NTI
BUILDING A SAFER WORLD

Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks

Verifying Baseline Declarations of Nuclear Warheads and Materials

PART OF THE *Cultivating Confidence Verification Series*

About the Verification Pilot Project

The Verification Pilot Project of the Nuclear Threat Initiative (NTI) convened technical and policy experts from around the world to develop recommendations for new approaches to verification that could enable future progress on arms reductions. As the two-year project moved forward, it became clear that innovating verification could also prompt near-term progress on non-proliferation and nuclear security.

NTI partnered with senior leaders from the U.S. Departments of Defense, Energy, and State as well as the governments of Norway, Sweden, and the United Kingdom. That dialogue identified the key challenges that became the subjects of the project's three expert working groups, which included more than 40 technical and policy experts from a dozen countries. *Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks* includes an overview and reports from the three working groups:

- The ***Innovating Verification Overview*** includes a foreword by Sam Nunn, NTI's chief executive officer and co-chairman, and key project findings and recommendations across report topics.
- ***Verifying Baseline Declarations of Nuclear Warheads and Materials*** analyzes how baseline declarations can contribute to near- and long-term arms control and non-proliferation goals and how to verify them without compromising sensitive information.
- ***Redefining Societal Verification*** explores how advances in information technologies, big data, social media analytics, and commercial satellite imagery can supplement existing verification efforts by governments and increase contributions from outside experts.
- ***Building Global Capacity*** considers the value of expanded international participation in the verification of nuclear arms reductions and how this participation can increase confidence in nuclear threat reduction efforts among all states.

The project builds on *Cultivating Confidence: Verification, Monitoring, and Enforcement for a World Free of Nuclear Weapons* (Nuclear Threat Initiative, 2010), which outlined key issues that states need to address to ensure that nuclear weapons reductions can proceed in a safe and transparent manner.

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July 2014

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Corey Hinderstein
Vice President, International Program

Andrew Newman
Senior Program Officer, International Program

Kelsey Hartigan
Program Officer, International Program

Contributors

VERIFYING BASELINE DECLARATIONS OF NUCLEAR WARHEADS AND MATERIALS WORKING GROUP

Chair, Nuclear Materials Subgroup: John Carlson
Counselor
Nuclear Threat Initiative
Formerly with the Australian Safeguards and Non-Proliferation Office

Chair, Warhead Subgroup: James Fuller, Ph.D.
Independent Consultant
Formerly with Pacific Northwest National Laboratory

NTI Program Lead: Kelsey Hartigan
Program Officer, International Program
Nuclear Threat Initiative

Warhead Subgroup

Mona Dreicer, Ph.D.
Deputy Director, Center for Global Security Research
Lawrence Livermore National Laboratory

Leesa Duckworth
Non-Proliferation Program Specialist
Pacific Northwest National Laboratory
Formerly with the Pantex Plant

Malte Göttsche
Research Associate, Carl Friedrich von Weizsäcker Centre for Science and Peace Research
University of Hamburg

Corey Hinderstein
Vice President, International Program
Nuclear Threat Initiative

Steinar Høibråten, Ph.D.
Chief Scientist
Norwegian Defence Research Establishment

David Keir, Ph.D.
Programme Director, Verification and Monitoring
The Verification, Research, Training, and Information Centre
Formerly with the U.K. Atomic Weapons Establishment

D. Burgess Laird
Senior Analyst
Institute for Defense Analysis

Martin Williamson, Ph.D.
Technical Advisor, Office of Nuclear Verification
National Nuclear Security Administration
On temporary assignment from the Y-12 National Security Complex

Nuclear Materials Subgroup

Matthew Bunn, Ph.D.
Professor of Practice
Harvard Kennedy School
Co-Principal Investigator
Managing the Atom Project

Anatoli Diakov, Ph.D.
Researcher
Center for Arms Control, Energy and Environmental Studies, Russia

Corey Hinderstein
Vice President, International Program
Nuclear Threat Initiative

Ramamurti Rajaraman, Ph.D.
Emeritus Professor of Physics
Jawaharlal Nehru University, India
Co-Chairman
International Panel on Fissile Materials

Therese Renis
Section Head, Division of Concepts and Planning, Department of Safeguards
International Atomic Energy Agency

Elise Rowan
Communications Officer
Nuclear Threat Initiative

Jonas Siegel
Project Manager and Outreach Director
Center for International and Security Studies at Maryland

Morag Smith, Ph.D.
Program Manager
Los Alamos National Laboratory

Lars van Dassen
Head, Office for International Relations
Swedish Radiation Safety Authority

Thomas Wood
Senior Program Manager for Non-Proliferation Policy
Pacific Northwest National Laboratory

Members of the Nuclear Threat Initiative's Verification Pilot Project endorse the general tenor of this report but were not asked to support each individual finding and recommendation. The views expressed in this report do not reflect those of the institutions with which the working group members are associated; their affiliations are listed for the purpose of identification only.

1. Executive Summary

As states move to lower numbers of nuclear weapons and need the ability to detect and monitor smaller items and quantities of nuclear material, verification will become a more complex challenge. The full lifecycle—from material inventories, warhead assembly, and deployment to storage, dismantlement, and disposition—will eventually have to be monitored and verified, a task that will be extremely difficult if inspectors do not have detailed records of a state's total warhead and weapons-usable material inventory. Such records will take time to develop, and there are currently no agreed on mechanisms for recording, sharing, or verifying this information. Verifiable baseline declarations will be essential to filling this gap.

In 2012, the Nuclear Threat Initiative (NTI) charged a group of nearly 20 technical and policy experts with examining the issues and methods associated with verifying baseline declarations of nuclear warheads and weapons-usable materials. As part of NTI's Verification Pilot Project, the working group on verifying baseline declarations was divided into two subgroups. One analyzed warheads. The other studied nuclear materials.

The working group spent considerable time discussing what information a state might be required to declare up front and what exactly would constitute a baseline declaration. For this report, a baseline declaration is defined as an initial statement of the number or quantity of accountable items or materials—perhaps specified by parameters such as type or category—against which other information may be compared and future progress may be measured. Because the content, timing, and verification of an agreement that requires a baseline declaration would depend on which states were involved and how those states perceived the security environment, the working group did not try to prejudge the specific structure of future agreements and focused instead on arrangements that might be verified effectively.

VERIFIABLE BASELINE DECLARATIONS

A viable baseline declaration process could require states to declare the total sizes of their warhead and weapons-usable material inventories. Initially, this could be done in aggregate and be as simple as each state declaring three top-level numbers: the total inventories of warheads, highly enriched uranium (HEU), and separated plutonium. But because over time other states will need more confidence that these declarations are correct and complete, more detailed information would likely be required and subsequently corroborated by verification arrangements.

An agreement that requires a full inventory declaration, detailed accounts of items and material, and stringent verification protocols would be most effective. But if states prove reluctant, alternative arrangements could offer a path forward.

An agreement that at the outset requires a full inventory declaration, detailed accounts of items and material by type or use, and stringent verification protocols would be most effective. But if states prove reluctant to declare and verify this information in the near term, alternative arrangements could offer a path forward. More narrow verifiable baseline declarations could be a useful stepping stone for states that have not previously participated in arms control agreements and have limited experience with verification activities. For example, an agreement might only require the declaration and verification of a specific category of weapons, such as deployed or non-deployed warheads, or a subsection of a state's weapons-usable material holdings, such as plutonium recovered through dismantlement of retired warheads. For states relatively new to the process, this could provide a foundation on which to build future verification efforts. Even if verifiable baseline declarations were not paired with an agreement to reduce warhead or material inventories, the process could strengthen confidence in advance of a negotiation and facilitate reciprocal reductions.

Informal declarations—those that occur outside the scope of formal agreements and are not verified—have some value in promoting transparency and confidence. This concept is not new. Some states have already informally declared detailed information about their weapon stockpiles and material holdings. The United States, France, and the United Kingdom have unilaterally declared the sizes of their nuclear arsenals.* These measures can help establish data consistency over time. But formal baseline declarations—established cooperatively and including detailed verification provisions—would promote a much greater sense of security and stability and provide far better assurances for non–nuclear weapon states (NNWS).

* See Appendix B.

VERIFYING WARHEAD DECLARATIONS

Accurate verification of warhead inventories is pivotal to any significant arms reduction process. Warhead verification will be challenging. There are three overarching requirements:

1. Authenticating that an item declared to be a warhead or warhead component is actually that.
2. Uniquely identifying each inventory item so that it is never counted twice or substituted with a fake and can be tracked within a high-security environment.
3. Maintaining continuity of knowledge throughout the process so that items can be monitored until they are removed from a state's inventory through final and irreversible dismantlement.

Where nuclear warheads are present, there will always be a fundamental tension between intrusive verification activities and stringent physical security, information security, and safety requirements. Given these constraints, this report outlines several issues and opportunities for verifying future warhead declarations. Several recommendations also are included for how parties might cooperate during future inspections and establish multilateral technical engagements that can lay the groundwork for future action.

VERIFYING WEAPONS-USABLE NUCLEAR MATERIAL DECLARATIONS

Over the long term, if states are to have confidence that future arms reductions are not negated by the production of additional warheads, it will be essential that all weapons-usable nuclear material be accounted for, tracked, and continuously verified. At the outset, the most effective declarations of weapons-usable nuclear material will include an aggregate total of a state's HEU and separated plutonium inventories, with as much detail as possible about the aggregate quantity of material in specific categories and uses. Given the political and technical challenges of accomplishing this, this report includes a sample form to guide states in preparing for future declarations and focuses on national preparatory work that can facilitate more robust declarations. A particularly significant undertaking is nuclear archeology—that is, validating plutonium and HEU production and preserving the materials, facilities, and records needed to clarify historical production, uses, and losses of nuclear materials.

MULTILATERAL TECHNICAL ENGAGEMENT

A number of the basic methods needed for more complex verification tasks exist today, though further technical development is also required. For example, no inspecting party has been able to authenticate a measurement system with a built-in information barrier—a system of procedures, devices, or software used to protect sensitive information—after it has been used to examine a classified item. In addition, states have not yet developed detailed verification provisions for material in sensitive forms, such as in warheads or naval propulsion programs.

Perhaps a greater challenge is that there is an uneven playing field. The United States and Russia have extensive verification experience, and important work has been done with the International Atomic Energy Agency (IAEA) and between the United Kingdom and Norway. There is, however, a more general need to build international capacity and revitalize multilateral exchanges on the tools and methods required for future verification scenarios. While states have to ensure that sensitive information is not compromised, expanded participation in future verification activities could have concrete benefits. Because both nuclear weapon states (NWS) and NNWS have an interest in all parties living up to the commitments made under the Non-Proliferation Treaty (NPT), the declaration and verification of warhead or material baselines could provide a useful platform for evaluating these commitments. Involving NNWS could strengthen trust and cooperation and help create a common understanding of challenges and constraints that nuclear warhead environments impose.

International scientific cooperation has helped address technical obstacles, promote common understanding of verification challenges, and inform policymakers of new and developing technical capabilities that could support the verification of new agreements. The former U.S.-Russia Warhead Safety and Security Exchange and other scientific cooperation arrangements, such as the U.S.-Russia-IAEA Trilateral Initiative and U.K.-Norway Initiative, engaged experts from different states to work on difficult hypothetical verification problems. Such activities can lead to common verification tools, acceptance of new verification mechanisms, and ultimately, progress on stalled policy priorities.

ESTABLISHING THE ABSENCE OF UNDECLARED WARHEADS AND MATERIALS

While the details of declarations and verification protocols are subject to negotiation, any agreement—particularly agreements that accompany deep reductions—will require states to confirm that other states are not withholding a cache of warheads or materials from a declaration or conducting illicit activities at secret locations. To address this issue, states have largely relied on intelligence information, sometimes combined with rights to some form of challenge inspection. Nuclear warheads and small quantities of weapons-usable nuclear material—which likely would be the subject of future agreements—are much more difficult to find than long-range ballistic missiles, bombers, or submarines.

In the future, the technical measures discussed in this report can provide detailed information to support compliance determinations, but these tools and methods alone will not be enough. Given the substantial challenges and potential consequences of undeclared items, facilities, and materials, it will be important to integrate information from a variety of sources, including state declarations, other treaties or agreements, intelligence information, the activities of inspectors, and open-source information from journal articles, memoirs, satellite imagery, and traditional and social media. Over time, this integrated information can strengthen confidence that states are living up to their commitments, but it will be a long and difficult process. All stakeholders should prioritize the development and strengthening of verification resources and methods and use baseline declarations as a platform for capacity and confidence building.

WORKING GROUP RECOMMENDATIONS

The full working group put forward the following recommendations as priorities for governments to address the challenges of verifying nuclear warhead and weapons-usable nuclear material declarations. Perhaps most important, the group concluded that all parties—states with nuclear weapons, states without nuclear weapons, and international organizations—can and should play a role in future verification and monitoring activities.

International scientific cooperation can lead to common verification tools, acceptance of new verification mechanisms, and ultimately, progress on stalled policy priorities.

The working group recommends that stakeholders:

- **Expand multilateral technical engagements.** Multilateral engagement on cooperative inspection methods, equipment, and activities should be expanded and prioritized. It can take years to qualify tools for inspections. States that have collaborated in developing and testing specific methods for high-security authentication, unique identification, and continuity of knowledge become intimately familiar with their design and application. Such familiarity can foster cooperation and may make states more likely to include these systems in future agreements. Outside experts and rising specialists from states without extensive verification experience should also be encouraged to participate. Including NNWS experts can strengthen international confidence in the integrity of verification systems and arrangements. Priority should be given to approaches that enable such participation without compromising sensitive information. Future collaboration should also take into account relevant safety and security qualification standards so that new methods and equipment comply with multiple national standards.

- **Prioritize verification research and dialogue.** Collaboration on verification methods and techniques should be complemented by a sustained dialogue among international experts on practical and technical approaches to baseline declarations and verification arrangements. Such a process would be most effective if it were conducted at the government level, with participation from other experts. Topics for engagement could include:
  - Declaration content and format
  - What information states are prepared to make public, exchange with other states confidentially, or share with particular states
  - What information should be preserved through nuclear archeology programs to facilitate future verification, such as historical information on material flows and facility information
  - What is needed for effective verification, what existing measures can achieve, what complementary regimes and activities can contribute, what obstacles may arise, and what areas require further development
  - Who would verify baseline declarations, what areas might be priorities for verification, and how verification could be phased in to address these top priorities
  - How an integrated system for verification and evaluation could be developed, and how states can mitigate the risks posed by the retention or clandestine production of warheads or materials.
- **Review national classification standards and information.** For future verification systems to be as effective as possible, parties will need to deal with differences in national classification standards. This should begin with each state reviewing internally what it currently considers classified information, and whether certain information can be declassified or shared in some form with other governments in the context of deep reduction and verification requirements. The process should involve information security experts and verification specialists to better understand the benefits and risks involved and assess how to manage them. The careful sharing of classified information can simplify verification procedures, make technical methods easier to implement, and give states more confidence in the results.

SUBGROUP RECOMMENDATIONS

In addition to the recommendations of the full working group, each subgroup also outlined specific recommendations for states, international organizations, and outside experts to address unique challenges in verifying warhead and nuclear material declarations.

Warhead Subgroup Recommendations

- **Prioritize joint research on authenticating information barriers.** The United States, Russia, the United Kingdom, and others have had limited but important success in developing and demonstrating measurement systems with integrated information barriers that protect sensitive information. Verification measurements on classified warhead items or materials have been made in the presence of foreign specialists without releasing classified information. However, to date, it has not proved possible for these foreign specialists to authenticate the inspection system. For the host state to protect classified measurement results and at the same time allow an inspecting party to confirm that the equipment works as advertised, significant additional research and testing is needed. Creative solutions and suggestions for improvement should be solicited from information technology experts and could be crowdsourced as well.

- **Initiate an international technical assessment on warhead containers.** The ability to accurately measure a containerized warhead or component, without revealing sensitive information, is essential. The design and configuration of storage containers may vary dramatically depending on the container's purpose and intended contents, adding additional complexities to potential verification efforts. A container study would give states a better understanding of container effects and help determine if standardized containers or standardized container design principles could simplify the confirmation process. Because some containers' internal configurations might be sensitive, modeling may be needed in certain cases.

- **Designate standalone verification facilities.** Verification activities at existing nuclear weapons facilities impose major security and safety burdens on those facilities and may prevent normal operations for a substantial amount of time. The facilities were never designed to host foreign inspectors. Extensive efforts must be made to protect nuclear weapons design information and other sensitive information, and some health and safety concerns may make it impossible for inspectors to carry out some tasks they deem necessary. Standalone facilities designed and built for verification activities would eliminate the disruption of normal operations at active nuclear weapons facilities. Special facilities could also be used during a dismantlement process, where verification would likely constitute an even higher burden on operational facilities. Prospective treaty partners or other international parties should be encouraged to participate in the design process and observe and verify the construction of any standalone facility to counter possible accusations of built-in opportunities for cheating.

- **Strengthen independent peer review and vulnerability assessments on ongoing research and development efforts.** As promising technologies advance through the development process, programs need to involve additional independent, scientific certification and vulnerability assessment teams. A more extensive peer-review process would bolster research and development (R&D) outcomes and acceptance, as would the detailed publication of research results.

- **Launch a joint study on the applicability of IAEA technologies for warhead environments.** IAEA measurement techniques and containment and surveillance instruments should be studied and tested for use in a warhead environment. Currently, the IAEA employs a wide variety of safeguards tools and techniques, including tags, seals, unattended monitoring, and environmental sampling. An international team of experts should explore whether or not these technologies would be useful for verification and could be used in a warhead environment.

- **Discuss warhead environments and safety and security requirements as a part of the P-5 dialogue on verification.** The P-5 states (China, France, Russia, the United Kingdom, and the United States) need to discuss and share information about the general nature of the safety and security concerns and procedures that characterize their respective weapons environments and which would bound the activities allowable in a baseline verification process. This information could be sensitive and might therefore be shared only among P-5 states—at least in the early stages of such a dialogue. The information sharing would constitute a type of confidence-building measure that would help strengthen the basis for multilateral arms control in the future.

Materials Subgroup Recommendations

- **Preserve national records and collect oral histories from retired personnel.** To facilitate future baseline declarations and enable verification of those declarations, a top priority should be to preserve current and historical information on the production and disposition of weapons-usable nuclear materials, including physical and digital records. Where records are incomplete or inconclusive, questions should be clarified with personnel familiar with the operations concerned. Because some nuclear programs have been running for decades, these individuals are aging and may be nearing retirement or even deceased. This process should begin immediately, while personnel who can clarify details of historical operations are still available to recount oral histories.

- **Pursue joint R&D on nuclear archeology methods.** Funding and expertise for collaborative R&D of nuclear archeology methods for different reactor types and uranium enrichment technologies should be prioritized. Methods for graphite-moderated plutonium production reactors are well established, but further work is needed to develop approaches for heavy water reactors as well as gaseous diffusion and centrifuge enrichment plants.

- **Preserve physical facilities, where possible, to permit future verification activities.** U.S. plutonium production reactors at Hanford are temporarily preserved in an environmentally sound manner within newly built enclosures, making future studies on their graphite cores possible. Physical facilities should be preserved in a similar manner elsewhere. In most cases, such preservation will be compatible with verifiable facility deactivation and may also be the most cost-effective course of action.

- **Take and preserve measurements and samples before dismantling or disposing of facilities or waste.** Where dismantling facilities or disposing of relevant waste products is planned, measurements and samples should also be taken and preserved to make sure future verification efforts are possible and credible. Experts from other states or multilateral entities could also be asked to take measurements at facilities or validate quantities and characteristics of materials. Where anomalies exist, other experts could be brought in as a confidence-building or transparency measure to reconstruct missing information.

- **Lead nuclear archeology demonstrations.** The United States and Russia should collaborate to demonstrate to other interested states the current capabilities and limits of the graphite isotopic-ratio method (GIRM), a nuclear archeology technique for calculating plutonium production that relies on measuring the isotopic ratio for impurities in graphite from graphite-moderated reactors. Demonstrations at one U.S. reactor and one Russian reactor could be a precursor to international technical collaboration to improve existing nuclear archeology methods and develop new approaches for other types of reactors.

- **Develop verification approaches for naval fuel.** Due to national security and proprietary concerns, HEU in the naval sector is a particularly vexing verification challenge. States that use HEU in naval fuel should establish a cooperative dialogue to develop verification approaches to confirm, without compromising sensitive information, that none of the material designated for naval use is being used to produce warheads, in violation of agreements.

- **Share best practices.** Some states have valuable experience that, if shared, could enable other states to make unilateral declarations, reduce barriers to formal baseline declaration arrangements, and move the development of verification methods forward. U.S. and U.K. experts should engage with their counterparts in other states with nuclear weapons to share their experience in assembling information on their historic plutonium and HEU production and use. This would enable states to implement best practices and establish their own inventory histories for unilateral declarations and future baseline declarations and verification. It would also be helpful if South Africa were prepared to develop a report on its experience of having the equivalent of a baseline declaration verified and if the IAEA, in consultation with South Africa, reported on its perspective on the lessons from the South African experience.

- **Make informal declarations on holdings of weapons-usable materials.** Voluntary and informal declarations of weapons-usable material holdings, unilaterally or in collaboration with other states, can be done without having to wait for formal agreements. These measures are of significant value in helping to establish data consistency over time. Some states have made informal declarations already. The more detailed the declarations are, the greater their potential value to transparency and confidence building.

- **Transfer weapons-usable materials that are excess to military requirements to civil programs under IAEA safeguards.** Where weapons-usable materials have been sanitized and are excess to military requirements, as with materials released through warhead dismantlement or stocks that are no longer needed, the material should be either verifiably disposed of and rendered practicably irrecoverable or transferred to civil programs and placed under IAEA safeguards. A longer-term objective should be for the IAEA to apply active safeguards to all weapons-usable materials in civil programs in all states. A study is needed on the funding and resources that would be required for the IAEA to do this.

2. Introduction

At a time when the path for future arms reductions is unclear, the Nuclear Threat Initiative's Verification Pilot Project was designed to lay the technical and policy groundwork for future progress and government action on near-term and long-term arms control and non-proliferation challenges. In the current security environment—poor U.S.-Russian relations, tensions on the Korean Peninsula, questions about how a more assertive China could tilt the balance in the Asia Pacific, ongoing hostility between Pakistan and India, a continued focus on Iran's nuclear program, and a persistent threat from non-state actors—there are serious questions about how states can best reduce nuclear dangers and have confidence that all parties are doing their part.

As states contemplate arsenal reductions and each warhead becomes marginally more significant, geopolitical tensions and mistrust could stall further action if there is insufficient confidence in the ability to monitor and detect smaller items and quantities of nuclear material. Eventually, insight into the full scope of a state's nuclear weapons program and the verification of nuclear warheads and weapons-usable nuclear materials will be essential. Otherwise, there will be no assurance that warheads withdrawn from service and dismantled are not simply replaced or that the overall number of warheads does not increase.

Verifying future nuclear reductions will be complex and challenging. All warheads, not only delivery vehicles, will eventually need to be counted and verified—a metric inspectors have not used in past agreements.* Non-strategic nuclear forces will need to be accounted for and verified, a difficult challenge given that states with large non-strategic arsenals cannot agree on what exactly constitutes a non-strategic warhead. Warheads held in containers in storage facilities will also need to be monitored and accounted for.

