners visited the site where many of the UK-Norway efforts took place. Working Group 1 also received a special briefing about the Trilateral Initiative between the United States, the Russian Federation, and the International Atomic Energy Agency (IAEA) that focused on the verification of weapon-origin plutonium stored in both countries. The Working Group also studied whether there are useful lessons to be drawn from verification organizations like the IAEA and the Organization for the Prohibition of Chemical Weapons (OPCW).

Problems and Challenges Addressed: Principles for Nuclear Disarmament Verification

To have a solid basis for its work, Working Group 1 drafted a set of principles to be applied to nuclear disarmament verification efforts. These principles of verification are:

- **Effectiveness:** Verification must provide parties to an agreement with sufficient confidence of the compliance by other parties to that agreement.
- **Confidence-building:** A verification mechanism should help build confidence in the viability of the underlying agreement.

- **Non-proliferation:** Verification must not lead to the transfer of proliferation sensitive knowledge.
- **Non-interference:** The level of interference of verification activities is moderated by national interests, notably those related to security and safety.
- **Efficiency:** Verification mechanisms must be cost/resource-effective.
- **Determinacy:** Verification must balance clarity, simplicity, and flexibility.
- **Structure:** The role and position of national authorities in the context of verification must be well-established and balanced.

Deliverable 1 elaborates upon these principles. The Working Group realized that these principles of verification are closely linked to the concepts of transparency and irreversibility and had a thorough discussion of both.

Early on, Working Group 1 also decided to examine the nuclear weapon lifecycle in its entirety. After some discussion, the Working Group concluded that dismantlement of nuclear weapons would lead to nuclear disarmament if it could be guaranteed that no production of nuclear weapons material was taking place.

Key Findings: Monitoring and Verification Objectives

What would it take to verify what happens in these steps? What are the objectives and the requirements during these steps? This is described in Deliverable 2, sumarized below:

- **Step 6: Nuclear weapon in storage at the dismantlement facility.** The objective in the dismantlement facility is to confirm that the nuclear weapon selected is indeed a nuclear weapon. This requires measurements—agreed upon beforehand—of indicators that can, indeed, confirm this within agreed parameters. In addition, inspectors also will seek to use means of identifying the item, e.g., with a unique identifier together with associated documentation.
- **Step 7: Movement of the nuclear weapon within the dismantlement facility.** The objective is to confirm that the nuclear weapon brought into the dedicated dismantlement area is the same as the one selected for inspection. This requires the means to verify the unique identifier.
- **Step 8: Nuclear weapon dismantlement.** Inspectors will not be able to observe the dismantlement itself, in order to avoid spreading proliferation-sensitive information. The objectives, then, are to ensure that nothing leaves the dedicated dismantlement area unobserved, to restore the chain of custody as soon as possible once the dismantlement has been completed, and to confirm that what leaves the dismantlement facility are the components of the nuclear weapon as declared and that no SNM or HE is left behind. This requires the means to make the necessary measurements and observations with regard to monitoring the perimeter

of the dedicated dismantlement area and with regard to the movement of components leaving the facility in sealed containers.

- **Step 9: Movement of separate components within the dismantlement facility.** The objective is to confirm that the components that left the dedicated dismantlement area are the same ones arriving in the temporary storage facility—in other words, to establish the chain of custody. This can be done by visual inspection or measurements.
- **Step 10: Storage of components at the dismantlement facility.** The objective is to ensure no movement of the containers takes place until they are moved for their final disposition. This includes periodic SNM and HE measurements as well as providing confidence that the SNM and HE remain in temporary storage until they are moved for their final disposition.

