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Comprehensive nuclear material accounting

A proposal to reduce global nuclear risk

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Contents

Executive summary

Existing national and international standards for accounting for nuclear materials, including those designated for military use, are insufficient to meet current and future nuclear security, nonproliferation, and weapons reduction demands. Improved accounting practices are needed to provide reliable assurance that nuclear materials designated for peaceful use have not been diverted to state-level nuclear weapons programs or stolen by non-state actors, as well as to deter or detect diversion or theft, were it to occur. Implementing an effective and efficient comprehensive, global nuclear accounting system is also a critical element of creating the conditions for future nuclear security if global nuclear energy use increases as part of the effort to mitigate climate change and countries make deep cuts to, or potentially eliminate, their stockpiles of nuclear weapons and nuclear materials designated for military use.

Policy makers from around the globe have recognized the importance of ensuring that all countries with nuclear materials or weapons practice high standards of material control and accounting (MC&A), but the emphasis of current initiatives to improve MC&A has been on national laws and regulations—and primarily in states without nuclear weapons. States have yet to develop comprehensive requirements that address the full scope of nuclear risks and that are meant to be adopted by all states—including nuclear weapons states.

This study examines a range of current material accounting practices and requirements and argues that in order for MC&A to fully perform the functions necessary to reduce global nuclear risks to an acceptably low level, its emphasis needs to transition from ensuring the non-diversion of nuclear materials to military uses to providing positive inventory control of nuclear materials, whereby national and international authorities can actively account for the location and form of all designated nuclear materials on a continuous and detailed basis.

Near-term steps to achieve higher standards of nuclear accounting

By beginning to rethink the specific goals of MC&A and the current requirements on national- and facility-level systems, all states can ensure that they are equipped to meet the current and future demands of policy makers and the public for high standards of accounting and managerial control over all types of nuclear materials. Indeed, as states reevaluate their nuclear material accounting requirements and pursue near-term nuclear accounting objectives in coordination with each other, they would facilitate efforts to achieve the more difficult objectives of implementing a comprehensive global system that can provide the level of effective and efficient accounting needed for a world with much more nuclear energy use and many fewer nuclear weapons.

Below is a brief list of near-term action items that national governments should pursue:

For non-nuclear weapons states. IAEA member states should review whether IAEA MC&A requirements for states with comprehensive safeguards agreements and in-force Additional Protocols are sufficient to meet emerging security threats, including the detection and deterrence of nuclear material diversion to state-level weapons programs and to non-state actors, and the potential for insider threats. In particular, they should consider:

- **expanding the accounting and reporting requirements for certain source materials** to include reporting mass measurements for uranium ore concentrate, ensuring the transit matching of uranium ore concentrate drums, and tracking uranium hexafluoride containers with the assistance of universal unique identifying numbers;

- increasing the required **reporting frequency of changes to special fissionable material inventories and the frequency of physical inventories** at both process and storage facilities for special fissionable materials;

- **instituting advanced information management tools**, including IAEA mailboxes, at all facilities with special fissionable materials to ensure the timely, electronic reporting of nuclear material accounting information from the facility level to the agency; and

- requiring all facilities with nuclear materials to **maintain and operate electronic databases of nuclear material accounting information and be capable of electronically transmitting or sharing that data** with national and international authorities.

For nuclear weapons states. All nuclear weapons states, including those outside of the Nuclear Non-Proliferation Treaty (NPT), should review the structure and requirements of their national- and facility-level MC&A systems in light of emerging security threats, including the possibility of diversion of nuclear materials to non-state actors, the potential for insider threats, and the need to provide assurance that special fissionable materials are not redirected to military use.

In particular, all of these states should consider adopting MC&A requirements that at a minimum meet enhanced IAEA requirements. Adopting these requirements would improve international understanding of the capabilities of accounting systems in these states, and it would signal weapons states' willingness to abide by the same standards imposed on non-nuclear weapons states. Just as importantly, accounting for nuclear material in a manner that could support further reductions in nuclear weapons stockpiles could also help to demonstrate these states' willingness to pursue their NPT Article VI commitments. These states should also consider introducing more stringent nuclear material reporting requirements into nuclear cooperation agreements as a way to further guard against the non-diversion or misuse of these materials.

All nuclear weapons states should also explore the potential benefits of greater disclosure about the amounts, status, and location of military-use nuclear materials and about how these materials are accounted for on a daily basis. At the very least, these states should make publicly available one-time declarations about their production and use of special fissionable materials, as the United States and the United Kingdom have already done. They should also be willing to make publicly available general information about the management systems in place aimed at accounting for and managing military-use materials.