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* The exception to this is the New Strategic Arms Reduction Treaty (New START). Certain provisions allow for the counting of deployed warheads on randomly selected delivery vehicles.

Weapons-usable nuclear material will need to be continuously monitored and verified, a fundamentally different task from simply counting items. Figure 1 provides a graphic representation of the nuclear weapons and military materials lifecycle.

The scope of these challenges underscores the role that verification can play in fostering international cooperation and strengthening states' abilities to reduce nuclear dangers safely and securely. States are unlikely to have sufficient confidence in near-term or long-term arsenal reductions without evidence that the declared numbers of warheads and materials are correct and that there are no additional undeclared weapons or weapons-usable material.

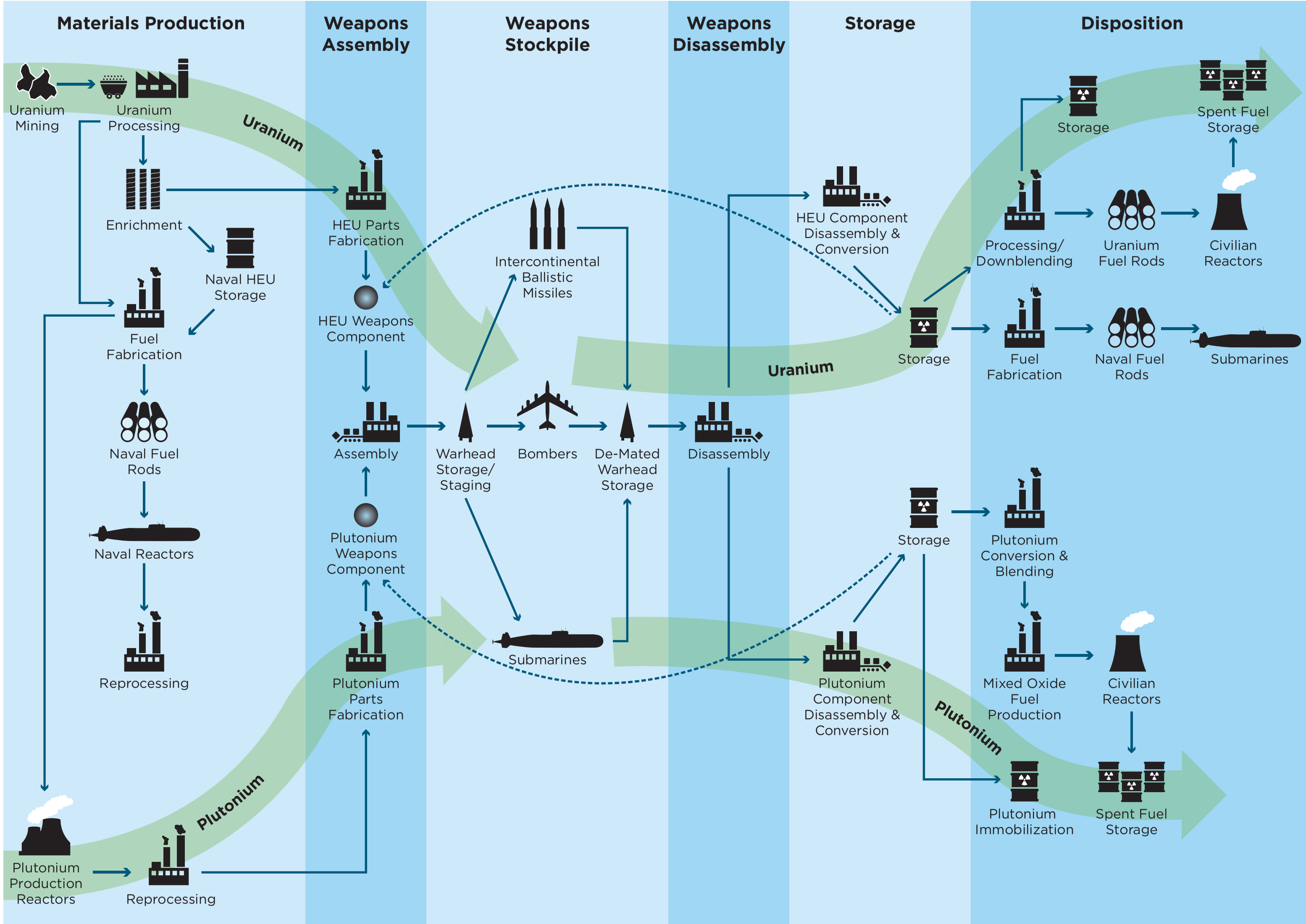
In 2012, the Nuclear Threat Initiative (NTI) convened a group of technical and policy specialists to examine the issues and methods associated with verifying baseline declarations of nuclear warheads and weapons-usable materials. The working group was divided into two subgroups, addressing warhead declarations and nuclear material declarations. It will be extremely difficult for inspectors to verify the full lifecycle of a nuclear program—from material inventories to warhead assembly and deployment to storage, dismantlement, and disposition—if they do not have a detailed record of a state's total warhead and weapons-usable material inventory. Verifiable baseline declarations can help address this concern, strengthening confidence and technical know-how for future verification challenges.

THE CASE FOR BASELINE DECLARATIONS

For this report, a baseline declaration is defined as an initial statement of the number or quantity of accountable items or materials—perhaps specified by parameters such as type or category—against which other information may be compared and future progress may be measured. The baseline declaration concept is not new. Some studies have considered this process in great detail,* and some states have already declared certain information either unilaterally or through formal agreements (see "Examples of Declarations"). These declarations, reports, and activities build on a long history of verification research and development and cooperative verification exchanges. In recent years, however, there has been a lull in such exchanges and in progress on bilateral or multilateral agreements. Verifiable baseline declarations could spur renewed technical engagement and build confidence among diverse scientific and technical communities.

* Reports by the National Academy of Sciences and International Panel on Fissile Materials are two examples of studies that have been done in this area. See Committee on International Security and Arms Control and National Research Council, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities* (Washington, DC: The National Academies Press, 2005); and International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2013: Increasing Transparency of Nuclear Warhead and Fissile Material Stocks as a Step toward Disarmament* (Princeton, NJ: IPFM, 2013).

Figure 1: Generic Lifecycle of Nuclear Weapons and Military Materials



This graphic illustrates basic components of a nuclear weapons and military materials lifecycle. The functions depicted are not specific to any one country, and not all countries undertake the steps shown. Where multiple arrows lead to the same function, it does not mean the functions are performed at the same facility.

EXAMPLES OF DECLARATIONS

Unilateral Declarations

In 1996 and 2012, the U.S. Department of Energy released declarations about the historical production and current holdings of plutonium and highly enriched uranium (HEU).

In 2000 and 2006, the United Kingdom government issued a report on the U.K.'s historical production of plutonium and HEU, as well as an account of current holdings.

In 2008, France declared its warhead arsenal would not exceed 300 warheads.

In 2010, the United States declared it had 5,113 active and inactive nuclear weapons in the U.S. stockpile. In April 2014, it announced the U.S. stockpile of nuclear warheads consisted of 4,804 warheads.

In 2011, the United Kingdom declared its overall stockpile of nuclear warheads would be limited to 180 warheads by the mid 2020s.

IAEA Guidelines for the Management of Plutonium (INFCIRC/549)

In 1997, nine states—Belgium, China, France, Germany, Japan, Russia, Switzerland, the United Kingdom, and the United States—agreed to make annual declarations of certain separated plutonium holdings, as well as an estimate of plutonium contained in holdings of spent civil reactor fuel, per INFCIRC/549.

New Strategic Arms Reduction Treaty Data

The United States and Russia release the data each party declares under the New Strategic Arms Reduction Treaty (New START). As of April 2014, Russia had 1,512 deployed strategic warheads and the United States had 1,585 deployed strategic warheads. The New START declarations include an aggregate total of the items limited under the treaty; data on deployment location, storage, and repair facilities; and testing locations for treaty-accountable items. Verification data collected through inspections is not shared beyond the treaty partners.

U.S.-Russia Material Declarations

In the past two decades, the United States and Russia have negotiated a number of agreements related to weapons-usable nuclear materials involving declarations of particular subsets of stocks. For example:

- Under the 1993 HEU Purchase Agreement, Russia declared 500 metric tons of weapons-origin HEU as excess to its military needs and available for downblending and sale and sold it to the United States for use in nuclear power plants. The United States conducted monitoring activities at four Russian facilities to confirm that the low-enriched uranium (LEU) was of weapons-origin HEU metal. Russia currently maintains the right to conduct monitoring activities at one U.S. LEU processing facility and three fuel fabrication facilities to confirm that the LEU material is fabricated into reactor fuel for civilian reactors. Routine implementation over a 20-year period has allowed the two sides to employ a variety of transparency techniques, including real-time automated monitoring of uranium material flows at blending facilities and nondestructive assay of HEU in various forms.
- Under the 1997 Plutonium Production Reactor Agreement, Russia declared the amount of plutonium produced in its plutonium production reactors after the entry into force of the agreement. The United States has the opportunity to monitor this material.
- Under the 2000 Plutonium Management and Disposition Agreement and its 2010 protocol, the United States and Russia each declared 34 tons of weapons plutonium as excess to their military needs and committed it to be dispositioned and monitored. Monitoring will begin only after the material has been converted to unclassified forms and mixed (in Russia's case) with a modest amount of civilian plutonium to hide the specific isotopics of the original weapons plutonium.

The baseline declaration process could unfold in a number of ways. It could require the states involved to declare the total size of their warhead and weapons-usable material inventories. Initially, this could be done in aggregate and be as simple as each state declaring three top-level numbers: the total inventories of warheads, HEU, and separated plutonium. But because states will need more confidence over time that these declarations are both correct and complete, more detailed information would be required, along with verification provisions to corroborate these details.

An agreement that requires at the outset a full inventory declaration, detailed accounts of items and material by type or use, and stringent verification protocols would be the most effective, but because states may be reluctant to declare and verify such information in the near term, alternative arrangements may offer a path forward. More narrow verifiable baseline declarations could be stepping stones for states that have not previously participated in arms control agreements and have limited verification experience. A narrower agreement might require a state to declare and verify only a specific category of weapons, such as deployed or non-deployed warheads, or a subsection of a state's weapons-usable material holdings, such as plutonium recovered through dismantlement of retired warheads. This could build a foundation for future verification efforts. Even if verifiable baseline declarations were not paired with an agreement to reduce warhead or material inventories, the process could strengthen confidence before a negotiation and facilitate reciprocal reductions.

By agreeing to cooperatively declare and verify information about warhead or nuclear material inventories—whether in aggregate or specific to one sector or type of weapon —states can mitigate risks and build trust. This can be done in a variety of ways and will almost assuredly evolve over time. In the near term, states could informally declare information, either unilaterally or in collaboration with other states, and later negotiate bilateral or multilateral agreements that define specific parameters and allow for cooperative verification measures. Such informal declarations could promote transparency and confidence. But formal baseline declarations—done in a cooperative manner and including detailed verification provisions—could promote an even greater sense of security and stability and provide far better assurances for non–nuclear weapon states (NNWS).

Without a clear understanding of warhead and nuclear material inventories, it will be nearly impossible to confirm that there are no hidden items or clandestine activities.

Security and Stability Benefits of Baseline Declarations

Without a clear understanding of warhead and nuclear material inventories, it will be nearly impossible to confirm that there are no hidden items or clandestine activities, making additional arsenal reductions extremely difficult. By declaring and verifying baseline inventories of warheads and weapons-usable nuclear materials, a state can assuage other states' real and perceived national security concerns. This will be an essential first step in maintaining the confidence of all states in a long-term arms reduction process. Baseline declarations and credible verification could also improve regional stability, especially in regions such as South Asia, by increasing transparency and providing a basis for dialogue, military-to-military interactions, and joint technical verification projects. Additionally, the process could help reassure U.S. allies and mitigate long-term questions about the United States' extended deterrence guarantee, reducing the risk that they seek to develop their own nuclear weapon capabilities. Preparing nuclear material baselines also creates immediate security benefits, prompting all states to undertake a process of fully characterizing and accounting for all weapons-usable materials, which, in turn, sharpens the focus on improving nuclear materials security.

Demonstrating Progress on Non-Proliferation Treaty Commitments

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) came into force in 1970 and is the cornerstone of the non-proliferation regime. Article VI of the NPT calls for parties to pursue "negotiations in good faith on effective measures relating to cessation of the nuclear arms race and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control." In declaring baseline warhead inventories, nuclear weapon states (NWS) could demonstrate that they are moving toward complying with disarmament commitments, as NNWS have called for.[1] To further increase confidence, states could consider including NNWS in baseline verification activities. While states would have to ensure that they do not violate articles I and II of the NPT by sharing potentially sensitive information and inadvertently assisting, encouraging, or inducing "any non–nuclear weapon state to manufacture or otherwise acquire nuclear weapons," NNWS participation could have concrete benefits: It could strengthen trust and cooperation and create a common understanding of the challenges involved and the constraints that nuclear warhead environments impose.

CONTEXT AND SCOPE

This report is divided into four parts. This chapter has highlighted some of the information that states have already declared and the value of more collaborative, verifiable baseline declarations. Chapter 3 examines the tools and techniques that might be used to verify a baseline declaration of nuclear warheads and the challenges associated with inspections in active warhead environments. Chapter 4 details the materials that states might declare and verify and the tradeoffs associated with the decision to include or exclude certain materials or inventory holdings. Chapter 5 looks at how states can deal with the long-term risks of undeclared warheads and materials; Chapter 6 presents the findings and recommendations of the working group as a whole.

In accounting for warheads and their nuclear components, the treaty objects are in the form of discrete items, whereas for nuclear materials, the currency is mass quantities. This had implications for how the two subgroups approached baseline declarations and how the two realms intersect over time. Near-term action on weapons-usable materials can promote more stringent nuclear security practices and serve as a useful confidence-building measure. But the core objective for any declaration of weapons-usable nuclear material would be to prepare for the point when states have to verify both warheads and materials to confirm compliance.

The working group largely refrained from commenting on what the terms or context for a particular agreement might be, though it was generally assumed that progress would be made in steps and that it would take time for states to declare and verify all warheads and weapons-usable materials.* It was also understood that states would need assurances that any future regime contemplating deep reductions or elimination would deal with issues of non-compliance and enforcement. These issues may be the most pressing challenges over the long term. But the focus of this report is on steps that states can take to increase confidence now and eventually confirm that baseline declaration are both correct and complete.

* Although national intelligence assets will be crucial to detecting and monitoring proliferation activities and helping to determine whether a state is complying with its treaty obligations, the working group focused extensively on cooperative measures that might be jointly developed and undertaken in future agreements. It did not explore at length how national technical means might specifically contribute to this process or how reductions and verification might proceed in uncooperative environments.

3. Verifying Nuclear Warhead Baseline Declarations

OVERVIEW

Over the past several decades, the United States and Russia have developed and implemented detailed verification protocols to monitor each side's nuclear arsenal and to verify treaty compliance. Both states have significant expertise in monitoring and conducting on-site inspections, but this experience has largely focused on declaring and counting delivery vehicles rather than individual warheads. Certain provisions in the New Strategic Arms Reduction Treaty (New START) now allow for the counting of deployed warheads on randomly selected delivery vehicles, a trend that is likely to continue as arsenal reductions proceed and each warhead becomes marginally more significant. As parties contemplate future warhead reductions and possible multilateral arrangements, verifiable baseline declarations of nuclear warheads would strengthen confidence and offer a valuable platform for collaborative scientific and technical exchanges.

Warhead verification will be challenging, especially absent an agreement to share classified information. Warheads and warhead components will have to first be authenticated to confirm that the items match what was declared. Then each declared item must be counted and uniquely identified to ensure that it is counted only once. Throughout this process, parties will have to maintain continuity of knowledge (CoK) so that inspectors can confirm that the items have not been tampered with over time.

For inspectors to authenticate, uniquely identify, and track warheads, it will be essential to understand the effects of more intrusive monitoring and verification and to design verification protocols in a way that mitigates safety and security risks. Virtually any method used to verify warhead baseline declarations is going to affect facility operations and put some sensitive information at risk. Some inspections will cause serious disruptions, and all personnel and equipment will be required to conform to extremely detailed safety and security protocols. Despite these challenges, there are opportunities to protect sensitive information and minimize disruptions to the host's operations. Parties could:

- Share information about facility safety requirements and consider using tools and equipment the host has already approved
- Explore verification opportunities near the shipment and receipt points when a warhead departs or arrives at a military warhead storage area or serial production facility
- Agree to protective procedures that limit inspectors' access to only the information and facilities needed for verification
- Design inspections that minimize the effects on dual-mission sites where conventional operations are also taking place
- Schedule and plan out proposed verification activities so that inspections can occur during non-operational shifts or, where possible, in separate dedicated buildings
- Manage the collection of handwritten and electronic data use by using forms that only record item numbers and yes-or-no answers and select equipment with integrated information barriers

Many of the basic technical methods and equipment required for warhead verification exist today, but some do not. For instance, no inspecting party has been able to authenticate a measurement system with a built-in information barrier after the equipment has been used to examine a classified item. Generally, however, the basic methods and techniques needed for future verification scenarios are well understood. Perhaps a greater challenge is the uneven playing field. The United States and Russia have a great deal of verification experience, and the United Kingdom and Norway have likewise done important work. But there is a more general need to build international capacity and revitalize multilateral exchanges on the tools and methods that will be required for future verification processes.

This chapter details the technical methods, issues, and opportunities associated with verifying baseline declarations of nuclear warheads and outlines a number of recommendations for near-term action and study. It explores the characteristics of a warhead environment and how certain operating procedures could be affected if states choose to declare and verify information about their warhead inventories.

Options for Warhead Baseline Declarations

The information in a warhead baseline declaration could be organized in a number of ways, and with different degrees of detail. For instance:

- Fully assembled warheads could be counted along with nuclear subcomponents, such as pits and secondaries.
- Warheads and their components could be grouped by type or status (e.g., deployed, non-deployed, or reserve).
- Information about warhead deployment sites (as in New START), production and retirement facilities, or staging facilities could be included in an inventory declaration.

How the declaration is structured will affect not only how it is verified, but also how and where inspections can take place. One way to consider nuclear warhead stockpile inventories is to divide warheads into two categories: those in the active stockpile and those in the inactive stockpile. In the United States, warheads in the active stockpile are typically in the custody of the military and are located at military deployment sites (i.e., bases), either deployed on delivery vehicles (i.e., ICBMs, SLBMs, or heavy bombers)* or held in non-deployed status (sometimes referred to as reserve warheads) and are stored in warhead storage areas (WSAs). Reserve warheads at military sites are not permanently found in a state of non-deployment; they are routinely rotated into deployment to support warhead maintenance requirements. A warhead may be removed from its delivery vehicle for depot-level maintenance, which is typically performed in the military WSA, or for more extensive maintenance, which may require transportation to a non-military serial production facility. Active stockpile warheads may thus move inside and outside a site within their lifecycle.

Despite challenges, there are opportunities to protect sensitive information and minimize disruptions to the host's operations.

When a warhead is transferred from a military to a non-military serial production facility, it is considered to be inactive.** U.S. warheads are transported to a serial production facility when they need extensive maintenance and refurbishment activities, such as life extension programs or other complex repairs, or when they are to be dismantled after retirement. When a weapon is retired, it is removed from its delivery vehicle and shipped to long-term storage at a non-military facility. It will remain there until it is rotated in for dismantlement. During this period, minimal access or handling takes place.

* ICBMs are intercontinental ballistic missiles. SLBMs are submarine-launched ballistic missiles.

** The U.S. Departments of Defense and Energy use different terminology. Inactive warheads can also be considered reserve.

Source: U.S. National Nuclear Security Administration

The National Nuclear Security Administration's Pantex Plan is the only U.S. serial production facility.

UNDERSTANDING WARHEAD ENVIRONMENTS

When determining which methods and tools might be most appropriate for verifying a baseline inventory in a nuclear warhead environment—that is, any deployment site or storage area where warheads are present—it is essential to understand the specific disruptions that such a process might impose. This can inform the type of information included in a declaration, when states might be prepared to make such declarations, and the verification protocols that parties might agree to implement. Familiarity with operating conditions can help mitigate disruptions and ensure compliance with different safety and security requirements.

This study uses U.S. warhead environments as an example of the basic steps of the nuclear weapons lifecycle. Warhead environments in other nuclear-armed states may be quite different, and the lack of insight into these differences will require flexibility among all parties. It will be essential to understand the normal operating conditions in such environments and what verification approaches would most easily mesh—or seriously conflict—with existing operations. It would also be valuable to understand the potential for unusual operating conditions that may be common to a region or facility due to acts of nature and any change in operations behaviors that would be expected when such off-normal events occur.

Disruption of Allowed Activities

Nuclear warhead facilities require tightly controlled and managed operations. Every activity is planned in detail in advance. Warhead movements to storage, removal from a delivery vehicle, and maintenance are all closely planned. Short-notice on-site inspections, of the type that the United States and Russia have grown accustomed to under the Strategic Arms Reduction Treaty (START) and New START, give the inspecting party more confidence that the host is complying with the terms of a given agreement. But they inevitably disrupt facility activities, plans, and schedules, as it is sometimes necessary to halt or otherwise conceal certain allowed activities, especially at dual mission sites.

Some military deployment sites host both nuclear warheads and non-nuclear munitions. Heavy bombers, for instance, can carry either nuclear warheads or conventional munitions. On-site inspections (OSIs) at such sites need to be designed to distinguish between nuclear and conventional munitions while minimizing the effects on allowed operations. Designing inspections that minimize the disruption to conventional operations will be challenging, but differentiating conventional from nuclear warheads is, in principle, straightforward. Radiation detection equipment could be employed—as it is today under the terms of New START—to demonstrate that containers and munitions declared to be holding non-nuclear items or to be non-nuclear are, in fact, as declared. Non-military serial production facilities also have ongoing missions and activities that need to be protected and segregated for safety and security reasons.

Minimizing disruptions will be a fundamental concern to the host and may be a point of contention for all parties involved in the design of a warhead verification protocol. While short-notice inspections will likely be an important component of future agreements, scheduling and planning verification activities with the host can reduce disruptions to allowed activities. Such preparation could allow the host to determine sanitization requirements for access areas and potentially reduce some of the facility security issues that would be more prevalent in a short-notice or unannounced verification visit. Arranging verification activities on non-operational shifts or to on-site but separate dedicated buildings could also prevent or mitigate disruptions to unrelated and allowed operating processes.

Safety

There are extensive safety requirements and procedures associated with the deployment, production, maintenance, and storage of nuclear warheads. In the United States, such requirements include not only a set of overarching facility safety principles but also in-depth and painstakingly developed and reviewed safety protocols concerning the hazards associated with each type of operational environment. For example, in a facility where heavy machinery or hazardous chemicals are used, personnel follow extremely specific safety protocols and use protective equipment tailored to the hazards in that particular environment. Safety protocols are directly related to the level of damage or injury that an accident in that specific area could cause to personnel, equipment, the facility, the warhead, the local external population, and the environment. These protocols account for approved and intentional actions, as well as acts of nature, unapproved actions, unintentional behavior, and accidents at each stage and configuration of an activity.

Because of the nature of the relationship between safety requirements and approved operations, any equipment or materials used in a baseline declaration verification protocol must be designed to adhere to appropriate safety standards. The equipment must meet general safety requirements and also be approved for use in its specific environment. Given the rigidity of facility safety requirements, such details need to be shared up front at the first possible opportunity.