The Working Group agreed that in carrying out these steps, inspectors would need to take into account various constraints. Importantly, the lack of direct observation of the dismantlement of the nuclear weapon into its SNM and HE components means that complete certainty about the non-diversion of this material is not possible. The monitoring and verification process must therefore be an assessment of an amalgam of indirect observations that provide acceptable assurance that the nuclear weapon components have been accounted for as expected. In addition, Inspected States have responsibilities for adhering to legal and regulatory obligations regarding safety, security, and non-proliferation. These responsibilities pertain to personnel in the different facilities during inspections and to inspectors. Whether and how these responsibilities can be combined with credible inspections needs to be worked out. A tool kit of techniques and technologies will be required to meet the different challenges in each facility and during transportation.

Key Questions and Gaps Going Forward: Identifying Future Efforts and Skills/Gaps in Expertise

The Working Group also addressed two additional key questions: (1) "What would collaborative verification efforts require in the future?" and (2) "What skills and areas of expertise presently exist and where do gaps exist?"

Deliverable 3 makes a distinction between political expertise and technical expertise, and provides an overview of existing capacities, based on a questionnaire circulated to Partners. It will be necessary to build on institutional and technical capabilities for nuclear safeguards and national security, establish mechanisms for further collaboration, and form partnerships among States with and without nuclear weapons. It is important to start building a verification culture. Building such a culture and building capacity will take time, as demonstrated by the experience of developing safeguards and the verification of nuclear testing.

As part of the agenda for the November 2015 IPNDV plenary meeting, participants toured Norway's Institute for Energy Technology (IFE), which played a role in the UK-Norway Initiative.

Working Group 2: On-Site Inspections

Problems and Challenges Addressed: Inspection Activities and Techniques to Verify Compliance with Future Agreements

On-site inspections (OSI) will serve various functions in any mechanism to verify nuclear disarmament undertakings. Working Group 2 examined how OSI can work to provide assurance of the dismantlement of one or more nuclear weapons in two key respects. The first is to make measurements to confirm a State's declaration that a particular item is a nuclear weapon. The second is to confirm that SNM and HE from a declared nuclear weapon have been separated and placed in monitored storage. Assurance of the dismantlement of nuclear weapons as part of a disarmament agreement will require monitoring of steps beyond those discussed by Working Group 2.

Verification of nuclear weapon dismantlement can offer lessons for the design of other inspection processes.

Working Group 2 has benefited from prior work done by several States to develop concepts and potential techniques for inspectors to monitor the dismantlement of a nuclear weapon, as well as the relevant experience from arms control treaties, such as New START. That research and experience has focused mainly on verification under a bilateral agreement. The Working Group has considered how verification might work under a plurilateral or multilateral agreement. Although there may not be great differences between the kinds of technical measures that are useful for verification of bilateral and multilateral agreements, the design of inspection procedures and compliance assessment mechanisms will vary, and the Working

Group examined the differences. The group also examined the experiences and identified relevant lessons from other major arms control treaties.

Key Findings: The Challenge Protecting Sensitive Information

The extraordinary sensitivity surrounding access by inspectors to facilities where nuclear weapons and their components are present is the most substantial challenge for the design of inspection processes. The way in which inspections are conducted will need to ensure:

- The safety of all personnel during an inspection
- The safety of all items and equipment during an inspection
- That no proliferation-sensitive information is released to inspectors
- The protection of security-sensitive information

The design of almost every aspect of verification where nuclear weapons are present will need to find ways to achieve its objectives while respecting these precepts. Working Group 2 considered numerous approaches that could prove helpful in this respect.

Prior negotiation and codification of procedures for the conduct of inspections at each dismantlement facility is one way to lower the risk of unplanned disclosure to inspectors of sensitive information. A facility-specific agreement would be developed by the verification entity with the Inspected State. Managed access arrangements would be built into the terms of such an agreement.

At the same time, the provisions of a multilateral verification agreement would need to apply consistently among its parties. Common objectives and procedures for the conduct of inspections would be detailed in an inspection access protocol. The protocol would be agreed by all parties to the verification agreement as model guidance for the conduct of inspections. It would elaborate inspection goals to be achieved and options of inspection activities and measurement techniques that aim to avoid disclosure of proliferation-sensitive information to inspectors. The implementation of protocol requirements through each facility agreement would be approved by a treaty executive body.

Safety during inspections will be a concern of all participants. Although the operator of an inspected site will understand best what actions may or may not pose a risk for safety, the adoption of common safety standards among inspected sites, in consideration of already existing national safety norms and regulations, would help to manage the impact of safety on inspections.

Key Findings: Inspection Concepts for the Basic Dismantlement Scenario

Under a verification agreement, relevant States would declare items as nuclear weapons to be dismantled over a certain period. Declarations also would specify the facilities and sites where dismantlement would take place. Several locations would be specified for a dismantlement facility where different kinds of activities may take place.

At Norway's Institute for Energy Technology (IFE), IPNDV participants received a briefing on technologies related to information barriers and lessons from the UK-Norway partnership.

At a first location in the dismantlement facility, inspectors would make observations and conduct measurements with respect to verifiable attributes of a nuclear weapon. Measurements of radiation from a containerized nuclear weapon would aim to confirm that it contains at least a specified quantity of plutonium and/or highly enriched uranium. Other techniques may aim to compare radiation templates for a nuclear weapon and the nuclear material removed from it. The results from these intrusive measurements would be filtered through information barrier mechanisms to avoid disclosure of sensitive information. Other verifiable attributes of a declared nuclear weapon would be those related to the presence of HE and could include parameters such as a containerized nuclear weapon's mass and center of gravity, both of which are likely to be considered classified information.

The dedicated dismantlement area would be an enclosed space to which inspectors do not have access while a nuclear weapon is dismantled. Inspectors could nevertheless gain assurance that the declared nuclear weapon has been dismantled by conducting checks of the contents of the dedicated dismantlement area prior to and after its use. At another location, inspectors would make observations and measurements with respect to containers in which the SNM and HE components of the nuclear weapon are removed and placed in secure temporary storage. SNM and HE would be stored in separate containers.

Maintaining chain of custody with respect to each nuclear weapon and its components will be central to achieving inspection objectives. Containment and surveillance techniques similar to, but adapted from, those used in IAEA Safeguards and other existing verification regimes, could be applied. The design of containment and surveillance arrangements would be very site-specific because of differences in building design. The need to ensure that the security of nuclear weapons is in no way compromised will also present challenges.

The arrangements would need to be worked out through site visits before any dismantlement inspection takes place, then specified in a facility agreement. Inspection equipment will need to be of a design that does not risk the unplanned disclosure of sensitive information or the safety of personnel. Arrangements will also be needed so that each side in an inspection can trust that equipment will function as it should.