At the same time, any verification process will need to adjust to the host facility's safety requirements—not vice versa. Safety concerns can be mitigated by using specific tools and equipment that the host has already approved or supplied, or by having equipment specifically certified for certain tasks. Mitigation of safety problems may also be possible through physical and electrical isolation, procedural restrictions, and use controls. Equipment use procedures and applications should be easily understandable and designed to be flexible, rather than requiring very specific techniques and uses.

Source: U.S. National Nuclear Security Administration

Two Pantex production technicians work on a W76 warhead while a co-worker reads the procedure step-by-step.

In the United States, safety issues that may affect the nuclear warhead environment are evaluated through a formal process called a nuclear explosive safety study (NESS). These studies analyze the effects of materials, equipment, and energy sources on the detonation system of a nuclear explosive device. Explosive safety approval is required for any piece of equipment proposed for use on or near a nuclear explosive device. Equipment that could be a source of electromagnetic radiation, electrostatic discharge, heat, or energy will be especially important to assess. The U.S. Department of Defense (DOD) *Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide* is used to certify equipment operated in DOD environments and significantly influences explosive safety certification for DOE explosive environments.[2] As the certification process can be quite protracted, the developers of verification equipment and any personnel using such equipment or devices on or near warheads must be familiar with different explosive safety requirements.*

Protecting Sensitive Information

In any agreement requiring a verifiable baseline declaration, parties must balance the need for intrusive verification activities with requirements for protecting sensitive information. Sensitive information falls essentially into two categories: information related to warhead design and information regarding operational environments or procedures. While the physical threat associated with an inspection would likely be considered low, operational and design information are potentially at risk. Such risks can be managed if inspections take place at certain points and the access of inspectors is limited to only the information and parts of the warhead environments that are absolutely necessary to verify a declaration.

Because transportation schedules, routes, and the equipment associated with transportation are considered sensitive information, any verification activities applied to warhead transportation would raise significant challenges and should be avoided in favor of more static operations. Potential opportunities for verification would exist at or near shipment and receipt points. Inspections to facilitate continuity of knowledge—the process by which specific materials and items are continuously tracked until they are no longer subject to treaty commitments—should be considered when:

- A warhead departs or arrives at a military WSA
- A warhead departs or arrives at a serial production facility
- A warhead moves on-site on military installations or a non-military serial production facility

* A recent program to implement a unique identification device (UID) for items at the U.S. Pantex facility, while not specifically designed for possible use in a treaty negotiation scenario, took approximately five years to method-select, certify for safety and security issues, and configure.

Confirming continuity of knowledge at these points could also make dismantlement verification easier by solving or greatly simplifying item authentication at the front end of verifying warhead destruction.

One complicating factor is that custody transfer procedures at U.S. non-military and military facilities are typically quite inflexible. Access is normally restricted at these points to personnel who are essential for completing the activity and have the appropriate security clearances and need-to-know status. A foreign inspection of the actual departure and receipt of the transported items would likely require an agreement to share operational classified information. This could be challenging, but there are precedents: Under New START, on a bilateral and classified basis, the United States and Russia exchange specific information on deployed warhead locations, down to global positioning system (GPS) coordinates. Certain types of operational security information, such as public highway transportation schedules, should be considered at least as sensitive as certain types of design information. But generally, agreements that permit the careful sharing of some operational information will face less resistance because information related to warhead design, which is extremely sensitive, would not need to be shared.[3]

If foreign inspectors are granted even limited access at a warhead facility, information about allowed nuclear operations that are not subject to the baseline verification agreement will be a major security concern. To mitigate this, inspection team access might need to be restricted to non-operating shifts. Access would likely be tightly enforced using the indigenous guard force and could be sequestered to a specific building or area at the site involved, consistent with treaty arrangements. Protectively masking facility features, requiring security escorts, and other protective procedures may also limit inspectors' visual access to only the information and parts of the warhead environments that are absolutely necessary to verify a declaration.

Measures would also be needed to manage the collection of both handwritten and electronic data. Information collected during an inspection would be subject to thorough review by the facility security offices. Data deemed sensitive or questionable may need to be withheld. Equipment with memory devices, whether hardwired or removable, would not typically be allowed to leave the facilities with any stored data. If the removal of stored data could not be confirmed, or if exposure to the environment alone resulted in security concerns, the equipment could also be detained. Information written in languages, codes, or formats that resulted in the information being indecipherable or questionable in nature, as well as handwritten maps, charts, or diagrams, could be withheld. To deal with these challenges, inspectors could use forms that only record item numbers and yes-or-no answers rather than specific details or measurements. The host and inspector could also use agreed on information protection systems or barriers (IBs). As detailed below, the development of an approved template or attribute system utilizing yes/no or green/red light indicators, which reveals only simple, non-sensitive information, would be critical.

TECHNICAL METHODS

Inspectors, along with the host state, could use a number of technical methods for verifying baseline declarations. Specialized equipment and techniques will be required for three essential tasks: authenticating that an item declared to be a warhead or warhead component matches what was declared; uniquely identifying each item to confirm the declared inventory is correct; and maintaining continuity of knowledge (CoK) so that inspectors can verify the integrity of monitored warheads over time.[4]

Warhead Authentication

For this report, warhead authentication refers to the process of ascertaining that an item declared to be a nuclear warhead or warhead component is, in fact, a nuclear warhead, as declared. This process might also confirm that a warhead is of the type declared. Future baseline arrangements may use multiple concepts and measurement techniques to authenticate a warhead, including random sampling, key indicators, attribute measurements, and template matching.

In the design and conduct of a warhead authentication protocol, the intrusiveness, complexity, and cost can influence the concepts and techniques parties agree to use.

- **Intrusiveness.** More intrusive protocols will have a greater effect on operations at the host site and could result in more information being revealed, intentionally or inadvertently. On the other hand, more intrusive measures can also give parties more confidence in the conclusions drawn.
- **Complexity.** Verification tasks can be relatively simple or complex, depending on the equipment used and overall procedures for conducting warhead authentication tasks.
- **Cost.** Intrusiveness and complexity affect cost. Generally, the more complex and intrusive the warhead authentication protocol, the more expensive it will be to implement. This includes costs associated with the development and acquisition of specific measurement technology; safety certifications for the use of equipment within specific facilities and with specific objects (i.e., warheads); security certifications to understand what information may be at risk with different monitoring and measurement techniques and corresponding mitigation strategies; and the operational costs of hosting an inspection, including escorts for foreign inspectors, additional security procedures, and lost productivity.

Authentication methods will also vary in the level of confidence they can provide. The term *confidence* can be applied in different contexts and with different nuances in meaning and implication. It can refer to an inspector's level of trust that specific measurement equipment is yielding accurate measurement results. In warhead authentication, such trust depends on the efficacy of the inspection approaches. Generally speaking, increased confidence requires increased intrusiveness—and given that there are multiple tradeoff considerations regarding intrusiveness, complexity, and cost, a key question is how much confidence is practical given the treaty objectives, additional verification measures, and the overall effects of cheating.

Sampling of Warheads for Authentication

Random sampling procedures are powerful inspection tools that can greatly reduce the cost and intrusiveness of verification by minimizing the number of inspections required. The International Atomic Energy Agency (IAEA) uses random sampling strategies for safeguards applications, drawing compliance conclusions for an entire inventory based on inspections performed on a subset of that inventory. While random sampling procedures provide confidence in the accuracy of an entire declaration, they do not fully address concerns related to the detection of clandestine items.

Many sampling procedures exist, and selection is typically based on the unique features of the inventory and the sampling acceptance criteria. One relevant sampling procedure, known as zero-acceptance sampling, only accepts the entire inventory if zero defects—items that are not as declared—are found. An inspecting party might randomly inspect n containers of declared warheads from an inventory of N warheads. Each warhead container would be determined to be either acceptable (as declared) or unacceptable (not as declared). The required sample size, n, can be determined once the inspecting party specifies values for the minimum detectable percent defective (p) and the detection probability or confidence level ($1 - \beta$), such that the entire population, N, is unacceptable if one or more of the inspected containers are not found to be as declared. The required sample size is approximated by the following:[5]

$$n = N(1 - \beta^{\,1/pN})$$

As a simple example, assume a country has a total of 1,000 declared warheads (N). The inspecting party determines that out of the 1,000 warheads, if $p = 1$ percent (10 warheads) or more, then a sample should have at least 95 percent probability of detecting at least one bad warhead, thus rejecting the entire inventory. The inspection party can calculate the sample size to have a detection probability ($1 - \beta$) of at least 0.95 of finding at least one defective item in a sample from an inventory having 1 percent (10 of 1,000) or more defective items as such:

$$n = N(1 - \beta^{\,1/pN}) = 1000(1 - 0.05^{(1/0.01*1000)}) = 259$$

Based on this criterion, an inspector would randomly inspect items until either finding an item that was not consistent with the declaration and thus rejecting the entire inventory or finding 259 consecutive items to be as declared and accepting the entire inventory. Other sampling arrangements could also be considered, such as sequential sampling plans that allow for a few defects while still declaring the inventory to be acceptable. The advantage of zero-acceptance sampling, however, is that fewer samples are needed.

Key Indicators

Key indicators—an approach used under New START—can provide a basis for nuclear warhead authentication. The United States and Russia exchange aggregate warhead data semiannually and identify by site the aggregate number of warheads deployed on ICBMs, SLBMs, and heavy bombers. During an inspection, the inspected party presents information on the exact number of warheads deployed on each delivery system. The inspecting party then randomly selects a deployed system to confirm that the number of warheads present equals the number declared. The key indicator is the deployed delivery system. Each object seen on a deployed and randomly selected strategic delivery system is assumed to be a nuclear warhead unless demonstrated to be non-nuclear.

Parties must agree on a set of attributes that balances the need for higher confidence with the increased costs of measurement equipment design, security reviews, and greater operational disruptions.

As fewer warheads are deployed, key indicators may become less useful. Nevertheless, they may offer a less expensive, technologically simpler means to aid in warhead authentication. A similar approach could be contemplated for non-deployed warheads, though with reduced confidence. In such a scenario, the location, configuration of stored items, and identifiable security features could indicate that the items in storage containers are indeed nuclear warheads or components, but measurements would likely be needed to provide additional confidence.

Attribute Measurements

Attributes can be used to indicate specific characteristics of an item under investigation without revealing more detailed, sensitive information. Warheads are known to contain certain materials—such as plutonium, uranium, and high explosives. Typically, the specific numerical values of these attributes are classified but not the fact that these attributes exist. For instance, the amount of plutonium in a warhead is classified, but if an inspecting party can confirm the presence of plutonium without having to see a specific measurement, the inspector will have greater confidence that the item is in fact a warhead, and the host state can protect extremely sensitive design information, a fundamental advantage of this approach. Parties to an agreement will have to determine whether the use of such attributes is permissible and whether the release of sensitive information is necessary to authenticate an item. One way to protect sensitive information is to rely on thresholds for attribute measurements: Instead of displaying the absolute numerical value of a particular measurement, the equipment can be programmed (e.g., through an information barrier system) to indicate only whether or not a measured quantity is above or below an agreed-upon level. If a measurement is within the threshold, a green light is illuminated to indicate a positive reading. If an item does not have a certain attribute or does not contain a certain amount of material, a red light could indicate that the item might not be authentic.

Source: The United Kingdom-Norway Initiative

An inside view of the jointly developed United Kingdom-Norway prototype information barrier system, designed to protect sensitive information and show a green or red light depending on whether the results meet defined criteria.

If parties decide to use attributes in a future agreement, they will need to determine how many to use. Often, more than one or two attributes are needed to build confidence, though including additional attributes also increases costs. Parties must agree, therefore, on a set that balances the need for higher confidence with the increased costs of measurement equipment design, security reviews, and greater operational disruptions.

The following is an illustrative, but not comprehensive, list of unclassified (in the United States) attributes that could be considered for warhead authentication. Approaches for measuring these attributes are discussed, and references are provided for additional information. Techniques for measuring the attributes vary in readiness to be deployed. Some are based on well-developed and more rigorously assessed concepts, while others are still experimental. Although not comprehensive, the list makes up a robust set of core attributes to which more regime-specific attributes could be considered to further increase confidence.

- **Presence of Plutonium-239.** Pu-239 emits gamma rays with sufficient intensity and energy that they are likely to be observed from an item under investigation. The presence of Pu-239 can be confirmed through gamma-ray spectroscopy using a high-purity germanium (HPGe) detector. Gamma-ray spectroscopy in this context is a technologically mature, relatively low-cost technique.[6]

- **Plutonium-240 Content below a Specified Threshold.** High-resolution gamma-ray spectroscopy can also be used to determine Pu-240 content. The relative intensities of two gamma rays—642.5 keV (kilo-electron volt) for Pu-240 and 646.0 keV for Pu-239—are directly proportional to the relative ratio of Pu-240 to Pu-239. These gamma rays are typically chosen because they are very close in energy levels, minimizing effects due to variation in detector detection efficiency and matrix attenuation. A low ratio of Pu-240 to Pu-239 indicates the presence of weapons-grade plutonium. As stated previously, gamma-ray spectroscopy in this context is a relatively low-cost technique.[7]

- **Plutonium-239 Mass above a Specified Threshold.** The mass of Pu-239 in an item under investigation can be measured using a combination of two methods: high-resolution gamma-ray spectroscopy and passive neutron multiplicity analysis. The ratio of Pu-240 to Pu-239 can be determined using high-resolution gamma spectroscopy (see above). A neutron multiplicity counter (NMC) measures the number of neutrons the item emits and exploits the fact that neutrons from spontaneous or induced fission are emitted essentially simultaneously. The Pu-240 mass is calculated by measuring the neutron count rate (singles), the rate of correlated pairs (doubles), and correlated triples (triples) that are emitted from Pu-240 spontaneous fission. The Pu-240/Pu-239 ratio is used to convert the Pu-240 mass into the Pu-239 mass estimate.[8] NMC technology is considered mature when certain reasonable assumptions are met, though quantitative mass assessments are vulnerable to the presence of shielding between the Pu-239 and the detector. Determining the Pu-239 mass is also considered a more intrusive attribute than presence.

- **Presence of Uranium-235.** The presence of U-235 has traditionally been determined in two ways, depending on the configuration of the item under investigation. In the absence of shielding, the gamma-ray spectrum U-235 emits can be used to determine its presence, measured through gamma-ray spectroscopy using a HPGe detector. However, due to the low energy of the most prominent gamma rays emitted from U-235, minimal shielding between the U-235 and the detector can easily reduce the measurable signal such that the U-235 cannot be detected.[9]

  In the presence of shielding between the U-235 and the detector, an active interrogation approach can, in principle, be used as an alternative to passive detection. Active interrogation uses the fissile nature of U-235—namely, that thermal neutrons or high-energy photons can induce fission in U-235, thus allowing detection of the fission products' multiplicity. Several technologies using active interrogation have been demonstrated to indicate the presence of U-235, but field experience is still somewhat limited and the approval process for use in sensitive facilities remains challenging.[10]

- **Mass of Uranium-235 above a Specified Threshold.** As described previously, a neutron source can be used to induce fission in U-235. Measurement of the neutron singles, doubles, and triples allows the calculation of the mass of U-235 through active neutron multiplicity analysis. While the idea to use active neutron multiplicity to determine U-235 mass has been around for some time, literature and field experience are very limited.[11]

- **Uranium Enrichment (Ratio of Uranium-235 to Uranium-238) above a Specified Threshold.** As in measuring for the presence of U-235, uranium enrichment can be determined in multiple ways, depending on the configuration of the item under investigation. If there is minimal shielding between the uranium and the detector, the enrichment can be determined either by comparing the intensity of the peak from the 185.7-keV gamma ray emitted from U-235 to a previously measured calibration curve generated using known enrichment standards, or by measuring and comparing the ratios of gamma-ray intensities from U-235 and U-238.[12]

  In the presence of shielding between the U-235 and the detector, an active interrogation approach must be used to determine the uranium enrichment. While methodologies using active interrogation to deduce the enrichment level are still being researched, potential active interrogation technologies for uranium enrichment determination include active neutron multiplicity analysis, neutron imaging, and muon radiography.[13] These active interrogation approaches are more expensive and intrusive than passive measurement techniques, but, as already noted, they are much less technologically mature.

- **Presence of High Explosives (HE).** Methods to detect explosives typically rely on detecting the presence of nitrogen or the ratios of carbon, nitrogen, and oxygen that set explosives apart from most other materials. One technique, somewhat successfully demonstrated in the past, detects the presence of HE in the item under investigation by probing it with a high-energy neutron source and observing gamma-ray signatures unique to oxygen-16 and nitrogen-14. This is a technologically mature approach for HE verification; its cost and intrusiveness are moderate.[14]

Selecting suitable measurement methods for attribute determination that both the host and the inspector trust can be a challenge. Shielding and self-absorption of the fissile material—that is, radiation from the interior of the fissile material absorbed by the fissile material itself—can affect quantitative measurement results or hinder the analysis altogether. While the host can propose measurement methods that enable correct attribute determination, the inspector must be confident—independent of host assurances—that a measurement method is properly suited.

The inspecting party may be largely unaware of an item's configuration, given the potential sensitivity of the object. If inspectors authenticate a fully assembled warhead, parts of the warhead itself can act as shielding because the warheads and warhead components are already stored in appropriate containers. If an inspector has relatively little knowledge of the configuration, measurement methods that are the least vulnerable to shielding should be favored. Or, in some cases, the host party could share sample configurations. The designs of some storage containers are unclassified and thus shareable. Declassification reviews could be conducted on further storage containers or configurations to assess whether further cooperation is possible. To address these issues, additional research and testing is required on the majority of the presented techniques to ensure that measurement methods are sufficiently robust to protect against vulnerabilities.

Templates

Templating uses the unique radiation spectrum or other measurable properties of a previously authenticated item to confirm that other items are identical. When an item is presented for authentication, its physical properties signature is measured and compared with a previously generated template of the independently authenticated item, such as a randomly selected warhead from a deployed weapons system. If the measured signature of the object matches that of the template, then the second object is considered authentic.

To authenticate an item using templating, parties could use a full unique signature approach by comparing, for example, the full gamma-ray emission spectrum of two items or possibly the set of values from a collection of attributes.

A warhead templating scenario would likely include the following elements:

- Inspectors choose a randomly selected warhead or otherwise independently authenticate an item.
- Continuity of knowledge procedures are used to assure the inspecting party that the randomly selected warhead is the same item presented for template generation.
- A full-spectrum measurement or extensive set of numerical value measurements associated with key attributes are recorded, and the values are stored as a template for subsequent matching. The attribute-value measurements would likely include nuclear and non-nuclear properties, such as overall weight, Pu-239 and U-235 mass, and HE presence.
- The results are stored within a secure device. The measurement system would contain an information barrier with hardware and software features that together enable sensitive information processing while revealing only non-sensitive results. This should also enable the inspecting party to authenticate the equipment after the measurements are taken.

- Various secure storage configurations, including tamper indicating devices and enclosures, are used to ensure the security of the measurement system and template.
- Subsequent warheads selected for authentication are measured and the results compared with the template contained within the secure storage device to provide a result of matches versus non-matches.

With this approach, it is extremely important that the warhead used to generate the template is presented in the same configuration as subsequent items will be presented for authentication. For example, if items are presented in specific storage containers, then the template should be generated from a warhead in a storage container identical to the one to be used during subsequent verification measurements.

It is extremely important that a warhead used to generate a template is presented in the same configuration as subsequent items will be presented for authentication.

The rationale for pursuing templating rather than conducting threshold-based attribute measurements is the potential it offers for confirming specific warhead types without revealing potentially sensitive design information. Templating may also allow for faster inspection times and require less complex measurement equipment.* However, more detailed research and testing is needed on how to establish the authenticity of the template, protect sensitive design information that the template may contain, and protect the template between measurements.

Unique Identification

Unique identifiers are intended to negate double or other forms of miscounting of nuclear warheads. There are two basic ways to securely identify a warhead. One is to record an available fingerprint-like intrinsic feature of the item to track it. Another is to apply a counterfeit- and tamper-resistant label-like tag to the item.

Unique identification devices (UIDs) require extensive safety and security scrutiny to be deployable in a nuclear warhead operating environment. Applying tags and seals to equipment and containers in non-military nuclear power facilities under IAEA inspections is a commonly accepted practice. By contrast, tags and seals on nuclear warheads, especially those still a part of the active inventory, pose significant challenges. Explosives safety, information security, containerization, and operational disruptions will be major considerations for any effort to uniquely identify warheads and their nuclear subcomponents, especially if UIDs are affixed to or measured directly from the war-

* In a 1997 research and development measurement campaign at the U.S. Pantex facility, a template system devised by Sandia National Laboratories routinely was able to complete a measurement and authenticity-like determination of actual warhead items in minutes based on full gamma spectrum comparisons to stored templates, whereas the use of two other systems incorporating the comparison of attribute-like values from the objects sometimes took hours to complete.

head or nuclear subcomponent. For example, warheads and their separated but intact nuclear components are almost always containerized, which has implications for how and where tags can be applied.*

There are basically three possible configurations for uniquely identifying a warhead or sensitive nuclear component:

- The UID can be directly affixed to the warhead or nuclear component, perhaps witnessed by the inspecting party, but with only the host personnel touching the item.
- A unique and secure seal can be placed on the warhead container or component container. It is possible the inspecting party could affix the seal after either witnessing the item being placed in the container or being allowed to make a template or other nuclear measurement to help confirm that the declared, containerized item is authentic. Such an approach might mitigate some of the more difficult safety and security issues associated with attaching a tag to the warhead itself and be more in line with normal operational procedures.
- Combining aspects of both approaches, an integrated UID system could be applied to both the warhead or its components, as well as to the exterior of their container. Such an approach could add confidence to the confirmation and counting process without requiring intrusive radiation measurements.

Treaty-useful high-security UIDs for nuclear warheads and their nuclear components and containers have largely not been developed to any reliable degree. There are three basic ways to compromise a UID. One is to generate a counterfeit. The second is to devise a way to remove and replace a UID without detection. The third is to alter the UID reader to give false results. The UIDs approved for use on warheads and their nuclear components must be highly resistant to these attacks.

During the START era, an unprecedented technical effort was mounted in the United States to develop a highly secure unique identifier for the first stages of treaty-accountable ICBM and SLBM rocket motors.[15] Ultimately, however, U.S. and Russian negotiators decided to use a simpler but much less reliable approach of manually recording serial identification numbers that the host country supplied. But because the host supplies the serial number, this kind of unique identification is generally considered less secure.

Given the extensive early START UID development effort, continuing studies, and successes over the past 25 years in the United States, the United Kingdom, and also jointly under the U.S.-Russian Federation Warhead Safety and Security Exchange (WSSX) program, it is clear that effective and secure methods and procedures can be developed to meet strict confirmation criteria for validating baseline declarations of warheads and their intact nuclear components. With the development of more advanced miniature

* A notable exception is gravity bombs, as the skins of the bombs are considered their containers.

electronics and microprocessors, particularly promising and highly secure approaches may be offered by active tags and seals—devices that are powered for increased functionality.