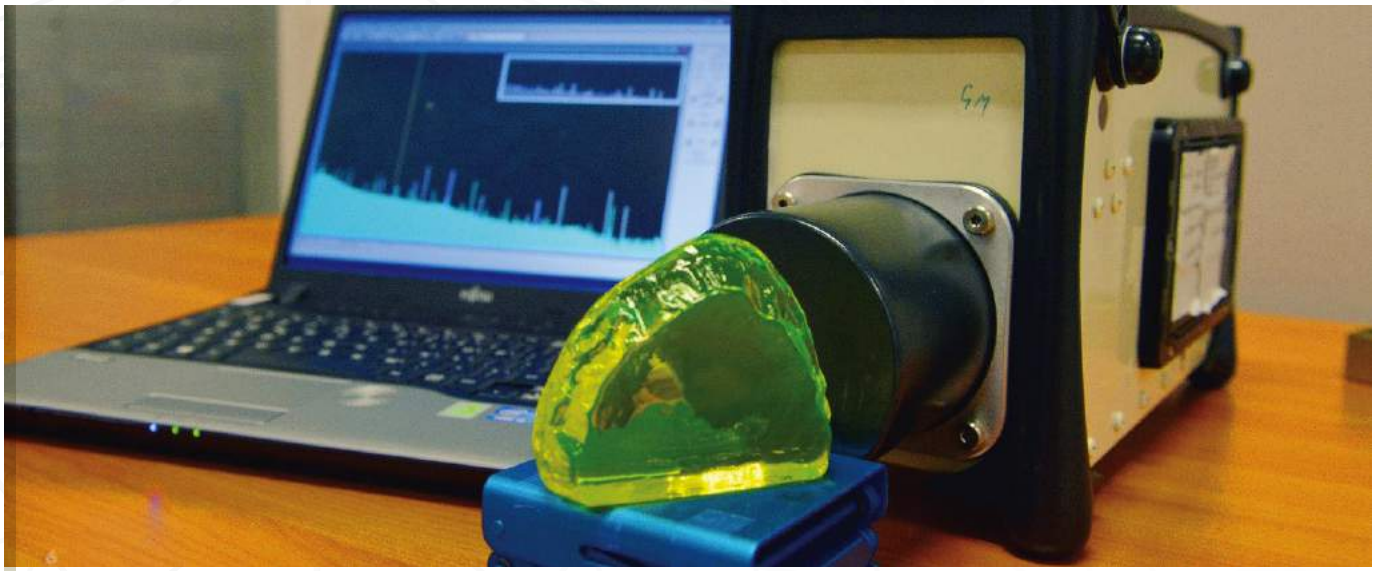
Using a pre-developed and agreed format, the inspectors and the Inspected State representatives would record what transpires during the course of the inspection. The totality, accuracy, and integrity of the inspection report must be such that it can serve as the basis for further review and discussion between the parties to a disarmament agreement and to help determine compliance.

Working Group 2 considered elements of a framework to support inspection of nuclear weapon dismantlement, including the technical capacity needed by a verification entity as well as the steps such an entity would take to prepare to conduct inspections. The selection, training, and designation of inspectors were also examined. Effective implementation of inspection procedures is also likely to require training for Inspected State escorts so that they can properly support the inspection process while protecting national interests.

Key Questions and Gaps Going Forward

Regarding future work, the ideas considered by Working Group 2 will need to be studied in greater depth to facilitate the development of practical OSI procedures and methods. The scope, role, and implementation of procedures to measure verifiable characteristics of a nuclear weapon and its relevant components remain at an early stage of development. The process through which inspection findings enable member States of a disarmament agreement to gain assurance of compliance by others will be an important topic for future work.

Inspections of the kind described here would offer only part of the assurance needed to be confident that a State has met its commitments under a disarmament agreement. The subsequent disposition of nuclear material, to ensure it is not available for use in nuclear weapons, would need to be verified also. In addition, knowledge of the relevant information and characteristics of a nuclear weapon that has been declared for dismantlement will add to assurance that it is, in fact, as declared. As well as confirming declared actions such as dismantlement of nuclear weapons, the verification of nuclear disarmament will also need to include "completeness" mechanisms through which States can gain assurance of the absence of undeclared activities, contrary to the terms of a disarmament agreement. These aspects of verification for nuclear disarmament should also be studied more widely by the IPNDV.



Credit: Dean Calma/IAEA

A gamma spectrometer is used to identify the presence of nuclear material.

Working Group 3: Technical Challenges and Solutions

Specific technologies and methods will be needed to support future nuclear arms control and disarmament initiatives. Nuclear weapon verification, and monitored dismantlement of nuclear weapons in particular, will require extensive collaboration and technology development and testing. Although significant contributions have already been made, this work has largely been conducted within a handful of States. Many issues remain unresolved, especially related to providing enough information regarding a nuclear weapon without providing proliferation-sensitive information to the Inspecting Party in violation of Article I of the Nuclear Non-Proliferation Treaty (NPT).

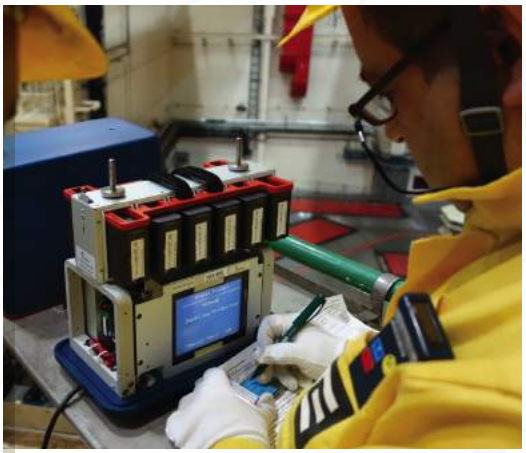
Problems and Challenges Addressed: Identifying Solutions for Key Technical Challenges

Working Group 3 sought to identify solutions for key technical challenges related to monitoring nuclear disarmament, particularly issues relating to nuclear warhead authentication:

- Is the item presented really a nuclear weapon?
- What are the methods for establishing and maintaining chain of custody of both items and facilities?
- Is the monitoring data genuine and is the equipment functioning as expected?

The Working Group's focus in Phase I was on the nuclear weapon dismantlement process and the monitored storage of SNM and HE immediately following the dismantlement process.

Working Group 3 began by surveying related research and initiatives undertaken to date. The Working Group received a series of presentations on previous key activities and lessons learned from the joint U.S.-UK technical cooperation on nuclear disarmament verification, UK-Norway Initiative, and from individual Partners. This allowed the Working Group to begin to understand the technical requirements and constraints for monitoring nuclear weapons and nuclear weapons dismantlement and to begin to understand various technologies available for the given Basic Dismantlement Scenario.



Credit: Petr Pavlicek/ IAEA

Inspectors will use surveillance technologies to monitor access to or movement within storage and dismantlement areas.

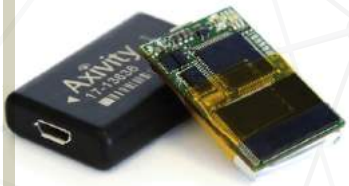
Key Findings: Applicable Technologies

The applicable technologies identified by the Working Group were divided into several categories:

- Technologies that can identify attributes of a nuclear weapon and provide confidence that the measurements taken of the item in the container are consistent with those of a nuclear weapon
- Technologies that can be used to detect SNM in a container after dismantlement
- Technologies that can be used to detect HE in a container after dismantlement
- Technologies that can be used to maintain the chain of custody of the items being monitored
- Technologies that can be used to maintain the chain of custody in the facilities and locations that are part of the nuclear weapon dismantlement and storage process

Within each category, key parameters and limitations for each technology were identified to allow differentiation between technologies and methods and to allow the selection of the technologies that best fit the requirements for the various steps of the monitoring scenario.

The group concluded that many of the technologies and methods currently used for nuclear safeguards are potentially applicable to monitoring nuclear weapons and their component SNM and HE materials throughout the dismantlement process. The issue with using many of these technologies "as is" is that much of the data obtained when used on a nuclear weapon would be proliferation-sensitive. Therefore, procedures and additional technical requirements are necessary to prevent such information from being transferred. In considering a particular technology, it is also important to consider the safety requirements necessary to ensure the equipment and methods used do not endanger the user, the facility, or the nuclear weapon.



Accelerometers can be used to verify the chain of custody of an object by recording its movement down to the micrometer.

Credit: Axivity

Credit: Sandor Tozser/IAEA

Inspectors will apply and check tags and seals on containers to verify chain of custody of the nuclear weapon and its components throughout the dismantlement process.

Inspectors may use a Trusted Radiation Identification System (TRIS) to confirm that the declared item for dismantlement is a nuclear weapon.

Key Questions and Gaps Going Forward: Areas for Technology Development or Re-Engineering

Based on the technology requirements for the Basic Dismantlement Scenario identified by the Working Group, there are several areas where technologies either need to be developed or re-engineered to be used specifically for this type of activity. The technologies and methodologies that need to be developed are:

- Detection methods for HE in a closed container using a method that is not a swipe sample or destructive to the container or contents
- Quantification methods for the threshold mass of HE in a closed container that may contain additional contents
- Passive measurement of uranium isotopics and threshold uranium mass in a closed container

Inspectors can use 3D laser scanners to map a room with distance measurements and detect changes in the configuration of a room.