The ultrasonic intrinsic tag and RuBee tag are two promising UIDs, but more testing and development is needed. The ultrasonic intrinsic tag (UIT) is based on ultrasonic scanning, similar to harmless medical diagnostics, of shallow subsurface random and unique intrinsic features of the item being identified. The UIT approach shows promise based on the technical safety reviews Pantex has undertaken to date, but development of this technology has been halted, so no further assessments are underway. The RuBee tag was recently approved for use on items at Pantex. The RuBee approach is based on technology similar to that of conventional but secure radio-frequency tags and was pursued after an extensive down-selection process involving more than 150 commercially available devices. It was the only approach that met the extremely restrictive explosives safety and security design criteria but required about five years to certify and implement.

Negotiations will go much more smoothly if both sides cooperatively develop and vet the technologies long before formal negotiations begin.

Further UID development will likely require significant lead time, well beyond that needed to demonstrate a prototype idea. Ideas must be independently evaluated against defeat, explosive safety, information security, complexity, cost, and disruptiveness to allowed operations. Negotiations about using a particular unique identification method on very sensitive items, such as nuclear warheads, will go much more smoothly if both sides have cooperatively developed and vetted the technologies. The best way to make this happen is to undertake UID development on a cooperative basis long before formal negotiations begin.

Continuity of Knowledge

For this report, CoK is the process of keeping continuous track of specific materials and items until they are no longer subject to treaty commitments. CoK provides an uninterrupted thread of evidence that is used to verify the integrity of monitored warheads over time. An integrated system of tools and procedures can be used to establish and maintain CoK, under which warheads subject to control within a monitoring regime are identified, tracked, and verified throughout their productive lifecycle.

Many containment and surveillance measures can be used to establish and maintain CoK. Technologies could include cameras that provide unattended or remote monitoring, UIDs that provide confidence in the identity of an object, tamper-indicating devices (TIDs) in the form of uniquely identified seals, and tamper-indicating enclosures to assure item integrity. These tools, particularly integrated into a system, can be used to effectively establish and maintain CoK.

Unattended and remote monitoring allow equipment installed in a facility to monitor treaty-related items and activities when an inspector is not present. In unattended monitoring, data are temporarily archived at or near the sensors and periodically retrieved by inspectors. In remote monitoring, data are securely transmitted to remote locations and may involve minimal local data archives as a contingency in case of a communications failure. Current technologies used in unattended and remote monitoring include image acquisition and analysis, thermal signatures, neutron and gamma-ray measurements, and monitoring of seals. Security systems may also be incorporated into monitor sites, such as storage facilities and specific items therein. Such security systems may include video cameras, entry and exit alarms, portal monitors that screen for the movement of fissile material through an entryway, and heat and motion sensors.

Some modifications might be necessary to accommodate certain safety and security requirements. For instance, portal perimeter continuous monitoring (PPCM) may be useful for verifying non-deployed nuclear warhead inventories, a notion arising partly from its successful implementation among the verification measures for the Intermediate-Range Nuclear Forces Treaty. Because of the sheer size of future verification tasks, however, PPCM may have limits for a nuclear warhead verification regime. It could provide too much information about the operational and logistic patterns of nuclear warheads and reveal associated physical security personnel movements and procedures.

Monitoring activities pertaining to non-deployed warheads would be least complicated when such warheads are in storage rather than in transport. Passive unique identification and highly secure seals for checking at points of shipment departure and receipt hold the potential for an inspectorate to maintain adequate continuity of knowledge while minimizing, to the point of complete non-interference, the challenge to transportation security. Random, more intrusive inspections using template matching could add considerably to the confidence of the broader CoK process but could significantly complicate stored item monitoring. Monitoring retired nuclear warheads in facilities designed and built for long-term storage would have challenges but could be as simple as confirming the absence of activity in the facility or with previously authenticated and uniquely identified warheads.

INVOLVING NON–NUCLEAR WEAPON STATES IN FUTURE VERIFICATION ACTIVITIES

International scientific cooperation has helped to preemptively address technical obstacles, promote common understanding of verification challenges, and inform policy-makers of feasible verification technologies (see "Examples of Cooperative Verification Studies and Activities"). The U.S.-Russia Warhead Safety and Security Exchange (late 1990s through 2005) and other scientific cooperation arrangements, such as the U.S.-Russia-IAEA Trilateral Initiative, engaged experts from two or more countries to work on difficult hypothetical verification problems. Cooperative activities can set the precedent for using common verification tools and facilitate acceptance of new verification mechanisms.

Going forward, there would be significant value in having experts from NNWS participate in future cooperative research and inspection activities. Because sensitive design information is unlikely to be shared with inspectors, even if the inspector is from a state with nuclear weapons, it is possible to develop verification protocols that include NNWS under IAEA auspices, on a state-by-state basis, or through some other form of multilateral engagement. The potential exception is if weapons state partners to a verification arrangement decide that sharing weapons design information among themselves would not significantly jeopardize their own security and would solve or simplify a difficult verification problem.

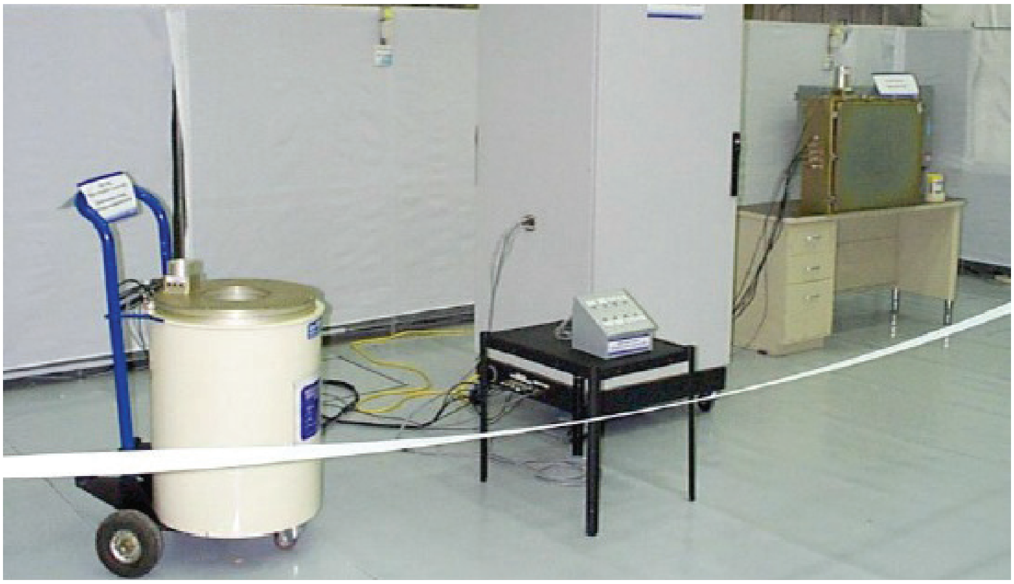
Important work has already taken place with NNWS specialists through the IAEA-Russia-United States Trilateral Initiative and the United Kingdom-Norway Initiative.[16]

The IAEA-Russia-United States Trilateral Initiative

In 1999, at Los Alamos National Laboratory, the Trilateral Initiative demonstrated an inspection of an unclassified plutonium sample using radiation-based measurement equipment with a rudimentary information barrier to protect sensitive information.[17] It did not, however, allow IAEA or Russian visitors to rigorously authenticate the data acquisition system after the demonstration. Approximately a year later, an inspection of an actual U.S. nuclear warhead component using radiation-based measurement equipment with a first-generation information barrier was conducted for Russian weapons specialists as part of the formal negotiation between the United States and the Russian Federation on the Monitoring and Inspection Agreement for the Mayak Fissile Material Storage Facility. During this demonstration, the Russian specialists were not afforded any additional access compared to the IAEA representatives.

The U.K.-Norway Initiative

The U.K.-Norway Initiative (UKNI), ongoing since 2007, is designed to address the technical and procedural challenges of verifying nuclear warhead dismantlement. The collaboration is exploring, for the first time, how all state parties to the NPT can contribute and cooperate to this end and has focused specifically on increasing the role of NNWS. UKNI uses fictional and generic scenarios to identify challenges to verifying nuclear warhead dismantlement. The aim is to research, develop, and test tools, techniques, and methodologies for possible future verification efforts. The initiative has developed a technical program of work split into two overarching areas: on-site inspection methodology and joint technology development.[18]



Source: U.S. National Nuclear Security Administration

In 1999, the United States demonstrated an attribute measurement system with an information barrier at a Trilateral Initiative workshop held at Los Alamos National Laboratory.

In a future verification regime for nuclear warhead dismantlement, inspecting parties are likely to request access to highly sensitive facilities. The host party will likely have to manage such access carefully to prevent the disclosure of proliferative or otherwise sensitive information; inspectors also have an obligation not to gain such information. Managed access processes and techniques look to satisfy the concerns of both inspectors and the host state, although even with procedures in place, the inspecting party is unlikely to obtain full access to sensitive areas. UKNI has successfully carried out several exercises, all of which provided practical opportunities to deploy technologies and test procedures, thereby increasing the mutual understanding of the issues involved.

To protect proliferative and otherwise sensitive information, the deployment of instruments and equipment must also be carefully managed. Mutual trust is very important. The host must be certain that the technologies can only collect and relay non-sensitive information as agreed between the parties, and the inspector must be certain that the information relayed accurately reflects the true state of the system being measured. The key aim of the joint technology development project is to understand how both parties could work together to ensure mutual confidence in the building and maintenance of inspection equipment. As a case study, the project has developed a prototype gamma radiation attribute measurement system, incorporating information barrier technology, to prevent the release of proliferative or otherwise sensitive information.

Source: U.K.-Norway Initiative from the Norwegian Defence Research Establishment (FFI)

As part of the U.K.-Norway Initiative, experts conducted managed access exercises to verify a hypothetical treaty between two fictional countries, Luvania and Torland. Here, inspectors from Luvania monitor the dismantlement of one of Torland's nuclear gravity bombs.

NTI Working Group on Building Global Capacity

The NTI working group on Building Global Capacity outlined a number of cooperative steps that states with and without nuclear weapons can take. These include sharing basic information related to definitions, methodologies, instruments, relevant technologies, processes, and procedures, as well as conducting joint development, testing, and certification of verification tools and nuclear forensics. The working group also recommended developing academic curricula that build awareness about verification concepts, provide basic knowledge, and build capacity in functional areas that are sustainable, aided by regional champions promoting cooperative approaches. Once an agreed on level of competency is acquired, states with nuclear weapons could conduct site visits at nuclear facilities to acclimatize hosts and visitors to safety and security requirements as a precursor to developing a mock inspector training course, modeled on the New START inspection regime that would be open to all states.

EXAMPLES OF COOPERATIVE VERIFICATION STUDIES AND ACTIVITIES

- **1991:** The Nunn-Lugar Cooperative Threat Reduction program was signed into law, providing a basis for extensive cooperation on the safeguarding and dismantlement of weapons of mass destruction (WMDs) in multiple countries, including Russia, Ukraine, Belarus, and Kazakhstan.
- **1993:** The Gore-Chernomyrdin Commission and subsequent working groups were set up, providing for a platform for U.S.-Russian specialist-to-specialist discussions on cooperative means to monitor and reduce nuclear warhead inventories, in hopes that the two countries might develop verifiable agreements on actual weapons instead of on delivery vehicles.
- **1994:** Hazel O'Leary, the U.S. secretary of energy, and Victor Mikhailov, the Russian head of the Ministry for Atomic Energy (MINATOM) agreed that the United States and Russia would engage in mutual reciprocal inspections (MRI) of fissile materials removed from dismantled nuclear weapons. Even though the MRI was never implemented, joint research and development work evolved into the U.S. Energy Department–MINATOM Lab-to-Lab program.
- **1994:** The U.S. Russian Warhead Safety and Security Exchange Agreement (WSSX) was signed, allowing U.S. and Russian scientists to work together to better understand and enhance the safety and security of nuclear weapon dismantlement. The Lab-to-Lab program was ultimately subsumed into this effort.
- **1996:** The Trilateral Initiative was formed by the United States, Russia, and IAEA. The Trilateral Initiative was a six-year effort to analyze the legal, technical, and financial issues associated with placing sensitive items under IAEA safeguards. Part of the Trilateral Initiative focused on developing a measurement system that would allow the United States and Russia to submit classified forms of weapons-origin fissile material to the IAEA for verification and monitoring.
- **1998:** Specialists from the U.K. Atomic Weapons Establishment (AWE) began a comprehensive program of research into verification measures associated with arms control and transparency.
- **2000:** The U.S.-U.K. Cooperation (UKC) Program on Nonproliferation and Arms Control Technology was established, allowing U.S. and U.K. technical experts to test and evaluate the viability of potential technologies and concepts for nuclear weapons and facility monitoring and transparency and share classified information related to verification and monitoring technologies, as authorized by the U.S.-U.K. Exchange of Information by Visit and Report.[19]
- **2000–2001:** Technical demonstrations took place in both the United States and Russia using classified items. These items were examined using radiation-based attribute measurement systems under the watchful eyes of both Russian and U.S. specialists without the release of sensitive information. In one demonstration at the Oak Ridge Y-12 Plant, a classified item was ground to pieces behind a special physical barrier in the presence of Russian and U.S. observers.
- **2007:** The U.K.-Norway Initiative was created, marking the first time a state with nuclear weapons and a state without nuclear weapons collaborated on the technical and procedural challenges associated with future dismantlement verification.[20]

WARHEAD SUBGROUP RECOMMENDATIONS

- **Prioritize joint research on authenticating information barriers.** The United States, Russia, the United Kingdom, and others have developed and demonstrated measurement systems with integrated information barriers that protect classified information with limited but important success. Verification measurements on classified warhead items or materials have been made in the presence of foreign specialists without releasing classified information. However, to date it has not proved possible for these same foreign specialists to authenticate the inspection system after a measurement is taken. For the host state to protect classified measurement results and, at the same time, allow an inspecting party to confirm that the equipment works as advertised, significant additional research and testing is needed to resolve verification system authentication issues. Creative solutions and suggestions for improvement should be solicited from information technology experts and could be collaboratively crowdsourced as well.

- **Initiate an international technical assessment on warhead containers.** The ability to accurately measure a containerized warhead or component, without revealing sensitive information, is essential. The design and configuration of storage containers may vary dramatically depending on the container's purpose and intended contents, adding additional complexities to potential verification efforts. A container study would give states a better understanding of containers' effects and help determine if standardized containers or standardized container design principles could simplify the confirmation process. Because some containers' internal configurations might be sensitive, modeling may be needed in certain cases.

- **Designate standalone verification facilities.** Verification activities at existing nuclear weapons facilities impose major security and safety burdens on those facilities and may prevent normal operations for a substantial amount of time. The facilities were never designed to host foreign inspectors. Extensive efforts must be made to protect nuclear weapons design information and other sensitive information, and some health and safety concerns may make it impossible for inspectors to carry out some tasks they deem necessary. Standalone facilities designed and built for verification activities would eliminate the disruption of normal operations at active nuclear weapons facilities. Special facilities could also be used during a dismantlement process, where verification would likely constitute an even higher burden on operational facilities. Prospective treaty partners or other international parties should be encouraged to participate in the design process and observe and verify the construction of any standalone facility to counter possible accusations of built-in opportunities for cheating.

- **Strengthen independent peer review and vulnerability assessments on ongoing research and development efforts.** As promising technologies advance through the development process, programs need to involve additional independent scientific, certification, and vulnerability assessment teams. A more extensive peer-review process would bolster research and development outcomes and acceptance, as would the detailed publication of research results.

- **Launch a joint study on the applicability of IAEA technologies for warhead environments.** IAEA measurement techniques and containment and surveillance instruments should be studied and tested for use in a warhead environment. Currently, the IAEA employs a wide variety of tools and techniques, including tags, seals, unattended monitoring, and environmental sampling for non-proliferation purposes. An international team of experts should explore whether or not these technologies could be used in a warhead environment.

- **Discuss warhead environments and safety and security requirements as a part of the P-5 dialogue on verification.** The P-5 states (China, France, Russia, the United Kingdom, and the United States) need to discuss and share information about the general nature of the safety and security concerns and procedures that characterize their respective weapons environments, which would bound the activities allowable in a baseline verification process. This information could be sensitive and might therefore be shared only among P-5 states—at least in the early stages of such a dialogue. The information sharing would constitute a type of confidence-building measure that would help strengthen the basis for multilateral arms control in the future.

4. Verifying Weapons-Usable Nuclear Material Baseline Declarations

OVERVIEW

There is no official accounting of how much weapons-usable nuclear material is in the world today. Unofficial estimates indicate there are nearly 2,000 metric tons. Some of this material is in civilian programs, but the majority is in military programs, either in active warheads, retired warheads, naval propulsion programs, or storage, reserved for other potential uses. Information about how much weapons-usable nuclear material a state holds, and particularly the quantities in certain uses, can be sensitive. However, over the long term, it will be essential that all weapons-usable nuclear material is accounted for, tracked, and continuously verified if states are to have confidence that future arms reductions are not negated by the production of additional warheads.

Over time, historical production and use records may also be required to help substantiate declarations of current holdings. Given the sensitivity of some information and the difficulty of establishing accurate historical nuclear material flows, this will be challenging. Uncertainties in historical information can probably never be completely eliminated, but analysis for consistency across a range of data can provide confidence in the integrity of information.

This chapter outlines the materials, inventory information, and applications that states might consider declaring in future agreements and the benefits and risks associated with disclosing certain categories of information. Attention is also given to steps that states can take now, in advance of any agreement or declaration, to internally organize and prepare for future declarations and verification provisions. One particularly significant undertaking is the preservation of materials, facilities, and records that will be needed in support of nuclear archeology—the clarification of historical production, uses, and losses of nuclear materials. The section concludes with recommendations for dealing with areas where verification could be problematic and where additional research and development efforts will be required.

Options for Nuclear Material Baseline Declarations

In negotiating the terms of baseline declarations, one of the primary tasks for states will be to determine which materials should be reported. States could decide to declare information on a range of materials:

- Unirradiated materials or also irradiated materials
- Weapons-grade and non-weapons-grade materials
- Alternate nuclear materials
- Other non-fissile materials relevant to nuclear weapons, such as tritium
- Nuclear materials relevant to the production of weapons-usable materials, such as low-enriched uranium (LEU) in the form of enrichment feedstock (uranium hexafluoride, or UF_6) or all other nuclear materials.

Because of their potential effects on future arms reductions, the focus of this report is on weapons-usable nuclear materials: highly enriched uranium (HEU), separated plutonium, and, where relevant, U-233.*

Weapons-Usable Nuclear Material by Sector and Use

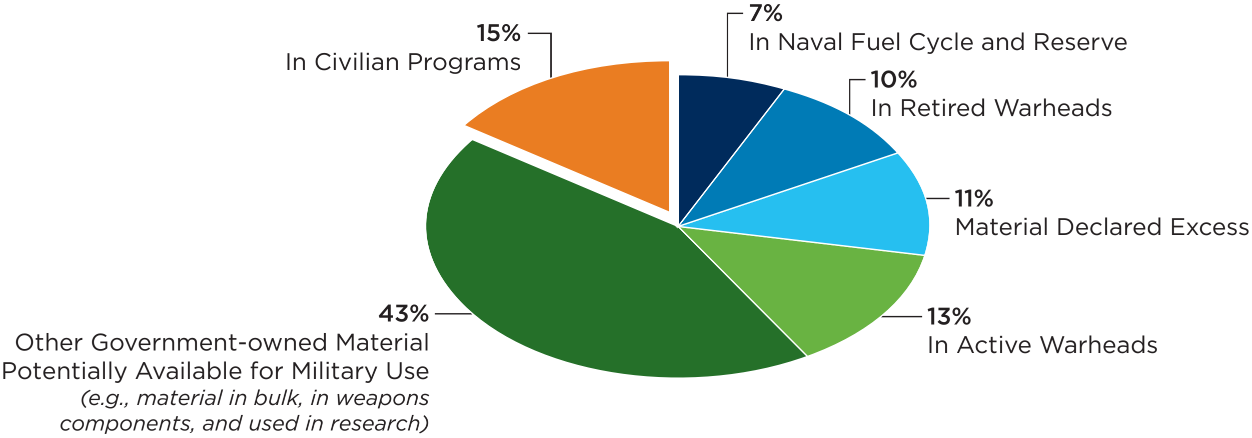
As Figure 2 illustrates, weapons-usable nuclear materials exist in a number of sectors and uses. As nuclear arms reductions proceed, states will need to provide assurance that there is no diversion of nuclear material to nuclear weapons from the dismantlement of warheads, from naval propulsion programs, from military stocks designated for non-weapons use, and from civil programs.

One key challenge is that nuclear material inventories are not static. Materials move between sectors and uses, and inventories are affected by nuclear decay.** Because of this, it is important to have a firm understanding of total holdings and a breakdown into sectors and uses; it is also important to track material flows over time. One example of how inventory holdings might shrink or expand is material in a dismantlement process. In a

* Uranium-233, produced through irradiation of thorium-232, is included here because it can be used as a nuclear explosive material. However, for practical reasons—radiation and heat emissions—uranium-233 has not been used in deployed warheads. The materials generally are termed *fissile materials*. However, because there is no internationally standardized usage for the term *fissile materials*, this term is not used in this study. Issues relating to other materials and material categories are discussed in Appendix C.

** E.g., decay of plutonium-241 to americium-241

Figure 2: Global Holdings of Weapons-Usable Nuclear Material by Sector and Use, 2012



Source: Nuclear Threat Initiative, Global Dialogue on Nuclear Security Priorities, Non-Paper 3: Comprehensiveness – Understanding Non-Civilian Nuclear Materials (Washington, DC: Nuclear Threat Initiative, 2012), 3, https://www.nti.org/media/pdfs/Non-Paper_3_-_Comprehensiveness_-_Understanding_Non-Civilian_Nuclear_Materials_1.pdf.

typical material flow, as warheads are retired, they are moved from deployment areas to storage. In due course, retired warheads are dismantled, and the nuclear components, or pits, are stored until they can be processed into unclassified forms and compositions. Once the nuclear material is declassified, it may be stored as part of stocks declared excess to military requirements, or the state may require materials from weapons dismantlement to be available for non-proscribed (i.e., non-weapons) military use, such as naval propulsion. Only if the proper irreversibility arrangements are in place can excess material be transferred to non-military stocks (i.e., civilian stocks) and excluded for use in warheads.

Tracking inventory changes is difficult because information about material in some sectors is more sensitive than in others. Whereas a state may already provide information on material in civilian programs to the International Atomic Energy Agengy (IAEA) under a safeguards agreement, and this material may well be eligible for IAEA inspections, there is considerable sensitivity surrounding the quantity of material in warheads.

Building on Existing Declarations

Some states have already released information about their total holdings as well as information about how much material is used for certain purposes. The United States and United Kingdom have published detailed reports of historic production and use of HEU and plutonium.