Credit: Dean Calma/IAEA

The technologies and methodologies that need additional development or engineering are:

- Methods for detecting explosives in a room from a distance
- Development of additional nuclear weapons template methods beyond those currently existing
- Development of information barrier methods that can be used with a variety of monitoring methods
- Evaluation of potential nuclear weapon intrinsic signatures before and after dismantlement

Although 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 Path Forward

Phase I of the Partnership also identified several important nuclear disarmament verification areas and tasks for additional analysis. Taken together, they inform the roadmap of next steps for the Partnership.

"[T]he importance of verification in future nuclear disarmament efforts is largely unquestioned, and the collective capacity of nations to address verification issues is increasing…through cooperative efforts like the IPNDV…"

Ambassador Robert A. Wood, U.S. Permanent Representative to the Conference on Disarmament

Different types of *declarations as well as access by inspectors to documentation and records* will be an important complement to chain of custody procedures and technical measurements for building confidence in dismantlement. The Partnership has begun to explore specific types of information that would be valuable as part of a cumulative process of building confidence in nuclear weapon dismantlement. Additional analysis is needed of such information and of how to balance the benefits for inspectors with the constraints on Inspected States.

Important *data handling issues* were identified in Phase I and should be addressed further. Those issues range from how to handle written and electronic data derived from the monitoring/inspection process to defining an overall framework for the reporting process. The latter would include defining the parameters for inspectors' data analysis, rights of the Inspected State to review and comment on inspection findings and reports, and how to resolve disputes that might arise during an inspection.

The *scope, role, and implementation of procedures* to measure verifiable characteristics of a nuclear weapon and its relevant components remain at an early stage of development. In some areas, new technologies will need to be developed or existing technologies re-engineered. Detection of HE in a sealed container is a tough challenge and should be a focus of future technology development. Existing potentially applicable technologies now used for safeguards would need to be re-engineered for verification of nuclear weapon dismantlement, particularly to protect proliferation-sensitive information.

Specifically, measurement techniques to provide confidence in the presence of SNM or HE will provide a great deal of information about the containerized nuclear weapon, some of which could be classified and/or proliferation sensitive. For that reason, *the use of an information barrier* to protect classified and proliferation-sensitive information will be essential. Promising concepts and technologies have been identified, but more work is needed to turn those

concepts into workable information barrier systems that can be used with various monitoring methods and eventually tested.

Detailed investigation of the concept of *nuclear weapon templates* stands out as another challenge for future Partnership work. In theory, it should be technically possible to take, in effect, a "snapshot" of a nuclear weapon within its container by measuring specific aspects or characteristics. With an information barrier to protect classified information, the use of such a template could help build confidence in monitoring/inspection of nuclear weapon dismantlement. Although this concept is potentially attractive, in practice additional detailed work would be needed on template methods (including what would be measured and how), ultimate feasibility, strengths, limitations, and how such a template would be used.

Cutting across Phase I's identification of monitoring/inspection technologies and procedures to provide confidence in the dismantlement of a nuclear weapon, the task remains to *begin to test those technologies and procedures* that are promising or even virtually in hand but have not yet been applied in practice. Examples include containment and surveillance approaches to ensure the integrity of those areas within a dismantlement facility associated with dismantlement activities; use of information barriers to protect proliferation-sensitive information; design of unique identifiers, tags, and seals for nuclear weapons while meeting safety and security requirements; and OSI procedures in facilities that are also sometimes engaged in ongoing nuclear weapon-related work. Such testing could take the form of table-top exercises, technology demonstrations, simulated inspections, as well as exercises to test chain of custody techniques in mock facilities, and other means.

Finally, the Phase I focus on the steps involved in the dismantlement process of a nuclear weapon—one of the most complex and challenging elements of nuclear disarmament verification—set aside the other dismantlement steps reflected in Figure 2. Thus, another next step will be to draw on the insights of Phase I to begin to address the verification challenges that arise in these *other steps*, both prior to and following the dismantlement of a nuclear weapon. In turn, there may be insights into how monitoring/inspection activities in those earlier and later steps could reinforce confidence in verification in the steps of the Basic Dismantlement Scenario.

Credit: Ralph Alswang

Conclusion: Carrying Forward the Partnership's Record of Accomplishment

Phase I of the International Partnership for Nuclear Disarmament Verification has successfully advanced the goal of identifying critical gaps and technical challenges with monitoring and verifying nuclear disarmament—and identifying potential solutions to fill those gaps and meet those challenges. In so doing, it also has improved understanding and knowledge of the complexities of nuclear disarmament verification. The Partnership has benefitted greatly from collaboration among countries both with and without nuclear weapons, all of whom have gained insights from each other in their shared pursuit of the Partnership's overall goal.

"Canada is supporting work on the technical issues that will need to be addressed in order to establish a credible nuclear weapons disarmament regime. This includes engagement with the International Partnership for Nuclear Disarmament Verification…"

Andrew Leslie, Parliamentary Secretary to the Minister of Foreign Affairs, Canada

As Phase I concludes, the Partnership's work has identified a path forward that should make possible multilaterally monitored nuclear weapon dismantlement, while successfully managing safety, security, non-proliferation, and classification concerns in a future nuclear disarmament agreement. Technical challenges in the development of monitoring and inspection systems still remain to be worked out, tested, and resolved; the specifics of implementing OSI procedures remain to be detailed and tested. But this very judgment—the result not of bilateral cooperation but of international collaboration—is itself a major Partnership accomplishment.

Looking ahead to the start of Phase II, the Partnership will build on the results as well as the national capacities and expertise from Phase I. Phase II will continue the vital multilateral collaboration, which is a defining feature of the Partnership.

Confidence in verification will be essential to future nuclear disarmament. Assuring that confidence requires that the many dimensions of monitoring/inspection of nuclear disarmament be identified, understood, and addressed successfully. The accomplishments of the IPNDV bring us closer to meeting this challenge.

Appendix

On the following pages, find information about IPNDV participants, Phase I meetings, and the list of deliverables. Additional analysis and background also is available at www.ipndv.org

IPNDV Participants

The IPNDV, through a unique public-private partnership between the U.S. Department of State and NTI, brings together more than 25 countries, including States with and without nuclear weapons.

Representatives from the following have attended various activities of the Partnership: Argentina, Australia, Belgium, Brazil, Canada, Chile, China,* the European Union, Finland, France, Germany, Holy See, Indonesia, Italy, Japan, Jordan, Kazakhstan, Mexico, the Netherlands, Norway, the Philippines, Poland, Russian Federation,* South Korea, Sweden, Switzerland, Turkey, the United Arab Emirates, the United Kingdom, and the United States.

*Participated as observers.

U.S. Department of State

The U.S. Department of State's Arms Control, Verification and Compliance (AVC) Bureau leads efforts to assess the adequacy of monitoring and verification resources in prospective and existing nuclear arms control and disarmament agreements and commitments, as well as promotes the identification, development, and implementation of verification technologies.

Nuclear Threat Initiative (NTI)

NTI is a non-profit and non-governmental organization that works to prevent catastrophic attacks with weapons of mass destruction and disruption (WMDD)—nuclear, biological, radiological, chemical, and cyber. For more information, visit www.nti.org.