The United States was among the first states to gather and release complete—or as complete as possible—declarations about weapons-usable nuclear material holdings. In

Table 1: U.S. 2012 Plutonium Material Balance Declaration (MT)

	1994	2009	Change
Receipts			
Production	103.4	103.4	0.0
Research Reactors	0.6	0.7	0.1
From Foreign Countries	5.7	5.8	0.1
From U.S. Industry	1.7	1.8	0.1
Total Receipts	**111.4**	**111.7**	**0.3**
Removals			
Expended in Wartime & Tests	3.4	3.4	0.0
Decay	0.4	0.5	0.1
Fission & Transmutation	1.2	1.3	0.1
Discarded to Waste	3.4	7.8	4.4
To Foreign Countries	0.1	0.2	0.1
To U.S. Industry	0.7	0.8	0.1
Total Removals	**9.2**	**14.0**	**4.8**
Classified & Rounding	0.1	0.1	0.0
Inventory Difference	−2.8	−2.4	0.4
Ending Inventory	**99.5**	**95.4**	**−4.1**

Source: U.S. DOE, *The United States Plutonium Balance, 1944–2009* (Washington, DC: National Nuclear Security Administration, 2012).

keeping with a range of commitments and transparency initiatives, the U.S. Department of Energy (DOE) prepared comprehensive declarations about the historical production and current holdings of plutonium and HEU. DOE released its initial plutonium declaration in 1996 and published an update in 2012. Information on its HEU holdings was released in 2006 and updated later that year.[21] The U.S. plutonium declaration focused on the material in the inventories of the DOE and Department of Defense (DOD), and thus excluded irradiated plutonium contained in civil spent nuclear fuel (see Table 1). Fissile materials accounted for in the initial and follow-up plutonium declarations were broken down by type of material, origin of material, and current location. The three types of materials declared were weapons grade, containing less than 7 percent Pu-240; fuel grade, containing from 7 percent to less than 19 percent Pu-240; and reactor grade, containing 19 percent or more Pu-240.

The U.S. HEU declaration included the total quantity and location of HEU in the U.S. inventory and defined HEU as containing 20 percent or more U-235, following the IAEA definition. It included a detailed accounting of HEU production by year and grade. In addition to declaring HEU mass by site, the report contained measurements of the amount of U-235 contained within the HEU, so as to make available the average

Table 2: U.S. 2006 HEU Material Balance—Metric Tons of U-235

Material Balance Element	Material Balance Category	1945 – 9/30/1996	10/1/1996 – 9/30/2004
Acquisitions	Production from Uranium Enrichment Processes	859.2	0.0
	Production from Blending	0.3	0.0
	Miscellaneous Receipts	0.0	0.8
	Receipts from Foreign Countries	4.9	0.4
	Total Acquisitions	**864.4**	**1.2**
Removals	Refeed at Enrichment Plants	114.2	0.0
	Nuclear Tests, Wartime Detonations, and Naval Reactor Use	31.9	0.0
	Fission and Transmutation	56.2	0.6
	Normal Operating Losses	4.9	0.5
	Transfers to Foreign Countries	34.6	0.3
	Downblending	1.5	29.8
	Inventory Differences	3.2	0.0
	Total Removals	**246.5**	**31.2**
Totals	Beginning Inventory	0.0	620.3
	Total Acquisitions (+)	864.4	1.2
	Uranium Enrichment Process Holdup (+)	1.7	0.0
	Classified Transactions (+)	0.3	0.2
	Total Removals (-)	246.5	31.2
	Equals Calculated U.S. Inventory	**619.9**	**590.5**
	Actual U.S. Inventory	***620.3***	***590.5***

Source: U.S. DOE, Office of Security and Safety Performance Assurance, *Highly Enriched Uranium Inventory: Amounts of Highly Enriched Uranium in the United States* (Washington, DC: U.S. DOE, 2006), fissilematerials.org/library/doe06f.pdf.

The DOE report explains the difference between the September 30, 1996 calculated inventory and the actual inventory. The calculated inventory is based on available historical information and records covering 50 years. The actual inventory is based on the nuclear material accounting system introduced in 1965.

enrichment level. The report also detailed the quantity and nature of acquisitions and removals from the HEU stockpile from 1945 to 2004 (see Table 2).

The United Kingdom also initiated efforts to make public certain information about its nuclear material holdings. In 1998, the U.K. government issued a strategic defense review, which declared the total size of its "defense stock of nuclear material." Under

Table 3: U.K. 2000 Plutonium Material Balance Declaration (MT)

ACQUISITIONS	
From Facilities Within the United Kingdom	15.99
From the United States	0.47
From Unidentified Sites	0.37
Inventory Difference	0.29
Total Acquisitions	**17.12**
REMOVALS	
To Facilities Within the United Kingdom	7.50
To the United States	0.47
Expended in Tests	0.20
Barter Material Issued to the United States	5.37
Discards/Sea Dump/Transfers to Waste	0.07
Stockpile	3.51
Total Removals	**17.12**

Source: U.K. Ministry of Defence, "Plutonium and Aldermaston—An Historical Account," 2000, www.fas.org/news/uk/000414-uk2.htm.

guidance from the review, in 2000, the U.K. government issued a report outlining the United Kingdom's historical production of plutonium, as well as an account of current holdings.[22] A report on the production and current holdings of HEU followed in 2006.[23]

The 2000 U.K. plutonium declaration included details about plutonium that was transferred to and removed from the Atomic Weapons Establishment (AWE) Aldermaston, the primary British nuclear weapons research and development complex (see Table 3). This complex also includes facilities for fissile material storage and weapons assembly. The transfers noted include the large quantity of separated plutonium that the U.K. program made available to the United States.

While the 2006 British HEU declaration also focused on HEU as defined by the IAEA (20 percent or more of U-235), it did not include information about the enrichment level of military HEU stocks, nor did it specify how much material each facility contained. It also acknowledged the difficulties of determining which materials had been produced for civil or military purposes.

In 1998 the IAEA published Guidelines for the Management of Plutonium (INFCIRC/549) in response to calls for increased international oversight of separated plutonium.[24] The guidelines substantially increased transparency about states' holdings of civilian plutonium. Under the guidelines, nine states—Belgium, China, France, Germany, Japan, Russia, Switzerland, the United Kingdom, and the United States—agreed to make annual declarations of certain separated plutonium holdings, as well as an estimate of plutonium contained in holdings of spent civilian reactor fuel. In general, these guidelines have led to the regular public release of updated information about certain types of plutonium holdings.

Even though the declarations focus specifically on civil plutonium, the United Kingdom and United States also include unirradiated plutonium declared as excess to military requirements. Declarations include separated plutonium in storage, plutonium in unirradiated mixed-oxide (MOX) fuel elements, plutonium in other unirradiated fabricated forms, and plutonium in the process of being fabricated or manufactured into these forms. The INFCIRC/549 guidelines do not differentiate plutonium that would fall under the categories of weapons grade from fuel grade in U.S. declarations.

States should build on the work that has already been done and informally declare information about their HEU and plutonium holdings.

In recent years, three states—the United Kingdom, Germany, and France—have also reported their civilian HEU holdings as part of their annual INFCIRC/549 declarations. The declarations are generally publicly available and serve as the basis for most independent estimates of national fissile material holdings.

There are some problems with INFCIRC/549 declarations. Because they are voluntary, some states release their annual declarations at a time of their choosing rather than on a regular schedule. The reporting on the amount of plutonium a state owns but that is held in another state is inconsistent. Some states include this information, while others exclude it from their declarations or do not make a declaration at all. For example, Germany does not declare the amount of German-owned separated plutonium stored in other states, nor does it declare the foreign-owned separated plutonium stored in Germany. In total, approximately 10.7 tons of plutonium are owned by states that do not make INFCIRC/549 declarations.

States should build on the work that has already been done and informally declare information about their HEU and plutonium holdings. Such declarations would be more valuable with formal verification provisions, but states would have an incentive to make truthful declarations to avoid loss of credibility if, as verification is phased in under subsequent agreements, major discrepancies are found with the declaration. Informal declarations could also contribute to transparency and confidence building and better prepare states for more formal arrangements.

THE DECLARATION PROCESS

Declarations could start at a general level and become more specific over time as parties agree to include additional details. Depending on the provisions of the particular agreement, an initial narrow declaration may ensure that a commitment to remove declared material from warhead use or from availability for warhead use can be verified. Because material declarations will also be providing corroborating evidence that warhead declarations are complete and that a state has not secretly retained a significant number of warheads, however, material declarations may need to be bounded by a comprehensive accounting of a state's total inventory and include as much information as possible on historic production and use of materials to help corroborate declarations of current holdings.

But because future warhead reductions will likely be progressive, and states are likely to retain substantial numbers of warheads for the foreseeable future, this corroborative aspect of material declarations is more of long-term importance. Declarations of total holdings and information on historical production and use are not essential at the outset—although the most effective baseline declarations would include an aggregate accounting of total holdings and be as detailed as possible for specific categories.

Verification would not necessarily apply immediately to all holdings but would be phased in as detailed arrangements are agreed upon for each step. While baseline declarations could cover total holdings of weapons-usable nuclear material, verification would apply initially to less-sensitive materials and be extended progressively in accordance with successive agreements.

The details of future declarations and verification protocols will be the subject of negotiation, but it is anticipated that baseline declarations would be followed by further declarations, updating or correcting information in the initial declarations and expanding on it by providing more detail. The specifics of the declarations could change over time, as verification is phased in and experience gained, as nuclear reductions proceed, and as confidence in the overall process increases.

Declarations will likely contain aggregated information to obscure sensitive information. Once verification is phased in, a substantial body of records and documentation will be needed to enable the information to be verified. Material accountancy and related information, including facility-specific records and information, will need to be made available to inspectors under appropriate confidentiality arrangements. The range of data needed will be extensive, and it might not be possible to establish ahead of time everything that the inspectors will find useful, especially for sectors where verification methods are less established.

Sample Weapons-Usable Nuclear Materials Baseline Declarations

Table 4 indicates the type of information that states would need to be prepared to declare, and subsequently have verified, if parties are to have confidence that a state's nuclear arsenal reductions are both complete and permanent. It will be some time before states are prepared to exchange all of this information, and it is unlikely that all of the information would be declared at once. Nonetheless, such information would almost assuredly be required over time.

Table 4: Weapons-Usable Nuclear Materials—Illustrative Baseline Declaration Summary

	Materials in warheads	Materials in stocks available for warheads		Materials in naval programs		Materials in other uses		Materials declared excess		**Total Materials in military programs**		Materials in civil programs
Plutonium	Unirradiated	Unirradiated	Irradiated	Unirradiated	Irradiated	Unirradiated	Irradiated	Unirradiated	Irradiated	**Unirradiated**	**Irradiated**	Unirradiated
WG												
Non-WG												
Totals												

	Materials in warheads	Materials in stocks available for warheads		Materials in naval programs		Materials in other uses		Materials declared excess		**Total Materials in military programs**		Materials in civil programs
HEU	Unirradiated	Unirradiated	Irradiated	Unirradiated	Irradiated	Unirradiated	Irradiated	Unirradiated	Irradiated	**Unirradiated**	**Irradiated**	Unirradiated
WG												
Non-WG												
Totals												

This sample worksheet for declarations shows aggregated current inventories, and the unit could be in tons or kilograms. See Appendix C for definitions of material types.

Declarations of Weapons-Usable Materials by Use

Given the sensitivities of many of the categories of use—in warheads, retired warheads, naval fuel—declaring and verifying this information will be challenging.* The following discusses the categories of use into which information on weapons-usable material might be aggregated in declarations, touching on verification issues for materials in the categories.

Nuclear Material Contained in Warheads

The need to protect nuclear weapon design information means that the likely form of a declaration about nuclear warheads will be the numbers of warheads, not details of the amount of material in the warheads. This highlights a major issue for baseline declarations: How much can be declared about nuclear material in weapons?

If the aggregate mass of nuclear material in weapons is excluded from the baseline declaration, the declaration will be incomplete about the material that is of greatest importance for the declaration process. This raises a fundamental question about whether

* Weapons-usable materials also appear in other military uses, including non-civil research reactors and critical assemblies, research activities, and laboratory standards.

to exclude production information for the material streams that went to nuclear warheads. Given the scale of weapons production in the United States and Russia and, to a lesser extent, the other nuclear weapon states, exclusion of such production information would create significant uncertainty about the possibility of materials or warheads diverted outside a monitoring regime. Hundreds of significant quantities of nuclear material could essentially disappear in the gap between the declared mass of non-weapons holdings and the declared numbers of warheads. Excluding all production and disposition information for the materials that went to nuclear warheads could adversely affect the value of the declarations.

One way to deal with this would be to bound the problem. Under this approach, the material flows that went into military holdings would be accounted for, but disposition between stocks (storage) and actual warheads manufactured would not be declared. The declaration would essentially contain a black box for material available for weapons use but would include a declaration of the mass that went into that black box. The difference between current holdings, declared use and disposition, and total production would represent the amount of material still within warheads. A declaration along such lines would provide a good understanding of the total amount of material produced and the division of that material into non-weapons and weapons uses and could be an important step in transparency between states. As stockpiles decrease over time, declarations of material available for weapons versus material surplus to military requirements could be adjusted, as the United States has already done.

Another option would be to declare total aggregate nuclear material in nuclear weapons. The issue with this approach is that it could enable a simple average quantity per weapon to be calculated—though for the United States and Russia, this would not be easy to do. Because a declaration would not distinguish between warheads containing plutonium and those containing HEU, a simple division would not meaningfully indicate the average quantity per warhead. However, for states with smaller numbers and models of warheads, and where either HEU or plutonium predominates, calculating an average per warhead would be easier.

Sensitivities are more obvious where the quantity of material used in a particular warhead design could be revealed, as when reductions proceed and material is transferred from warheads to verified stocks. At that point, verification techniques that mask sensitive information will be needed. At the baseline declaration stage described here, however, states need to critically examine the potential benefits they could derive from exchanging such information and whether the risks from doing so can be satisfactorily addressed.

Verification of nuclear warheads—deployed and non-deployed—and nuclear material in the form of weapon components is discussed in the warheads section of this report. Due to national security sensitivities, it is more likely that the nuclear material content of deployed warheads will not be verified, and all that will be available from each state will be unverified declarations of the aggregate quantities of plutonium and HEU contained in weapons.

Nuclear Material in Stocks Available for Weapons Use

This category could comprise materials specifically set aside for producing warheads; warhead components and sensitive materials arising from warhead dismantlement; materials actually in warheads, obscured through inclusion in this category as discussed above; and weapons-grade materials not allocated to any other use. Here, too, there are likely to be national security sensitivities, certainly for materials with classified isotopic composition. Inspector access to certain types of facilities could also raise sensitivities, requiring special managed access arrangements.

The quantity of HEU involved in the naval sector is huge, but information about naval HEU uses is likely to be regarded as highly sensitive, and substantial obstacles can be expected in developing verification arrangements.

The scope of verification for this material will be subject to negotiation. While it would be desirable to quantify all such material as early as possible, this might not be politically possible in the near term. At least to begin with, the main verification mission might be monitoring to ensure that continuity of knowledge is maintained. Where material is directly verified, this may have to be undertaken on an attribute or template basis, using techniques that can confirm that containers of material meet specified quantity and isotopic parameters without revealing sensitive details (see Chapter 3). Where material is non-sensitive in form and composition, in principle it should be possible to apply conventional verification measures similar to those applied in safeguards.

Weapons-Usable Materials in Naval Propulsion Programs

Many nuclear submarines and other nuclear-powered vessels use HEU of various enrichments, including weapons grade. In some states the quantity of HEU involved in the naval sector is huge.[25] The United States has set aside 128 tons of HEU for future naval use.[26] If Russia has reserved a similar naval stockpile, the global naval HEU stockpile could be some 250 tons—enough for more than 10,000 nuclear weapons. This is comparable to the number of assembled nuclear weapons in the world today. As arms reductions proceed further, material in naval stocks could exceed material in weapons.

Because of the quantity of HEU in the naval sector and the need to ensure this material is not diverted to nuclear weapons, naval reactor fuel and associated stocks may need to be included in the declaration and verification process.* Due to the sensitivity of naval

* A state might simply remove (divert) material from naval programs, believing it will not be detected. A state also may underdeclare the quantities of material in naval programs—that is, fabricate records—and divert the undeclared excess. If the state produces further material for naval use, which is unlikely in the near term for the United States and Russia but possible for others, it might overstate fuel requirements and divert the excess.

fuel designs, naval programs present major verification challenges. Any information about naval HEU uses is likely to be regarded as highly sensitive, and substantial political obstacles can be expected in developing verification arrangements.

There is no IAEA safeguards experience to draw on, as no non–nuclear weapon state (NNWS) has nuclear-powered naval vessels.* The standard IAEA safeguards agreement provides for nuclear material to be removed from safeguards for non-proscribed military purposes under arrangements to be agreed upon between the state and the IAEA, but this provision has never been invoked. For the largest naval programs—those of the United States and Russia—given the very large military HEU stocks outside naval programs, it may be some time before material in naval programs is considered a risk to disarmament, and there may be reasonable time to develop solutions.

Ideally, declarations would break down how much HEU was transferred into the program, how much is currently held as unirradiated stocks and fuel, and how much is in irradiated fuel in naval reactors or in storage. This would help bound the problem by focusing attention on the highest priority areas. Irradiated fuel—fuel in reactors and spent fuel in storage—would not be suitable for weapons use without reprocessing to remove fission products. The main verification interest in this material is as part of accounting for the total material in the program. Any risk of diversion to weapons lies primarily with bulk material (stocks) or with fresh fuel that is no longer required. For smaller programs, it may be easier to find pragmatic solutions. Continuity of knowledge could be maintained for nuclear material being transferred into a naval program, fabricated into fuel, and loaded into a naval reactor. Even if the material is not fully quantified, monitoring could ensure there are no opportunities for diversion. The declarations suggested here would help to define the extent of the situation for each state involved. A next step would be for experts from these states to meet and consider collaborative programs to develop verification solutions.

Nuclear Material in Stocks Declared Excess to Military Requirements

In the simplest case, nuclear materials declared excess to military requirements are not expected to be in sensitive forms and are not likely to have sensitive compositions. There seems to be no reason why measures similar to those used in safeguards could not apply. After initial characterization of these materials, the main verification mission is likely to be to monitor stocks remaining in storage. In addition, there will be verification of materials transferred from storage into civil programs or disposed of, possibly through immobilization in waste forms.

Where material declared excess is still in classified forms and compositions, such as in warheads and warhead components, it would be treated the same as material in weapons

* Canada considered acquiring nuclear submarines in the 1980s but did not proceed. Currently, Brazil has a program to develop nuclear submarines using LEU. The IAEA has been working with Brazil to develop verification procedures.

for declaration and verification purposes. However, such material could be placed under monitored storage to assure it is not redeployed in warheads.

Weapons-Usable Materials in Civilian Programs

Weapons-usable materials in civil programs, including for power generation and scientific research, should be included in declarations to ensure these materials never become available for weapons use. Declarations should contain information about unirradiated materials. Given the substantial quantities of spent fuel in many power programs and the effort that would be involved in calculating the plutonium content, irradiated materials would not need to be included. There may be a need in the future to declare and verify this information, but irradiated materials are not expected to be immediately relevant. Where material has come from dual-use processing facilities, information on these materials may also be needed to enable accounting for material flows through those facilities.

Where weapons-usable materials in civil programs are satisfactorily covered by IAEA safeguards inspections, or perhaps Euratom inspections, this should be sufficient for verification purposes. For the sake of completeness of baseline information, however, all such materials should be included in at least the initial baseline declarations.

VERIFICATION ISSUES

Inspectors will need to inspect, sample, and analyze, as appropriate, declared materials at declared locations to ensure that all material is present and accounted for. To verify declarations, inspectors will require access both to the materials and to detailed accounting records and related documentation for the inventories at each location. It is not feasible to verify a simple total of separated plutonium in a given state. The task has to be broken down into identifiable batches of material at specific locations—apart from anything else, to counter the possibility of substitution, in which a state presents the same batch of material to inspectors at several locations.

It may not be possible to fully verify materials in sensitive form or composition at the outset; certain verification procedures will need to be developed to ensure the protection of sensitive information. For some such materials, it may only be possible to establish continuity of knowledge to ensure materials are not removed.

It also is not simply a matter of verifying initial declarations. Ongoing verification will be required to ensure materials are not diverted to undeclared uses, such as making new warheads, and that newly produced materials are brought under declaration and verification arrangements. This will require verification procedures at all places where weapons-usable materials are held and produced, such as at enrichment and reprocessing facilities. It will possibly also mean monitoring locations where weapons-usable material could be recovered, such as waste storage. Some of this may be verified through complementary regimes, such as IAEA safeguards on weapons-usable materials in civil programs and future Fissile Material Cutoff Treaty (FMCT) verification arrangements. Otherwise, the necessary measures will have to be developed as part of the ongoing verification process.

Many techniques for nuclear material verification are well established. IAEA safeguards have proven highly effective in verifying the non-diversion of declared nuclear materials in NNWS. The United States and United Kingdom have demonstrated practical experience in preparing inventories for nuclear material in their military programs, showing historic production, uses, and dispositions. Through the Trilateral Initiative,* the United States, Russia, and the IAEA have some experience in tackling verification challenges associated with sensitive categories of material. And in South Africa, the IAEA was able to confirm that the country's nuclear weapons program was dismantled (see "Verifying Completeness: The Case of South Africa").

Going forward, extensive R&D to develop, test, and socialize verification methods is critical. All parties to a verification regime must understand the technical bases of verification methods and agree that they are relevant to verification objectives, as well as sufficiently reliable and accurate. Parties must be satisfied that the risks of verification errors are at an acceptable level. By this same token, cooperatively developing declarations might increase both trust and a realistic understanding of their precision. Adequate access and time for deliberate and careful application of verification measurements is important. In some cases, multistage sampling and analysis programs, in which earlier results dictate the nature of final verification measurements, may be required. Because nuclear inventories are not static, verifying initial baseline declarations will be the first step in a continuing process. Any declarations regime and its corresponding verification arrangements will have to include procedures for maintaining currency.

Who Would Verify?

Where sensitive materials and facilities are involved, inspections may be limited to a bilateral arrangement. However, global confidence in the integrity of the verification process is likely to require multilateral verification arrangements. NNWS will want to ensure there is no collusion among nuclear-armed states and that verification is carried out to requisite technical standards.

Where there are no sensitivities regarding material or facilities, the verification mission will be very similar to IAEA safeguard efforts, and there seems to be no reason why this could not be entrusted to the IAEA. Here the main constraint is likely to be the need to establish verification approaches and arrangements for specific facilities, including installation of verification equipment. Even where there are sensitivities, the development

* See Chapter 3.

VERIFYING COMPLETENESS: THE CASE OF SOUTH AFRICA

The international effort to verify the destruction of South Africa's nuclear weapons program in the early 1990s is the first example of rigorous verification of a state's nuclear material declaration for correctness and completeness.

When South Africa signed the Nuclear Nonproliferation Treaty (NPT) in July 1991, it declared its highly enriched uranium (HEU) holdings in an initial report to the IAEA without acknowledging why it had an inventory of this kind. The material was placed under IAEA safeguards, and IAEA inspectors verified the weight and isotopic composition against South Africa's initial declaration.

The verification task took on a new dimension in March 1993 when South Africa acknowledged the existence of a former nuclear weapons program, which it had dismantled independently, before signing the NPT. The IAEA assumed a new threefold mission, certifying that the previously declared HEU had been used in weapons; that South Africa had not produced more weapons than they declared; and that South Africa had fully dismantled its small arsenal of gun-type weapons.

Because South Africa had dismantled its nuclear weapons before opening its program to international inspection, observers relied heavily on verifying the characteristics of its nuclear material stockpiles to ensure that all the program's materials had been accounted for and all nuclear weapons destroyed. IAEA representatives found that most warhead records were unavailable, having been lost or destroyed. During the dismantlement process, further significant evidence had been lost, such as from the non-nuclear parts of the program. The key question for the inspection team was whether the large inventory of HEU declared and presented to the IAEA was consistent with what reasonably could have been produced.

To facilitate the verification exercise, South African authorities provided access to all facilities the team requested to visit, as well as detailed shift-by-shift operating records and stage operations logs for the entire 15 years of the enrichment plant's operations. South Africa provided historical flows and balances, as well as information on production and transfers of nuclear material. Some records dated back to the 1970s and, fortunately, had not been destroyed. To ensure the records were authentic, South Africa allowed inspectors to send samples away for forensic analysis.

The traditional U-235 material balance approach did not establish the completeness of South Africa's declaration because the South African material accountancy system lacked formal measurement controls for depleted uranium. However, the South Africans' operating records allowed the team to reconstruct plant operations across 15 years to determine the amount of HEU that could have reasonably been produced.

The records had been kept to maintain plant operations amidst persistent mixing and chemical loss problems, not to facilitate future verification. However, these records, coupled with the level of access South African officials granted inspectors to plant operators and personnel, were absolutely essential to facilitating the IAEA's completeness assessment. Important complementary information came from verification activities such as environmental sampling, recharacterization of wastes, and evaluation of non-nuclear production parameters.

To avoid any bias in the reconciliation, no member of the inspection team involved in the reconstruction was given any knowledge of the amount of material declared. The result of the inspectors' daily reconstruction exercise was very close to the amount of HEU initially declared and presented by South Africa and verified for correctness by the IAEA.

In judging completeness, the inspectors looked for consistency. The records, cooperation, transparency, and access granted by the South Africans over the life of the verification mission built the inspecting team's confidence that there were no undeclared facilities similar to the plant they had inspected and that the HEU from South Africa's former nuclear weapons program had been returned to peaceful uses under IAEA safeguards.

For states with larger stockpiles of nuclear weapons and materials, more expansive nuclear infrastructures, and longer program histories than that of South Africa, preserving supporting information and preparing material declarations in support of future verification is even more important. The confidence in South Africa's declaration could have been increased had South Africa involved other states or international entities in dismantling its nuclear weapons and maintained better documentation of its weapons program. And although the verification exercise to determine the completeness of its declaration was successful, it will be harder to replicate without such international cooperation if the scale of a state's program is significantly larger.

of attribute- or template-based methods and appropriate managed access arrangements should enable verification to be undertaken on a multilateral basis.

Expanding the capacity of the IAEA to monitor weapons-usable nuclear materials in nuclear-armed states will require substantial strengthening of the IAEA's human resources capacity and budget. The nuclear-armed states and the wider IAEA membership should seek agreement to establish a special fund to cover the costs of verifying baseline declarations and ongoing verification.

Lessons Learned from the IAEA

Where there are no complications of classified form or composition, verification of nuclear material could be based on methods developed for IAEA safeguards. These include methods such as on-site inspections and observation, measurements, and sampling and

Source: IAEA

The laser scanner takes three-dimensional images of rooms in nuclear facilities and compares them with previous images to see if any changes have been made.

Source: Petr Pavlicek/IAEA

Metallic seals are used to prevent unauthorized access to safeguarded materials. The inside of each seal has its own unique markings (like a fingerprint). Before a seal is used, the markings are recorded. If the seal is tampered with, these markings will change. When returned to the IAEA, the seal is carefully analyzed to ensure its integrity.

analysis, as well as containment and surveillance techniques for maintaining continuity of knowledge. In recent years, extension of these techniques to real-time or near-real-time remote monitoring has assumed increased importance. Information analysis, including use of satellite imagery, is becoming increasingly important, particularly in addressing the possibility of undeclared nuclear activities.

IAEA safeguards experience shows that verification can deliver a high degree of effectiveness for declared nuclear materials. Here, the challenges in baseline verification relate to accessibility and timing—that is, how and when materials will be made available for verification. That is not to say, however, that verification would be the same as the process for safeguards. It will be necessary to consider how the various parameters developed for NNWS—such as detection goals, timeliness goals, and what constitutes significant quantities of nuclear material—would be applied in states with nuclear weapons. For example, the significant quantity (SQ) for plutonium, defined for safeguards purposes, is 8 kilograms. This quantity may be too rigorous for states with thousands of nuclear weapons. In this case, a strategically significant quantity might be closer to 10 to 20 SQ (80 to 160 kilograms).* For states with smaller numbers of weapons, including the major weapon states as weapon numbers are reduced, a lower value may be important.

Verification of past production and use history—distinct from declared holdings, which may be verified by direct measurement—will present more challenges than the safeguards-like applications due to the potential for greater measurement errors and the difficulty of integrating information over several sets of production eras, facilities, and technologies.

Historical Nuclear Material Inventories

To enable verification of material declarations, a state will need to prepare and provide information on the total production of materials over the life of its nuclear program. Declarations containing information on the use or disposition of materials—that is, transactions that change the inventory of a particular material—would help reconcile current holdings with total production (see Figure 3). In accordance with nuclear material accountancy principles, current holdings should be the sum of total production and inventory changes (increases and decreases), such as nuclear transformation, losses, nuclear decay, consumption, and transfers (shipments and receipts). Any significant inventory differences or anomalies identified through material accountancy or verification would require investigation.

* For the purposes of the Trilateral Initiative, a significant quantity equivalent to 1 percent of the material inventory was considered.

Figure 3: Relationship of Historical Production, Uses and Losses, and Current Holdings

Production	+	Inventory increases	−	Inventory decreases	+/−	Inventory differences	should =	Current holdings
weapons-usable nuclear material produced by the state		additional material available to the state, e.g., transfers received		includes nuclear transformation, process losses, nuclear decay, consumption, and transfers (shipments)		differences between accounting inventory and physical inventory (otherwise known as MUF, material unaccounted for)		weapons-usable nuclear material now held by the state

Uncertainties in Nuclear Material Accounts

Nuclear material declarations are necessarily based on nuclear material accounting records. Broadly speaking, nuclear material accounting involves recording when materials are produced, consumed, altered, or lost; tracking when materials enter or exit a particular facility or material balance area; taking periodic physical inventories, in which actual material holdings are measured for quantity and composition; and reconciling records of material transactions, records of current inventories, and physical inventories.

Two issues must be addressed in using nuclear material accounting records to verify baseline declarations: whether the records are accurate and whether they exist in the first place. Drawing together information on current inventories should be straightforward, as current records would be up to date in most, if not all, relevant states. Historic records are more challenging. Reconstructing historic records is an important part of ensuring that current inventories are complete and that there are no significant holdings of nuclear material outside declared inventories.

Large programs, such as those of the United States and Russia, have an extraordinarily complex history, involving many facilities, forms of material, and production and processing approaches. This history stretches over decades and includes periods during which approaches to record keeping and accounting for the material changed substantially. Some of the original production and operating records have likely been destroyed, and many of the operators who could have helped explain those records are no longer available.

Apart from issues associated with whether historic records exist, material accounting records contain some inherent uncertainties, due to practical factors in making measurements, possible measurement errors, clerical errors, in-process material holdup, and unmeasured losses to waste. If there are uncertainties in a state's own understanding of its history, and those uncertainties cannot be reduced, the state may not be able to issue precise declarations. As a result of efforts by national regulators, the IAEA, and others to refine material accounting practices, improve measurement capabilities, and develop new information systems, today's material accounting uncertainties are generally small. Uncertainties will be of greater practical significance for the United States and Russia. As each country produced material for tens of thousands of nuclear weapons, even one percentage point of uncertainty is a very large amount of material in the context of disarmament. Other states have produced material for hundreds or dozens of weapons, so uncertainties are likely to be much smaller.

The 1996 U.S. declaration of historical plutonium production[27] listed an inventory difference—the difference between the quantities noted in the material accounting records and those measured in physical inventories—of 2.8 metric tons. With further effort, the DOE reduced this discrepancy, and in its plutonium declaration of June 2012,[28] the inventory difference was 2.4 metric tons. This represents 2.5 percent of the total plutonium inventory, a reasonable percentage considering the historic circumstances but, nonetheless, a very large quantity. Much of this inventory difference is thought to be in the form of waste from normal operating losses, but at this stage no one can say for certain.

Two issues must be addressed in using nuclear material accounting records to verify baseline declarations: whether the records are accurate and whether they exist in the first place.

The inventory difference for U.S. declarations of HEU[29] was much smaller in percentage terms—0.5 percent of the HEU inventory as of 2004—but again a substantial quantity: 3.2 metric tons of U-235. The inventory differences in U.K. declarations were 0.22 metric tons (1.0 percent) in 2006[30] and 0.29 metric tons (1.7 percent) for plutonium in 2000.[31]

Russia's Soviet-era accounting system was designed to monitor whether facilities were meeting production quotas, not to detect theft or to provide the basis for comprehensive material declarations. At many facilities, if output was within 3 percent of input, the difference was considered a normal loss to waste. It is very likely that when Russia matches historical additions and subtractions to current holdings, the uncertainties may be even larger than in U.S. declarations.

The problems facing states preparing baseline declarations are similar to the problems that, in due course, will face inspectors: how to reconstruct material production and disposition records where adequate records do not currently exist, and how to assess and validate the accuracy of historical accounting records. For historic production and disposition, both the declaring state and inspectors are likely to need to draw on nuclear archeology methods to complement nuclear material accountancy. Some uncertainties will remain even with substantial effort to improve historical accountancy records.

NUCLEAR ARCHEOLOGY: A TOOL FOR DECLARATIONS AND VERIFICATION

In states with large and long-running nuclear programs, the collection and analysis of nuclear material accountancy information will need to be complemented by activities collectively known as *nuclear archeology*.

Originally the term described a program of technical measures to initialize estimates of weapons-usable materials—that is, to validate the historical record of production of plutonium and HEU for weapons purposes. Today the nuclear archeology concept has evolved and expanded to include the preservation of materials, facilities, and records that will be needed to clarify historical production, uses, and losses of nuclear materials. Nuclear archeological methods can enable a more complete control regime for weapons-usable materials. This could address the extent and disposition of existing material stocks and their appropriate role in future weapons and weapons-limitation agreements.

Auditing Historical Records for Production and Use of Plutonium and HEU

As mentioned, both the United States and United Kingdom have undertaken audits of historical plutonium and HEU production, uses, and losses with encouraging results. For plutonium, the auditing process starts with a description of the design of plutonium production reactors and detailed data on the history of their operation.[32] Such data should include original records of fuel loaded into reactor cores, with details on mass and enrichment levels, enrichment levels and burn-up of discharged fuel, overall reactor power as a function of time, coolant flows and inlet and outlet temperatures, and records of design, operation, input, and output of reprocessing facilities. The original historical operating records for production reactors and reprocessing facilities could then be examined and analyzed to ensure they are consistent internally and with the declaration.

Auditing of HEU production at enrichment starts with the operational records for uranium entering the plant as feed; records of each product shipment, including quantity and enrichment level; and quantity and enrichment levels of the tails over the entire period of the plant's operation.[33] The mass of U-235 entering the plant should be equal, with some error, to the masses of U-235 in HEU shipments and in depleted tails. Validating the records will be complicated by factors such as use of different enrichment technology (gaseous diffusion and centrifuge), enrichment of recycled uranium, further enrichment of already enriched uranium, production of LEU for power reactor fuel, enrichment of tails, and variation in U-235 concentration in enriched material and tails. As a result, record keeping of the quantities and concentrations of input and output flows for such operations will not always be complete.

Another approach for verifying HEU production declarations would be auditing the historical records for separative work unit (SWU) production allocated to HEU production. Acceptability of this approach would require determination of cumulative SWU for HEU and LEU with an overall accuracy of less than one percent.

As some may doubt the authenticity or completeness of operating records, and some operating records have significant uncertainties, actual measurements of production facilities and related technical measures can provide a useful supplement, confirming and in some cases even improving the precision of declarations based on operating records alone.[34] Forensic analysis could also be applied to show that paper records are original.

Confirming Plutonium and HEU Production by Physical Verification Measurements

Physical methods for confirming historical plutonium production are based on the fact that neutrons alter the isotopic composition of the moderator and structural materials of plutonium production reactors. Isotopic ratio methods (IRM) are used to examine the isotopic compositions of samples taken from graphite and structural materials, correlating them with cumulative local neutron flow and cumulative local plutonium production in specified parts of the reactor core.[35] Samples are taken from the reactor's core structural components—concrete, steel, and graphite—with subsequent sample preparation and measurements of shifts in isotopic ratios for such elements as boron-11/boron-10, neon-21/neon-20, chlorine-36/chlorine-35, calcium-41/calcium-40, and titanium-49/titanium-50. For some reactor types, the data obtained and the knowledge of reactor physics allow estimating cumulative plutonium production in the entire core over its entire lifecycle with standard errors of less than two percent.[36]

The implementation of the isotopic ratio method for verifying plutonium production has shown promising capability. The best example of a nuclear archeology technique for calculating plutonium production is the graphite isotope-ratio method (GIRM), which relies on measurements of the isotopic ratio for impurities in graphite from graphite-moderated production reactors. It was developed by Pacific Northwest National Laboratory (PNNL) and demonstrated an acceptable accuracy. Examination of many reactor-grade graphites from several states shows that useful impurity elements are generally available. The PNNL calculation for the U.K. graphite-moderated, gas-cooled Magnox reactor, based on the estimated neutron fluence from measurements of isotopic ratio, predicted production of 3.633 tons of plutonium, while actual production as declared by the operator was 3.63 tons.[37] GIRM may make it possible to improve, not only confirm, the operator's own understanding of how much a given facility has produced. However, this work requires further discussions, experience sharing, and demonstrations among nuclear experts from different states.

One important limitation of the GIRM method is that it can be applied only to graphite-moderated reactors. An extension of the isotopic ratio method to heavy water-moderated production reactors, based on measurement of the isotopic ratios of chlorine, calcium, titanium, and nickel, has been proposed.[38] The applicability of this proposed method needs to be explored in full-scale experiments to quantify errors and validate optimum sampling strategies.

Analysis based on nuclear archeology techniques provides only an upper level for the total amount of plutonium produced in a reactor, because about 1 to 2 percent is lost during extraction of plutonium from irradiated fuel during reprocessing. The final estimate of useful cumulative plutonium production has to be combined with the uncertainties of GIRM and estimated reprocessing losses, bringing the accuracy of estimation to within 3 to 7 percent.[39]

It is possible to estimate historic production of HEU by measuring the processed uranium. In addition to U-238 (99.3 percent) and U-235 (0.7 percent), natural uranium contains traces of U-234 (0.0055 percent). Measurements of the ratio of U-234 to U-235 in tails from enrichment plants could be used to determine the product enrichment level.[40] To ensure highly accurate estimates, samples must be taken for tails from LEU, slightly enriched uranium, and HEU produced by enrichment plants over their lifecycles. When the ratio of U-234 to U-235 is combined with the mass for each type of tails or with information from other sources, it can help to estimate the enrichment and mass of the product and to build confidence that a declaration of production is accurate.

There are some major practical and technical drawbacks. First, because tails were considered waste, many were never measured properly and are no longer available because they were used in depleted uranium munitions, in ship ballast, or for other purposes. For tails in storage, a huge sampling campaign would be needed to create a detailed understanding of the contents of storage cylinders.

There are at least two more complications affecting estimations of measurements. The first is that the concentration of U-234 in natural uranium can vary by more than 10 percent from sample to sample. Another is the possibility that uranium used as enrichment feed was recycled through recovery by reprocessing reactor fuel. In this case, the isotopic composition of uranium feed would be different from natural uranium, and estimation requires that the composition of the feed uranium is known. The National Academy of Sciences has concluded that additional work is required to develop a method for accurate estimates of HEU production based on physical measurements.[41] One possible approach is to examine residual materials on the surfaces of enrichment plant equipment. Decay products of U-238 and other isotopes can be characterized with high accuracy at very low levels using secondary ionization mass spectrometry (SIMS) to yield information about uranium enrichment. PNNL is examining this set of methods in an internal research program, which is entering its third and final year.

Confirming Historical Records of Dispositions

In most cases, physical verification methods for historical inventory changes will be not possible, but measurements may be possible for materials still available, such as wastes.

NATIONAL PREPARATORY ACTIVITIES

In advance of any formal declaration or agreement, states will need to begin to prepare for nuclear material baseline declarations, including preparation and validation of the information to be gathered for baseline declarations. This will also provide insights into what is required for verification.

Much of the information that a state would gather as part of a predeclaration process will never need to be shared. This preparatory work, internal to the state, should include detailed information about material that went into nuclear warheads and nuclear testing, even if that information is sensitive. The state can decide later what to release. This decision will be better informed if the state has accurate information about its own holdings. Given the long-term importance of bringing all separated plutonium and HEU into the baseline process, the work should extend to civil material as well. Research reactors and power reactors may not be optimized for weapons-grade plutonium production, but they would still be relevant in a scenario in which all weapons-usable material is controlled, regardless of its current attractiveness.

Activities in the Preparatory Stage

Because the predeclaration process will not necessarily be tied to a particular declaration format, the order of collection and level of detail about activities and material holdings will likely differ from state to state. However, there are several overarching steps that all states might take as part of a predeclaration process (see Table 5).

- Prepare a complete list of nuclear material production facilities, focusing primarily on uranium enrichment facilities, plutonium production reactors, reprocessing facilities, and other facilities, such as hot cells, that have been used in the production of separated plutonium. This list of facilities should include all those capable of producing weapons-usable material, regardless of whether or not they remain active or how much material they have produced. As much information as possible should also be gathered about the types of operations and processes that have occurred at each facility.
- Gather and preserve detailed production records for each of these facilities, including both paper and digital records. These should include dates during which facilities were in operation and identify key personnel able to assist in explaining the operating history.

- Records for plutonium production reactors should include reactor type, coolant, and moderator; the makeup of the reactor core and various fuel designs; and operating records, including cooling water throughput, inlet and outlet operating temperatures, and the burn-up of the discharged fuel. Ideally, this information would be specific to discharge batches for each reactor.
- Production records for reprocessing facilities should include the type of reprocessing method; the flowsheet and list of reagents used in each process; amount and type of feed materials, including fuel design, batch origin and fuel burn-up, and waste products; and the total mass and isotopics of the plutonium separated. This information should be specific to each reprocessing batch.
- Production records for enrichment facilities should include enrichment technology used, cascade configuration, SWUs of configurations, operating temperatures and pressures, amount and type of feed materials and waste products, and total mass of HEU produced by enrichment level. Because enrichment facilities typically operate in continuous mode, records should be presented for monthly or annual production.

It may be difficult for a state to compile detailed records of historical production, particularly if records were kept poorly or not at all. But the process of gathering and consolidating records could be among the most important steps a state could take in preparing to make a material baseline declaration and in facilitating the verification of that declaration. States could:

- Ensure that appropriate nuclear material accounting practices are in place at all facilities with nuclear materials. Ideally, a state would have a national nuclear material accounting system that serves as a clearinghouse for nuclear material accounting records from all facilities.
- Make available as much information as possible about their nuclear material accounting standards and practices and about their nuclear regulatory processes generally, including information about historical material accounting practices. Such transparency, though not extending to information about specific materials, would provide insight and assurance to other states.
- Involve an international organization, a private entity, or another state in developing, maintaining, and regulating nuclear material accounting practices. This would be another way to increase transparency without making specific information about material accounting practices or regulatory processes publicly available.

The preparatory stage would also be an opportunity for a state to consider whether certain types of information are sensitive and could lead to security threats if shared, either with other governments or with the public, and to segregate, as far as possible, these records from those essential to supporting declarations of nuclear material production and holdings. As a trust-building mechanism, and to glean expertise from states with

Table 5: Preparatory Activities Governments Could Undertake for Baseline Declarations

Collection of documents (hardcopy and digital) relating to all aspects of the nuclear material cycle history.
Oral histories from nuclear workers to compensate for possible gaps in the surviving documentation.
Current inventories and the results from domestic safeguards measurements carried out to confirm those measurements.
Measurement data from current work used to validate the historical record (e.g., analysis of reactor graphite).
An archive or index that may or may not be a physical repository of all information but contains pointers to all of the available information and structures so it can be reviewed.
Reconciliation of the different accounting systems used.
Assembly of all the available information into a single summary of national holdings, including an estimate of the uncertainties on the values presented.
An internal audit of the summary of holdings to determine the accuracy of the summary and identify where there are gaps in the available evidence.
Identification and development of additional historical research efforts and physical measurement efforts that would fill gaps in the record or reduce the uncertainties.

more experience in pulling together historical information, states may find value in collaborating informally to collect and organize non-sensitive information in preparation for baseline declarations under a negotiated regime.

Nuclear Security Benefits

The preparatory process would have benefits for implementing national nuclear security requirements by identifying holdings of sensitive nuclear materials, especially if exchanges of information on nuclear warheads and weapons-usable nuclear material stockpiles take place between trusted partners, coupled with visits to some stockpile locations to help confirm the information exchanged.

First, the act of putting together the data and matching old production records to current holdings may prompt improvements in nuclear material accounting, as states seek to reconcile their data and avoid having similar problems and uncertainties arise in the future. Second, states are likely to be motivated to fix any obvious and embarrassing weaknesses in security, control, and accounting before allowing foreign visitors to come to their nuclear facilities. Third, information on how much material there is, and where, would contribute greatly to assessing the size of the nuclear security problem and planning for international cooperation to address it. Finally, if governments exchange this information, they could also partner to improve nuclear accounting and control measures, which could contribute to other long-term objectives.

MATERIALS SUBGROUP RECOMMENDATIONS

- **Preserve national records and collect oral histories from retired personnel.** To facilitate future baseline declarations and enable verification of those declarations, a top priority should be to preserve current and historical information on the production and disposition of weapons-usable nuclear materials, including hard-copy and digital records. Where records are incomplete or inconclusive, questions should be clarified with personnel familiar with the operations concerned. Because some nuclear programs have been running for decades, many of these individuals may be nearing retirement or are already deceased. This process should thus begin immediately, while personnel who can clarify details of historical operations are still available to recount oral histories.

- **Pursue joint R&D on nuclear archeology methods.** Funding and expertise for collaborative R&D of nuclear archeology methods for different reactor types and uranium enrichment technologies should be prioritized. Methods for graphite-moderated plutonium production reactors are well established, but further work is needed to develop approaches for heavy water reactors as well as gaseous diffusion and centrifuge enrichment plants.

- **Preserve physical facilities, where possible, to permit future verification activities.** U.S. plutonium production reactors at Hanford are temporarily preserved in an environmentally sound manner within newly built enclosures, making future studies on their graphite cores possible. Physical facilities should be preserved in a similar manner elsewhere. In most cases, such preservation will be compatible with verifiable facility deactivation and may also be the most cost-effective course of action.

- **Take and preserve measurements and samples before dismantling or disposing of facilities or waste.** Where dismantling facilities or disposing of relevant waste products is planned, measurements and samples should also be taken and preserved to make sure future verification efforts are possible and credible. Experts from other states or multilateral entities could also be asked to take measurements at facilities or validate quantities and characteristics of materials. Where anomalies exist, other experts could be brought in as a confidence-building or transparency measure to reconstruct missing information.

- **Lead nuclear archeology demonstrations.** The United States and Russia should collaborate to demonstrate to other interested states the current capabilities and limits of the graphite isotopic-ratio method (GIRM). Demonstrations at one U.S. reactor and one Russian reactor could be a precursor to international technical collaboration to improve existing nuclear archeology methods and develop new approaches for other types of reactors.