IPNDV Meetings

Plenary Sessions

Buenos Aires, Argentina
Host: Republic of Argentina
November 29–December 1, 2017

Abu Dhabi, United Arab Emirates (UAE)
Host: UAE
November 1–3, 2016

Tokyo, Japan
Host: Japan
June 28–30, 2016

Oslo, Norway
Host: Kingdom of Norway
November 16–18, 2015

Washington, D.C., United States of America (USA)
Host: USA
March 19–20, 2015

Joint Working Group Meetings

Geneva, Switzerland
Host: USA
June 27–30, 2017

Berlin, Germany
Host: Federal Republic of Germany
March 7–9, 2017

Geneva, Switzerland
Host: USA
February 18–19, and 22–23, 2016

Working Group Deliverables

These materials, as well as a range of additional resources, are available at www.ipndv.org.

Working Group 1: Monitoring and Verification Objectives

Co-chaired by the Netherlands and the United Kingdom

Deliverable One

A framework document with terms and definitions, principles, and good practices, and a broad flowchart showing possible monitoring and verification activities for key disarmament steps across the nuclear weapons lifecycle.

Deliverable Two

A detailed assessment of potential monitoring and verification requirements for monitoring the dismantlement of nuclear warheads, including what information might be needed to satisfy those requirements, and an assessment of the kind of assurance that States would likely seek from verification.

Deliverable Three

A capacity mapping document that outlines existing skills and areas of expertise applicable to key monitoring and verification activities, and identifies possible gaps; and a needs and planning document to fill gaps and identify priorities for future collaborative efforts.

Working Group 2: On-Site Inspections

Co-chaired by Australia and Poland

The following three deliverables were produced in a single document entitled, "2016–2017 Working Group 2 Output Report: Inspection Activities and Techniques."

Deliverable Four

A document outlining the key elements of OSI for verification of nuclear disarmament undertakings, potential new inspection activities and techniques that could effectively verify compliance with future agreements as well as options for managed access and their applicability at different types of facilities and sites.

Deliverable Five

A "best practices" document that highlights skills, training requirements, and lessons learned from inspectors and facility operators who have OSI experience in diverse environments as well as objectives and a broad outline for an inspector training course that would serve as a basis of future capacity building.

Deliverable Six

Proposed approaches and topics for future development of OSI for verification of nuclear disarmament.

Working Group 3: Technical Challenges and Solutions

Co-chaired by Sweden and the United States

Deliverables Eight, Nine, and Ten are incorporated into two comprehensive technology matrices.

Deliverable Seven

A series of presentations, workshops, or seminars on key activities and lessons learned from the joint U.S.-UK technical collaboration on nuclear disarmament verification, the UK-Norway Initiative, and other relevant activities.

Deliverable Eight

An assessment of existing approaches for warhead authentication, including the systems that support attribute measurements and templates and an outline of other techniques that could increase confidence that something is, in fact, a nuclear warhead.

Deliverable Nine

The development of a chain of custody paper, presentation, or demonstration involving unique identification and tamper-indicating devices in a specific environment, such as a mock warhead storage area.

Deliverable Ten

A mapping of existing and potential technical capabilities necessary to enable monitoring and verification at different stages of a nuclear weapon dismantlement process, and the level of confidence the technology brings to monitoring the dismantlement process, with a list that identifies capability gaps and weaknesses to inform future research.

International Partnership for **Nuclear Disarmament Verification**

The International Partnership for Nuclear Disarmament Verification (IPNDV) is an ongoing initiative that includes more than 25 countries with and without nuclear weapons. Together, the Partners are identifying challenges associated with nuclear disarmament verification, and developing potential procedures and technologies to address those challenges.

Goals

The IPNDV is working to identify critical gaps and technical challenges associated with monitoring and verifying nuclear disarmament. To do this, the Partnership assesses monitoring and verification issues across the nuclear weapon lifecycle.

The IPNDV is also building and diversifying international capacity and expertise on nuclear disarmament monitoring and verification. Through the Partnership, more countries will understand the process, as well as the significant technical and procedural challenges that must be overcome. At the same time, the Partnership is highlighting the importance of verification in future reductions of nuclear weapons.

For more information, **visit www.ipndv.org**.

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