- **Develop verification approaches for naval fuel.** HEU in the naval sector is a particularly vexing verification challenge, due to national security and proprietary concerns. States that use HEU in naval fuel should establish a cooperative dialogue to develop verification approaches to confirm, without compromising sensitive information, that none of the material designated for naval use is being used, in violation of agreements, to produce warheads.

- **Share best practices.** Some states have valuable experience that, if shared, could enable other states to make unilateral declarations, reduce barriers to formal baseline declaration arrangements, and move the development of verification methods forward. U.S. and U.K. experts should engage with their counterparts in other states with nuclear weapons to share their experience in assembling information on their historic plutonium and HEU production and use. This would enable states to implement best practices and establish their own inventory histories for unilateral declarations and future baseline declarations and verification. It would also be helpful if South Africa were prepared to develop a report on its experience of having the equivalent of a baseline declaration verified, and if the IAEA, in consultation with South Africa, were to report on its perspective on the lessons from the South African experience.

- **Make informal declarations on holdings of weapons-usable materials.** Voluntary and informal declarations of weapons-usable material holdings, unilaterally or in collaboration with other states, can be done without having to wait for formal agreements. These measures are of significant value in helping to establish data consistency over time. Some states have made informal declarations already. The more detailed the declarations are, the greater their potential value to transparency and confidence building.

- **Transfer weapons-usable materials excess to military requirements to civil programs under IAEA safeguards.** Where weapons-usable materials have been sanitized and are excess to military requirements, as with materials released through warhead dismantlement or stocks that are no longer needed, the material should be either verifiably disposed of and rendered practicably irrecoverable or transferred to civil programs and placed under IAEA safeguards. A longer-term objective should be for the IAEA to apply active safeguards to all weapons-usable materials in civil programs in all states. A study is needed into the funding and resources that would be required for the IAEA to do this.

5. Establishing the Absence of Undeclared Warheads and Materials

Even if all warheads and components in states' inventories have been authenticated, tracked, and verified, and all declared weapons-usable materials accounted for and continuously monitored, states will still need to deal with the possibility that undeclared warheads, materials, or material production facilities exist. To deal with this, it is essential to understand how a state might cheat, and in response, develop a system that deters illicit behavior and mitigates these risks by providing sufficient confidence that attempts to retain or clandestinely produce undeclared warheads and materials would be detected. National technical means (NTM) and other intelligence sources, production and assembly records, information collected during on-site inspections, and a range of other data from complementary regimes and activities will be essential to dealing with this challenge over the long term.

There are a few basic pathways for a state to hide or procure undeclared warheads or materials. A state could withhold a cache of warheads from the declaration process by keeping them outside the verification regime or passing off fake warheads as real. A state could also illicitly manufacture new nuclear weapons at secret locations, using existing, undeclared material; material diverted from a declared facility; or newly produced material from a clandestine production facility.

Any attempt to cheat would likely require the use of secret facilities. One or more secret storage facilities would be required to store and maintain undeclared warheads. Likewise, undeclared weapons-usable nuclear material would need to be stored and later fabricated into weapons components and assembled into nuclear weapons. If a state had made correct and complete declarations of its nuclear warhead and weapons-usable nuclear material stockpiles at the outset, a later decision to cheat would also require secret facilities to produce new nuclear material, process it into weapons components, and assemble the components into nuclear warheads.

Many facilities associated with nuclear programs are small and would be difficult to find, especially in a larger and territorially diverse state. Nevertheless, some clandestine activities would create indicators, such as radiation and gaseous and electronic emissions, that could reveal their existence. In Iran, the IAEA and the intelligence agencies of member states identified a series of facilities Iran had intended to keep secret, including the Natanz and Fordow enrichment facilities. The IAEA, with help from member states, succeeded in putting together a fragmentary but reasonably extensive picture of the organizations involved in the secret program and how they fit together. There can be no guarantee that secret facilities would be found, but the Iran example and others suggest that any state considering cheating using secret facilities would run the risk of detection.

A state attempting to cheat could also draw up false declarations that might be consistent with all the information initially available to inspectors. This is a serious challenge, but over time, intelligence and other sources of information can reveal inaccuracies. In Iraq, Saddam Hussein's officials made false declaration after false declaration, but these declarations were often internally inconsistent or contradicted by other information that inspectors managed to find, which allowed inspectors to press Iraqi counterparts on the discrepancies and get information that was closer to the truth. Similarly, Iran repeatedly made declarations to the IAEA that it now acknowledges were false, including its initial claim that it had not conducted unsafeguarded uranium enrichment experiments. But the IAEA—piecing together information from its own inspections, from open sources (such as a dissertation and a journal article that each described experiments that had not been declared to the IAEA), and from intelligence provided by IAEA member states—peeled back multiple layers of false statements to reveal Iran's deception.

The effort to confirm the completeness of a state's entire nuclear program inevitably draws from interrelated state activities that are different parts of the nuclear weapons and materials lifecycle. Inspectors would need to monitor and verify active warheads, reserve or non-deployed warheads, warheads awaiting dismantlement, material undergoing sanitization after dismantlement, material in reserve but not yet excess, and material in other uses and sectors, including naval and research.

In-depth cooperation from the inspected state is essential to drawing a conclusion about a state's entire nuclear program. Lack of cooperation can itself be an indicator that a state may be hiding information or items. The state needs to declare not only how many warheads and how much nuclear material it has, but also what it produced and where it all went. It needs to provide information about the operation of the facilities that produced this material so that information can be checked to the greatest extent

BASELINE DECLARATIONS AND UNDECLARED ITEMS

States that declare the total size of their stockpile may face skepticism. States might deliberately mislead or make partially true declarations, provide ambiguous declarations open to several interpretations, or provide genuine declarations that are open to great suspicion regarding their accuracy. And of course, at a given time, states may be willing only to declare a defined part of their inventory of nuclear warheads or components. As the equations below demonstrate, verifying baseline declarations can help mitigate these risks, given the insight the process provides.

If we consider a fixed but unspecified number of warheads to be deliberately undeclared at a time zero, t0, then a given state's total number of warheads at time zero would be

$$N_{total}(t_0) = N_{declared}(t_0) + N_{undeclared}(t_0),$$

where t = time, and t_0 = time zero, the start of the process. If the inspecting party is allowed to monitor only the change in the declared type of warhead, that is

$$d\,(N^{declared})/d\,t),$$

then all the verifier knows, after each inspection, is that the number of nuclear warheads extant in the state at time t is

$$N_{total}(t) = (N_{declared}(t_0) - N_{dismantled}(t)) + N_{undeclared}(t_0).$$

There is still a potentially large stockpile of undeclared items, $N_{undeclared}(t_0)$, and perhaps a question about the weapons that the state has dismantled, $N_{dismantled}(t)$. The inspecting party would need to verify the declared dismantled warheads through a sufficiently rigorous system and confirm that the dismantling state did not cheat on the dismantlement verification process by diverting warheads or components to a hidden location.

There would also be a question about whether a state had operated any clandestine manufacturing facilities over the period t_0 to time t. This would compound the uncertainty; $N_{undeclared}$ would not be a constant number and $N_{undeclared}$ at time t would become

$$N_{undeclared}(t) = N_{undeclared}(t_0) + N_{manuf.clandst}(t).$$

It follows that the equation for the total number of warheads in the state in question at some time t, which we will call $N^*_{total}(t)$, would more realistically become:

$$N^*_{total}(t) = (N_{declared}(t_0) - N_{dismantled}(t)) + N_{undeclared}(t_0) + N_{manuf.clandst}(t).$$

Nevertheless, were the state at any future time to decide or be forced to declare its undeclared numbers, either hidden or manufactured clandestinely, then the value of having at least monitored the number $N_{declared}(t_0) - N_{dismantled}(t)$ is significant.

practical. Inspectors will also need access to production records and to people involved in the production to help interpret those records.

Depending on how records were kept, nuclear weapon serial numbers may provide an additional source of verification information. If production records indicate that a weapon with a particular serial number was produced in a particular year, and there is no record of it having been dismantled or consumed in testing, inspectors could ask to be shown that particular weapon. If a randomly selected sample of weapons are all present in the declared stockpiles at the declared facilities, this could increase confidence that the overall declaration is complete.

The next step would be to permit inspection of original production records. In some cases, these may contain such sensitive information (e.g., elements of weapon design) as to make this a substantial challenge. In other cases, the information may simply refer to particular weapon serial numbers having been produced on particular days, which may not be especially sensitive. If original paper records are available, forensic techniques could be used to check their authenticity—for example, whether the paper and ink date back to the time when the records are said to have been made. Even if the originals are gone and only digital records are available, it may be possible to check them for internal consistency, consistency with other information available to other states, and the like. The mere willingness to make declarations of production and allow production records to be reviewed would contribute substantially to building confidence that the inspected state has told the whole story.

Another step would be for states to declare all the facilities that they used to make plutonium and HEU weapons components, with their production and destruction histories. All the same approaches just discussed could be used to check this information. Then, this information could be checked for consistency against the warhead production information, combined with declarations on how many nuclear weapon components are currently in storage outside of warheads.

States will also need information from national technical means, past agreements or declarations, and other complementary regimes and activities that can provide additional insight. For instance, with 34 parties, the Open Skies Treaty allows for aerial surveillance flights, using commercially available optical, infrared, and other sensors over the entire territory of member states. Although it is not likely that detailed weapons baseline and location data could be collected, it could provide additional information for detecting undeclared activities and add confidence to the baseline verification effort. Other proposals, such as a fissile material cutoff treaty (FMCT) that would prohibit further production of weapons-usable nuclear material for nuclear weapons, will be essential complements to the baseline declaration and verification process.

It is impossible to quantify how much confidence the full suite of verification measures for nuclear weapons and weapons-usable nuclear materials can provide. Even with an elaborate system to track known declared warheads, it will be difficult to have a high degree of confidence that no clandestine warhead manufacturing program exists unless there are other complementary regimes like an FMCT and verified conversion of fissile material from dismantled weapons to peaceful purposes.

Information derived in one particular agreement can increase confidence in the verification of another. Unfortunately, most of the transparency measures that have occurred to date have each grown up in isolation, with different officials negotiating them and pursuing different objectives and little effort to develop synergies among them. For example, the definition of what constitutes weapons-grade plutonium is different for the plutonium disposition agreement, the Plutonium Production Reactor Agreement, and U.S. proposals for the Mayak storage facility.

In the future, it might be possible to bridge the differences among the agreements through an integrated system. If a system were established to confirm warhead dismantlement, containers with HEU and plutonium components could be tagged and sealed at dismantlement facilities and tracked to storage facilities. These same containers could be shipped from their storage facilities to disposition sites, where the material could be confirmed to enter the process, and then be measured once it has been converted to unclassified form. This would provide transparency throughout the chain from assembled weapon to reactor fuel.

It is impossible to quantify how much confidence the full suite of verification measures for nuclear weapons and weapons-usable nuclear materials can provide.

Building on existing regimes is particularly important given the strong sensitivities that continue to exist in many states about declaring nuclear-related information. New declarations that build on steps already taken—or that incorporate lessons from past experiences—are more likely to succeed.

A SYSTEMS APPROACH

To gain confidence in the completeness of a state's baseline declaration using the full suite of complementary activities and regimes, a systems approach will likely be needed. In this regard, there are important lessons to be learned from the evolution of the IAEA international safeguards regime. The IAEA is currently investigating how to integrate the data available from state declarations, inspections and technical monitoring, open source information, Additional Protocol access, and other sources to gain a more complete view of a state's nuclear activities.[42] If all the information fits together—with no major contradictions, holes, or unexplained anomalies—the IAEA draws the broader conclusion that all the state's nuclear materials have been declared and are under safeguards and that nothing has been hidden.

Integrating data from different sources presents a number of challenges, including variation in the trustworthiness of the data. Data presented unilaterally, without the opportunity for verification, may raise more red flags than data collected in a verified, multilateral environment. Additionally, restrictions on sharing information collected under bilateral and multilateral regimes might limit dissemination beyond state signatories.

Sharing verification data outside the scope of original legal agreements has been an ongoing issue in bilateral and multilateral treaties. Bilaterally, there have been challenges with public sharing of New START declarations; multilaterally, with the protection of state-sensitive information and the limits to the IAEA and Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) sharing data gathered from the International Monitoring System.

If a systemic state-level approach were used for transparency and verification of the full lifecycle of states' nuclear weapons programs, some of the challenges of integrating data from complementary regimes and activities could be addressed as part of the development of the assessment process. Such an approach would allow for regimes monitoring weapons, materials, and delivery systems to be brought together to achieve an overall level of transparency and, ultimately, trust in confirming inventories. International cooperative projects should investigate whether systems approaches could be valuable for this purpose, so guidelines could be developed in advance of future treaty negotiations.

BUILDING A WEB OF CONFIDENCE

No single approach will eliminate the possibility that a state has managed to hide a small stockpile of nuclear weapons. In a real verification system, anomalies can arise because of good-faith mistakes, measurement errors, and equipment and human failures. Verification will need to include platforms for discussing and resolving such anomalies and for correcting and updating declarations, as the IAEA safeguards system and past arms control agreements have done. Drawing a conclusion about how much confidence one should have in the veracity of a declaration requires expert judgment based on all available evidence.

Data coming from a range of unilateral, bilateral, and multilateral agreements, as well as from tools such as societal verification, can be mutually reinforcing and provide far greater confidence than any of the individual measures alone can provide. With data exchanges at many points of nuclear weapon and material lifecycles, along with information states already have, it would become increasingly difficult for an inspected state to come up with a strategically significant lie that was consistent with the information available to the other parties to an agreement. A declaration about how many nuclear weapons a particular facility assembled each year would have to be consistent with the information intelligence agencies collected about that facility at the time, with what people who worked there or officials who oversaw the facility may have said in other contexts, with information about where those nuclear weapons went and the delivery vehicles to which they were assigned, and with information about the production of the relevant plutonium and HEU components. The information about plutonium and HEU component production would have to be consistent with intelligence and open-source information and with information about the production and shipment of plutonium and HEU. Information about the production of plutonium and HEU would have to be consistent with intelligence and open-source information, with information about production of fuel for plutonium production reactors and power for the enrichment plants, and with the wastes from these facilities. And so on.

Combining a broad range of information from many sources allows greater confidence that the overall picture in the declarations is complete, reducing the risk that anything substantial is hidden. How much confidence will be enough is ultimately a political judgment that policymakers will have to make, based not only on technical analysis but also on the perceived benefits of the proposed agreement, the overall level of trust among participating states, and the options available for responding to violations.

Verifiable baseline declarations would give policymakers a mechanism for building trust and confidence over time and mitigating the risks posed by undeclared warheads and materials. Further research and technical analysis is needed on a number of issues, perhaps most of all on core non-compliance and enforcement challenges. Any move toward deep reductions or elimination will be difficult, and these issues may be the most pressing challenges over the long term. This will be a long and difficult process, and more work is needed. Verifiable baseline declarations are an essential first step.

6. Recommendations

The full working group put forward the recommendations that follow as priorities for governments and steps that states can take to deal with the challenges of verifying nuclear warhead and weapons-usable nuclear material declarations. Perhaps most important, the group concluded that all parties—states with nuclear weapons, states without nuclear weapons, and international organizations—can and should play a role in future verification and monitoring activities.

The working group recommends that stakeholders:

- **Expand multilateral technical engagements.** Multilateral engagement on cooperative inspection methods, equipment, and activities should be expanded and prioritized. It can take years to qualify tools for inspections. States that have collaborated in developing and testing specific methods for high-security authentication, unique identification, and continuity of knowledge become intimately familiar with their design and application. Such familiarity can foster cooperation and may make states more likely to include these systems in future agreements. Outside experts and rising specialists from states without extensive verification experience should also be encouraged to participate. Including experts from states without nuclear weapons can strengthen international confidence in the integrity of verification systems and arrangements. Priority should be given to approaches that enable such participation without compromising sensitive information. Future collaboration should also take into account relevant safety and security qualification standards so that new methods and equipment comply with multiple national standards.

- **Prioritize verification research and dialogue.** Collaboration on verification methods and techniques should be complemented by a sustained dialogue among international experts on practical and technical approaches to baseline declarations and verification arrangements. Such a process would be most effective if it were conducted at the government level, with participation from other experts. Topics for engagement could include:
  - Declaration content and format
  - What information states are prepared to make public, exchange with other states confidentially, or share with particular states
  - What information should be preserved through nuclear archeology programs to facilitate future verification, such as historical information on material flows and facility information
  - What is needed for effective verification, what existing measures can achieve, what complementary regimes and activities can contribute, what obstacles may arise, and what areas require further development
  - Who would verify baseline declarations, what areas might be priorities for verification, and how verification could be phased in to address these top priorities
  - How an integrated system for verification and evaluation could be developed, and how states can mitigate the risks posed by the retention or clandestine production of warheads or materials
- **Review national classification standards and information.** For future verification systems to be as effective as possible, parties will need to deal with differences in national classification standards. This should begin with each state reviewing internally what it currently considers classified information and whether certain information can be declassified or shared in some form with other governments in the context of deep reduction and verification requirements. The process should involve information security experts and verification specialists to better understand the benefits and risks involved and assess how to manage them. The careful sharing of classified information can simplify verification procedures, make technical methods easier to implement, and give states more confidence in the results.

7. Appendix A

Definitions and Terminology

Alternative nuclear materials: elements, aside from uranium and plutonium, which are capable of a nuclear chain reaction, have the potential to be used in a nuclear explosive device, and are of safeguards interest. Based on information from the nuclear weapon states, the International Atomic Energy Agency (IAEA) has described americium and neptunium as two such materials.[43]

Assay: a measurement that establishes the quantity and composition of nuclear material present in the items being measured—e.g., the concentration of U-235 in a given enrichment product or in depleted uranium tails.[44]

Authentication: a term that is often used in two different ways when considering nuclear disarmament topics:

> **Equipment authentication:** the process by which an inspecting party gains appropriate confidence that the information reported on a treaty item by an inspection or monitoring system accurately reflects the true nature of the item.
>
> **Warhead authentication:** the process of confirming that a nuclear warhead item is real; ideally, this process is different and independent of methods used to maintain continuity of knowledge and is sometimes referred to as *initialization*.

Baseline declaration: an initial statement of the number or quantity of accountable items or materials—perhaps specified by parameters such as type or category—against which other information may be compared and future progress may be measured.

Certification: the assessment process conducted by the host party to gain appropriate confidence that verification equipment will reveal only that information that has been agreed to within the context of a specific verification regime and that is safe to use in the proposed manner and locations.

Completeness: term used in the context of an agreement requiring a state to declare all its holdings of nuclear materials, specified nuclear materials, or warheads. To confirm that the declaration is complete means to confirm that the state has declared all that it is required to declare and that there are no undeclared materials or items in contravention of the relevant agreements.

Continuity of knowledge: the process of keeping continuous track of specific materials and items until they are no longer subject to treaty commitments.

Cooperative verification: the process by which treaty partners assist each other in verifying that treaty obligations are being met; cooperative verification includes such activities as on-site access to weapons systems and military facilities, joint development of monitoring and inspection technologies, and the sharing of sensitive information among the parties.

Correctness: for nuclear material, the accuracy of a declaration compared to the physical inventory of nuclear material to which it relates, as confirmed by measurement, sampling, and analysis of the material that the state presents to inspectors as being included in the declaration; for warheads, the accuracy of a declaration compared with the inventory of warheads to which it relates, as confirmed by observation and other measures applied by inspectors.

Current holdings/inventories: the physical inventory of a state's nuclear material holdings, measured in accordance with nuclear material accountancy principles as the sum of total production and inventory changes, including nuclear transformation, losses, nuclear decay, consumption, and transfers.

Dismantlement: "the process of taking apart a nuclear warhead and removing all subassemblies, components, and individual parts for the purpose of physical elimination of the nuclear warhead; dismantled subassemblies, components, and parts, including nuclear materials, may be put into a disposal process, may be used again in another warhead, or may be held in strategic reserve."[45]

Enrichment product: the result of the uranium enrichment process, in the form of uranium hexafluoride, with varying concentrations of the isotope uranium-235.[46]

Fuel burn-up: for nuclear fuel, a measure of how much energy is extracted; usually computed by multiplying the thermal power of the reactor by the time of operation and dividing by the mass of the initial fuel loading, to give a figure in megawatt days per ton (MWd/t) of heavy metal (uranium, plutonium, etc.). Burn-up is an indicator of the isotopic composition of plutonium produced in reactor fuel.

Graphite isotope-ratio method (GIRM): a nuclear archeology technique for calculating plutonium production that relies on measurements of the isotopic ratio for impurities in graphite from graphite-moderated reactors, developed by the United States' Pacific Northwest National Laboratory.

Highly enriched uranium (HEU): uranium containing 20 percent or more of the isotope U-235.[47]

Host: the state that owns the nuclear warheads that are subject to cooperative inspection and monitoring, that is most concerned about protecting sensitive information from being divulged, and that is responsible for safety and security during inspections. Representatives of the host government facilitate and control all on-site inspections.

Information barrier: a system of procedures, devices, and/or software used to protect sensitive information from unauthorized release and, at the same time, allow inspection and monitoring equipment to be certified and authenticated and verification information to be presented.

Inspection: the examination of treaty-accountable items, typically during an on-site visit, according to a cooperative and formally negotiated protocol for the purpose of verifying a treaty-required declaration.

Inspector: unless otherwise indicated in this report, any external person (i.e., from outside the state) who undertakes verification activities, whether bilateral, multilateral, or international.

Inventory difference: the difference between the quantities noted in material accounting records and those measured in physical inventories; possible causes include measurement errors or losses to waste from normal operating processes. See also *material unaccounted for (MUF)*.

Irradiated material: nuclear materials, in the form of spent fuel or targets, that have been irradiated in a reactor and have not been chemically treated since unloading from the reactor; considered unsuitable for use in a nuclear explosive device or nuclear weapon without reprocessing to separate fissile material from fission products.

Irreversibility: the quality or state of not being able to be reversed; holds a number of meanings relevant to nuclear materials, including:

> **Legal irreversibility:** making a legally binding commitment not to use particular material in weapons again.[48] The relevant agreement could include verification to confirm that the commitment is honored.
>
> **Physical irreversibility:** making it physically difficult and costly to recover material for use in weapons—for example, by blending down HEU to LEU or using plutonium in mixed oxide fuel (MOX) or immobilizing it.
>
> **Political irreversibility:** making a political commitment not to return particular material to weapons use.

Isotopic ratio methods (IRM): a set of physical verification measures through which isotopic compositions of samples taken from graphite and structural materials can be correlated with cumulative local neutron flow and cumulative local plutonium production in specified parts of the reactor core.[49]

Key indicators: situational information or objects known to be associated with a treaty-accountable item that add independent credibility about a declaration related to the item.

Losses: nuclear materials lost to waste during processes such as enrichment, reprocessing, fuel fabrication, and manufacture of nuclear weapons.

Low-enriched uranium (LEU): uranium with a concentration of the isotope U-235 that is higher than that found in natural uranium but lower than 20 percent (usually 3 to 5 percent).[50]

Material unaccounted for (MUF): the difference between the amount of nuclear material recorded on the book inventory and the amount of nuclear material in the physical inventory, represented by the following equation:

$$MUF = (PB + X - Y) - PE$$

where PB is the beginning physical inventory, X is the sum of increases to inventory, Y is the sum of decreases from inventory, and PE is the ending physical inventory.[51]

Monitoring: the collection of information by a country on the forces and activities of another country using open-source information, national technical means, and cooperative inspections associated with an agreement or treaty.[52]

Neutron fluence: the number of neutrons traveling through a unit area over a unit of time over a certain time period.

Nuclear archeology: the application of technical methods to clarify or confirm historical production records and fill gaps in those records; this study suggests extending the term to also encompass preservation of materials, facilities, and records that will be needed to clarify historical production, uses, and losses of nuclear materials.

Nuclear component: the fissile nuclear material, such as plutonium or HEU, that has been formed for use in a nuclear warhead.

Nuclear explosive device: a nuclear warhead or other nuclear assembly system not necessarily associated with a military delivery system; such an assembly may be designed for peaceful use, a nuclear test device, or an improvised device constructed by non-state actors as an instrument of terror.

Nuclear material accounting/nuclear material balance: activities carried out to establish the quantities of nuclear material present within defined areas and the changes in those quantities within defined periods.[53]

Nuclear warhead: "that part of a missile, projectile, torpedo, rocket, or other munitions that contains either the nuclear or thermonuclear assembly system intended to inflict damage,"[54] or "any compact assembly of high explosive and accepted quantity of fissile material."[55]

Deployed warhead: a warhead maintained in an operational, ready-for-use configuration.[56]

Inactive warhead: a warhead maintained at a depot in a non-operational status.[57]

Non-deployed warhead: a warhead removed from a military deployed status but, typically, still part of a strategic reserve.

Retired warhead: a nuclear warhead or warhead type/class that has been permanently removed from future use for military purposes and is slated for eventual physical dismantlement.

Nuclear weapon: a military explosive system designed to inflict damage, consisting of both a fully functional nuclear warhead assembly and a delivery system; the terms *nuclear warhead* and *nuclear weapon* are often used interchangeably.[58]

Physical inventory: synonymous with current holdings; the sum of all measured or derived estimates of batch quantities of nuclear material on hand at a given time.

Plutonium grades: classification of plutonium according to its isotopic composition; *weapons grade* refers to the isotopic composition of plutonium typically used in nuclear weapons, *fuel grade* refers to the isotopic composition of plutonium in some power reactors, and *reactor grade* refers to the isotopic composition of plutonium typically found in discharged power reactor fuel.

There is no single internationally accepted system of grades. These grades formulated by the U.S. Department of Energy are commonly used:[59]

Weapons grade: contains less than 7 percent of the isotope Pu-240.

Fuel grade: contains between 7 percent and 19 percent Pu-240.

Reactor grade: contains more than 19 percent Pu-240.

Production factor: the amount of plutonium produced per megawatt-day of reactor operations.

Secondary ionization mass spectrometry (SIMS): an emerging nuclear archeology technique characterizing decay products of U-238 and other isotopes through examination of residual materials on the surfaces of enrichment plant equipment; capable of yielding highly accurate information about uranium enrichment.

Separated material: See **unirradiated material**.

Separative work unit (SWU): a unit used to measure uranium enrichment effort, namely, the energy input relative to the amount of uranium processed, the level to which it is enriched, and the level of depletion of the tails.[60]

Significant quantity: the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. Significant quantities take into account unavoidable losses due to conversion and manufacturing processes and should not be confused with critical masses. Significant quantities are used in establishing the quantity component of the IAEA inspection goal. See the table below for significant quantities, as defined by the IAEA:[61]

Material	Significant quantity
Direct use nuclear material	
Plutonium	8 kilograms
U-233	8 kilograms
HEU (U-235 ≥ 20 percent)	25 kilograms

Tails: the material, other than the enrichment product, left after the uranium enrichment process, which is mostly depleted of the isotope U-235.

Tails assay: the concentration of U-235 in the tails following the uranium enrichment process; indirectly determines the amount of separative work that needs to be done on a particular quantity of uranium in order to produce a given product.

Transparency measures: information, access, or other measures offered to provide greater insight into a state's strategy, posture, or infrastructure. In general, transparency measures are less intrusive than a verification regime.

Treaty accountable items: the specific items denoted in a formal treaty subject to treaty commitments, often referred to as items of accountability, items of inspection, or treaty-limited items.

Tritium: a radioactive isotope of hydrogen; adds to the explosive power of a nuclear weapon through a nuclear reaction.

Type I error: a false positive; in the context of verification, a valid declaration is rejected as being false.

Type II error: a false negative; in the context of verification, a false declaration is accepted as being valid.

Uranium hexafluoride: a chemical compound consisting of one atom of uranium combined with six atoms of fluorine. It is the chemical form of uranium that is used during the uranium enrichment process, for isotope separation, and as feed material for reactor fuel fabrication.[62]

Unirradiated material: nuclear materials that have not been irradiated in a reactor or have been separated from irradiated material through reprocessing. Unirradiated weapons-usable material requires less time and effort to be converted to components of nuclear explosive devices than do irradiated materials. Includes separated plutonium, HEU, and the plutonium content in MOX.[63]

Verification: the process undertaken to assess whether a country is complying with commitments in a treaty or agreement.

> **Effective verification:** a verification regime that provides the degree of assurance required by the parties; not an absolute but a matter of judgment, based on the parties' assessment of a number of factors.

Warhead design information: technical information that is typically considered sensitive and classified and made available only to trusted individuals within a nuclear weapons state; if known, it would help someone else manufacture a nuclear explosive device.

Weapons-usable nuclear materials: nuclear materials suitable for use in the manufacture of nuclear weapons. For the purposes of this study, these were taken to be HEU, separated plutonium, and U-233. These correspond to the IAEA's definition of direct-use materials for safeguards purposes.[64]

8. Appendix B

Nuclear Arsenal Declarations

Date	Country	Category or description	Number declared
4/2014	United States of America	U.S. stockpile of nuclear weapons (active and inactive)	4,804[1]
4/2014	United States of America	Warheads on deployed ICBMs, on deployed SLBMs, and nuclear warheads counted for deployed heavy bombers	1,585[2]
9/2009	United States of America	U.S. stockpile of nuclear weapons (active and inactive)	5,113[3]
4/2014	Russian Federation	Warheads on deployed ICBMs, on deployed SLBMs, and nuclear warheads counted for deployed heavy bombers	1,512[4]
6/2011	United Kingdom	Limit of U.K. overall stockpile of nuclear warheads (by mid 2020s)	180[5]
6/2011	United Kingdom	Limit of U.K. operational warheads	120[6]
5/2010	United Kingdom	Limit of U.K. overall stockpile of nuclear warheads (by mid 2020s)	225[7]
5/2010	United Kingdom	Limit of U.K. operational warheads	160[8]
3/2008	France	Ceiling for France's nuclear warhead arsenal	< 300[9]

1 U.S. Department of State, Fact Sheet, Transparency in the U.S. Nuclear Weapons Stockpile, April 29, 2014, http://www.state.gov/t/avc/rls/225343.htm

2 U.S. Department of State, Fact Sheet, April 1, 2014, http://www.state.gov/t/avc/rls/224236.htm

3 U.S. Department of Defense, Fact Sheet, Increasing Transparency in the U.S. Nuclear Weapons Stockpile, May 3, 2010, http://www.defense.gov/npr/docs/10-05-03_fact_sheet_us_nuclear_transparency__final_w_date.pdf

4 U.S. Department of State, Fact Sheet, April 1, 2014, http://www.state.gov/t/avc/rls/224236.htm

5 U.K. Secretary of State for Defence, Dr Liam Fox, http://www.publications.parliament.uk/pa/cm201011/cmhansrd/cm110629/wmstext/110629m0001.htm

6 U.K. Secretary of State for Defence, Dr Liam Fox, http://www.publications.parliament.uk/pa/cm201011/cmhansrd/cm110629/wmstext/110629m0001.htm

7 Foreign Secretary William Hague, https://www.gov.uk/government/news/foreign-secretarys-statement-on-the-nuclear-non-proliferation-treaty-review-conference

8 Foreign Secretary William Hague, https://www.gov.uk/government/news/foreign-secretarys-statement-on-the-nuclear-non-proliferation-treaty-review-conference

9 President Nicolas Sarkozy, Presentation of SSBM, "Le Terrible," March 21, 2008, http://www.ambafrance-uk.org/President-Sarkozy-s-speech-at,10430

9. Appendix C

Nuclear Material Baseline Declarations: Options and Process

DECLARATION CONTENT

Unirradiated and Irradiated Materials

The declaration process will likely cover all weapons-usable materials available, or potentially available, for nuclear weapons use. Primarily, this means unirradiated materials, as irradiated materials are not suitable for use in nuclear weapons without being separated. Irradiated materials could also be relevant, however, as parties need to be satisfied that arrangements are in place, through a fissile material cut-off treaty or similar agreement, to ensure that nuclear weapon stocks do not increase through further reprocessing. In addition, information on holdings of irradiated materials may be necessary for verifying material flows from military production facilities.

Accordingly, baseline declarations may need to include information on current holdings of irradiated weapons-usable materials (for irradiated materials in civil programs, see p. 92).

Weapons-Grade and Non-Weapons-Grade Materials

Plutonium. While there are no internationally agreed on definitions of isotopic grades for plutonium, the definitions applied by the U.S. Department of Energy (DOE) are well established:

- Weapons grade: Pu-240 content less than 7 percent;
- Fuel grade: Pu-240 content between 7 percent and 19 percent;
- Reactor grade: Pu-240 content more than 19 percent.

In U.S.-Russia discussions about nuclear material attributes, weapons grade plutonium is defined as having a Pu-240 to Pu-239 ratio of less than 0.1 (i.e., less than 10 percent

Pu-240). This was the definition used in the U.S.-Russia-IAEA Trilateral Initiative in testing attribute verification techniques.[65]

States will also need to decide if baseline declarations should distinguish among plutonium grades. As the declaration process is intended to support nuclear weapon reductions, verification arrangements should ensure there is no substitution of weapons grade by lower-quality plutonium (i.e., that the state concerned withholds weapons-grade plutonium). Differentiating among plutonium grades is also important for estimating total plutonium production, another potential verification priority. Fuel burn-up correlates with the Pu-240 percentage for a given reactor, and the production factor for total plutonium (gm Pu/MWdT) changes with burn-up. Neutron fluence for a particular reactor can be estimated, but to be useful that fluence needs to be allocated to grades of plutonium.

Accordingly, it will be helpful to differentiate between weapons-grade and non-weapons grade plutonium. The U.S.-Russia weapons-grade/non-weapons-grade split (i.e., 10 percent Pu-240) has the merit of having been applied in practice, and seems appropriate for the purposes of baseline declarations. This is not to imply that non-weapons grade plutonium is not relevant to disarmament. In the long run, all plutonium will be of weapons relevance, regardless of Pu-240 content; in a world with a small number of nuclear weapons and smaller stocks of weapons-usable materials, the strategic value of a few weapons would make lower-grade plutonium much more attractive than it was when weapons-grade plutonium was readily available.

Highly Enriched Uranium (HEU). In international practice, there is no distinction between weapons-grade and non-weapons-grade HEU as there is for plutonium. The U.S. DOE has a definition of weapons grade as being 93 percent or more U-235, but it is well known that nuclear weapons have been made with HEU below this enrichment. HEU of 80 percent enrichment was used for the Hiroshima bomb.

Reporting on all HEU holdings as being equally weapons-usable, however, is misleading, as, in practice, HEU at the lower end of the HEU range—below, say, 50 percent U-235—is unlikely to be used for nuclear weapons. The United States has recognized this by a number of different approaches to reporting on HEU inventories. One approach has been to report HEU inventories by both total HEU mass and total U-235 isotope, so it is obvious from the average enrichment value that not all the HEU is weapons grade. The problem with this approach is that it is unclear how much of the total HEU is at or close to weapons grade. While a formal definition of weapons grade for HEU is not essential, it would be helpful for baseline declarations to report HEU in two bands—say, 20 to < 90 percent U-235, and ≥ 90 percent U-235.

Alternative Nuclear Materials

The United States has acknowledged that americium and neptunium are potential nuclear-weapons-usable materials.[66] Some other elements with isotopic forms could potentially support an explosive nuclear chain reaction, but these are too rare or radioactive to be of major concern.[67] Based on information from the nuclear weapon states, the IAEA has described americium and neptunium as alternative nuclear materials (ANM) that are of safeguards interest and has established reporting arrangements and verification approaches for reprocessing plants (flowsheet verification) to monitor holdings of separated americium and neptunium in non–nuclear weapon states. If these holdings approach significant levels, the IAEA will consider formally declaring these as safeguardable materials.

Against this background, ANM could be relevant to disarmament. Although, as far as is known publicly, ANM are not currently used in nuclear weapons, ANM may become attractive if the availability of plutonium and HEU is affected by future stockpile reductions. This is not an immediate issue, however, and there is likely to be considerable sensitivity among the nuclear weapon states in revealing information on the potential weapons use of ANM. Thus the inclusion of ANM in declaration and verification arrangements at an appropriate time should be a matter for further study for nuclear-armed states and others.

Other Non-Fissile Materials Relevant to Nuclear Weapons

The obvious material of interest here is tritium, which is used in boosting the explosive yield of nuclear weapons.[68] In addition to tritium in military programs, substantial quantities are produced in civil programs through the operation of heavy water-moderated power reactors, and there are also significant civil applications.[69]

Because tritium decays at around 5.5 percent per year, limiting the production of tritium could force the pace of nuclear disarmament, or at least require significant changes to nuclear stockpiles. While this might sound appealing to disarmament proponents, however, it is unrealistic to expect that nuclear-armed states will be prepared to accept any mechanism that forces the pace of disarmament beyond their control. Nuclear disarmament will proceed at a pace influenced by confidence in the process, not dictated by a physical occurrence, such as diminishing stocks of a strategic material.

While the nuclear-armed states are unlikely to accept limits on tritium production, this does not mean there would be no value in declaring tritium holdings in military programs. It could be useful as a transparency effort: The more open states are about tritium, the more open they are being about their weapons programs, so the declaration of tritium may have a place on the road to further disarmament. In addition, information on historical tritium production is helpful in reconstructing the operating histories of some (dual-product) plutonium production reactors. Accordingly, total production and current holdings of tritium in military programs could be included in declarations complementary to the baseline declarations.

Other Nuclear Materials Relevant to the Production of Weapons-Usable Materials

Although the primary focus of the declaration and verification process would be weapons-usable materials, as stocks of materials available for weapons use are reduced, it may be desirable to also take account of material readily upgradable for weapons use. The main example is low-enriched uranium (LEU) in the form of uranium hexafluoride (UF_6), which can be used as feed material for producing HEU. If there are concerns about the possibility of diversion of LEU for higher enrichment, the verification arrangements may need to include LEU, at least until it has been further processed from UF_6. This is something that might be evaluated as part of a state-level verification approach. While this may be an issue for consideration in the future, such materials may not need to be included in baseline declarations.

DECLARATION OPTIONS

As discussed in this report, there are various options states could consider for the content of baseline declarations (see Table 4 in Chapter 4 for an illustration). Initially, each entry would be an aggregate figure for the total quantity of material included, but more detailed information in support of declarations would need to be made available to inspectors as verification is phased in.

A minimal declaration would be the total current inventory of weapons-usable nuclear material in military programs, without including irradiated material or differentiating between weapons-grade and non-weapons-grade material. In addition, the total inventory of such material in civilian programs would be declared; in the following discussion, it is assumed states would not object under any of the options to also declaring material in civilian programs.

However, it is to be hoped states can look beyond a minimalist model and will be prepared to break down this information into greater detail. This kind of breakdown will give a clearer picture of the status of materials in different parts of military programs and, in due course, will help in prioritizing verification efforts. However, there are many possible combinations and permutations, as shown in the following paragraphs.

Option A: Total quantity of each type of nuclear material in military programs

The declaration would show the total unirradiated holdings of each type of nuclear material (i.e., one figure each for plutonium, HEU, and U-233).

This is a minimal declaration and does not include irradiated material or differentiate between weapons-grade and non-weapons-grade material. A declaration of this kind is too broad to be reasonably verifiable. It would be primarily a transparency measure—a rather limited one—and a first step toward more meaningful declarations.

Option B: Figures for each type of nuclear material in military programs, broken down as:

- **Available for nuclear weapons**
- **In other uses**

The declaration would break down the total current unirradiated holdings of each type of nuclear material (plutonium, HEU, and U-233) into two totals. The first total, "available for nuclear weapons," would combine material in warheads and material in stocks available for nuclear weapons. The second total, "in other uses," would combine material in naval programs, material declared excess to military requirements, and material in other military use. These figures would not include irradiated material or differentiate between weapons-grade and non-weapons-grade material.

This option could be attractive for states reluctant to declare how much material (in total) is in weapons, though some way will eventually have to be found for this to be declared (see Option E).

Option C: Figures for each type of nuclear material in military programs, broken down as:

- **Available for nuclear weapons**
- **Declared excess to military requirements**
- **In other uses**

The declaration is similar to Option B except it would separate "excess material" from material "in other uses." Material "in other uses" would comprise material in naval programs and in other military use. These figures would not include irradiated material or differentiate between weapons-grade and non-weapons-grade material.

This kind of declaration is beginning to be more useful, because it identifies material available for verification—that is, it should be possible to verify material declared excess (the United States, United Kingdom, and Russia have declared excess material and made it available for monitoring).

Option D: Figures for each type of nuclear material in military programs, broken down as:

- **Available for nuclear weapons**
- **Declared excess to military requirements**
- **In naval programs**
- **In other uses**

The declaration is similar to Option C except it would separate the total quantity of material in naval programs from the total for material "in other uses." These figures would not include irradiated material or differentiate between weapons-grade and non-weapons-grade material.

Quantifying the material in naval programs will indicate how much of a problem naval programs present—or not—for the verification task.

Option E: Figures for each type of nuclear material in military programs, broken down as:

- **In nuclear weapons**
- **Available for nuclear weapons**
- **Declared excess to military requirements**
- **In naval programs**
- **In other uses**

The declaration would be similar to Option D except it would separate the total quantity of material in nuclear weapons from the total for material "available for nuclear weapons." This option still does not include irradiated material or differentiate between weapons-grade and non-weapons-grade material.

Declaring a total for material in nuclear weapons would focus attention on the main area of concern (weapons) and widen the scope of verification. Verification of "material available for weapons" could be straightforward, at least where this material is in unclassified form and composition.

Option F: Figures for each type of nuclear material in military programs, including irradiated material:

- **In nuclear weapons**
- **Available for nuclear weapons**
- **Declared excess to military requirements**
- **In naval programs**
- **In other uses**

The declaration would be similar to Option E except it would show totals for irradiated as well as unirradiated material. This option still does not differentiate between weapons-grade and non-weapons-grade material.

Adding irradiated material helps to narrow down how much of the HEU in naval programs presents a potential risk of diversion to weapons. Inclusion of irradiated material is also important as part of countering possible further undeclared production.

Option G: Figures for each type of nuclear material in military programs, including irradiated material, and divided by grades of plutonium and HEU:

The declaration would be similar to Option F, with the totals for each material type differentiating between weapons-grade and non-weapons-grade material. Differentiating between weapons-grade and non-weapons-grade will be particularly useful in narrowing the material of concern in naval programs.

HISTORICAL INFORMATION

Information on historical production, uses, and losses in military programs will also need to be assembled and made available to help in validating declarations of current inventories. States might not have all historical information at hand when baseline declarations are made, but this information will be needed as verification of declarations proceeds.

Suggestions for how historical information might be set out are shown on the next two pages for HEU and plutonium.

Military program: Historical production, uses, and losses of HEU at a certain date

Unirradiated HEU	**Kilograms**
Inventory increases	
(1) Production (enrichment)	
(2) HEU from reprocessing (recycling)	
(3) Transfers (receipts) from other states	
(4) Transfers (receipts) from civil program	
(5) **Total increases**	
Inventory decreases	
(6) Consumption (tests)	
(7) Discards to waste (including process losses)	
(8) HEU fuel (transfers to irradiated account; line 14)	
(9) Transfers to other states	
(10) Transfers to civil program	
(11) **Total decreases**	
(12) Inventory differences	
(13) **Ending inventory**	

Irradiated HEU	**Kilograms**
Inventory increases	
(14) Transfers (receipts) of HEU fresh fuel (see line 8)	
Inventory decreases	
(15) Fission and transmutation	
(16) Transfers to reprocessing	
(17) Final disposal (if applicable)	
(18) Total decreases	
(19) **Ending inventory**	

(20) **Ending inventory: irradiated plus unirradiated**	

Note: Similar declarations to be made for U-233, if applicable.

Military program: Historical production, uses, and losses of plutonium at a certain date

Irradiated plutonium	**Kilograms**
Inventory increases	
(1) Production	
(2) Transfers (receipts) of unirradiated plutonium fuel (line 16)	
Inventory decreases	
(3) Transfers to reprocessing	
(4) Nuclear decay	
(5) Fission and transmutation	
(6) Final disposal (if applicable)	
(7) **Total decreases**	
(8) **Ending inventory**	

Unirradiated plutonium	**Kilograms**
Inventory increases	
(9) Plutonium recovered by reprocessing	
(10) Transfers (receipts) from other states	
(11) Transfers (receipts) from civil program	
(12) **Total increases**	
Inventory decreases	
(13) Consumption (tests)	
(14) Nuclear decay	
(15) Discards to waste (including process losses)	
(16) Plutonium in fresh fuel (transfers to irradiated plutonium account; see line 2)	
(17) Transfers to other states	
(18) Transfers to civil program	
(19) **Total decreases**	
(20) Inventory differences	
(21) **Ending inventory**	

(22) **Ending inventory: Irradiated plus unirradiated**	

OUTLINE OF THE DECLARATION AND VERIFICATION PROCESS

Phase 1: National Preparatory Activities

- Action at the international level: Establishment of experts' dialogues, collaborative programs among the parties
- Action at the national level
  - preparing current inventories
  - assembling details on historical military production, uses, and losses
    - Bilateral or multilateral collaboration on validating this information, where possible, would contribute to confidence in the information.

Phase 2: Making the Baseline Declaration

Phase 3: Ongoing

- Current inventories regularly updated for inventory changes (new production, use, transfers)
- Information on historic production, uses, and losses to be assembled, revised, and corrected, as appropriate
- Verification to be phased in for material in current inventories
  - While the objective would be to cover all inventory areas as quickly as possible, introduction of verification is likely to be sequential due to sensitivities for some areas.
  - Verification measures introduced to address possible undeclared material and activities.
  - As the operational scope of verification widens, more and more of the information in the baseline declaration will be confirmed.
- Regular updated declarations (as distinct from the baseline declaration) to be issued showing current inventories, with particular focus on remaining nuclear material in weapons or available for weapons

10. Endnotes

1 The Final Document of the 2000 NPT Review Conference urged progress on "increased transparency by the nuclear weapon states with regard to the nuclear weapons capabilities … as a voluntary confidence-building measure to support further progress on nuclear disarmament." See NPT/CONF.2000/28. In 2010, NWS were encouraged "to agree as soon as possible on a standard reporting form … for the purpose of voluntarily providing standard information without prejudice to national security." See NPT/CONF.2010/50.

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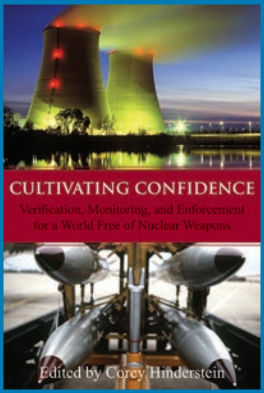

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