For all states. All states should engage in cooperative research and development of technological capabilities that will feed directly into their capacities to participate and have confidence in a comprehensive nuclear material accounting system. Possible areas of collaboration include:

- development of **information systems that can facilitate the secure exchange of detailed nuclear material accounting information** between states or between states and an international authority;

- development of **advanced in-process measurement capabilities that will enable real-time material accountancy** at process facilities, including enrichment, reprocessing, and fuel-fabrication facilities;

- development of containment and surveillance technologies that will enable **continuous monitoring of nuclear materials**, including items and bulk materials, throughout their lifetimes;

- research on how nuclear material storage and process facilities can be configured to **ease the physical inventory taking and materials measurement processes; and**

- research on the **effectiveness of national nuclear regulators** and ways to improve compliance with MC&A regulations in a manner that contributes to transparency efforts.

Many of these technical areas are currently being explored by individual national governments, but international, cooperative research and development will better ensure that all states have confidence in the operating capabilities of the many components necessary for more comprehensive MC&A arrangements.

To make the most of cooperative research and development, a nuclear weapons state (preferably the United States) should volunteer to develop a pilot initiative that seeks to demonstrate the technological feasibility of continuous, detailed accounting of both bulk and item forms of direct-use special fissionable materials. This effort should also involve the development and demonstration of information systems that are capable of securely storing nuclear material accounting information and making a subset of all this information available to an international authority or directly to other states according to agreed access rules.

Elements of a global comprehensive nuclear accounting system

To minimize risks in a future world where global nuclear energy use may have increased substantially and stockpiles of nuclear weapons may have been substantially reduced, if not eliminated, all states will have to employ comprehensive nuclear material accounting systems and practices that enable them to account for certain special fissionable materials on a near-continuous basis and other nuclear materials more frequently than they currently do. They will also need to develop information systems that allow for the coordinated management of all accounting information about all nuclear materials within their national borders. And all states will need to subject their systems to extensive enough international monitoring and transparency mechanisms to ensure that they all have confidence in other states' accounting and control of their materials.

In order to achieve these objectives, it is not necessary for MC&A systems to function identically in every state, but they all need to meet the same internationally agreed-upon requirements. The nature of past and current arrangements to reduce nuclear risks suggests that achieving further progress will involve making accounting requirements more equitable. Building such a comprehensive, global nuclear material accounting system will require international coordination and considerable political effort. For states to have confidence in such a system—confidence that the system permits them to assess other states' compliance with their nuclear risk reduction commitments—the system will have to operate for a number of years and be refined to address emergent concerns.

This study found that a comprehensive nuclear material accounting system would involve at least two levels of requirements: facility level and national level.

Facility-level requirements. Facilities with nuclear materials maintain accounting systems to help their operators—government agencies, government contractors, or commercial entities—meet national and international safeguards and security requirements. The effectiveness and efficiency of a comprehensive nuclear material accounting system will rely in large part on the capabilities of all facility-level systems to account for materials that are in storage, undergoing processing, or awaiting use on a daily (or near-real time) basis—including nuclear materials in military use. As such, under a comprehensive system, facilities should be required to operate material accounting systems that include:

- graded MC&A requirements that include **positive inventory control for all direct-use special fissionable materials**;
- the storage of itemized and bulk special fissionable materials in **"smart" containers that can be sealed, continuously monitored, and remotely interrogated;**
- the use of **monitoring and measurement technologies to account for in-process special fissionable materials** more stringently than currently done;
- the c**onsistent tracking of certain source materials**—primarily uranium hexafluoride and uranium ore concentrate—and the containers used to transport them;
- the use of a **uniform, global system of unique item identifiers** to make it easier for national systems to identify changes to material inventories;
- the compilation of **daily nuclear material book inventories** at every facility containing nuclear materials, to include all transactions and inventory changes; and
- **more frequent physical inventories** of all nuclear materials.

National-level requirements. All states should be required to maintain a national nuclear material accounting system that draws on detailed material accounting information from facility-level systems to ensure broad compliance with international standards and to provide assurance to international authorities and other states in line with larger nuclear security, nonproliferation, and weapons reduction commitments. Many existing national material accounting systems merely confirm that facility-level operators are meeting their regulatory requirements and accounting for financially and militarily valuable materials on an annual basis; other national material accounting systems merely maintain aggregate or summarized material accounting information. The level and frequency of reporting and access between states and between states and international authorities that could be a part of a comprehensive, global nuclear material accounting system is open for debate, but any level of transparency and frequency of reporting would require a national system that maintains up-to-date databases of detailed accounting information.

Each state should be required to:

- develop and deploy a national system capable of electronically receiving daily updates of facility-level material accounting information, of directly querying facility-level accounting systems, and of sharing a subset or aggregate of all material accounting data with an international authority or directly with other states;

- develop and use information systems capable of compiling daily facility-level material accounting reports and making a subset of material accounting information available to an international authority or other states;

- maintain an empowered, independent national regulator that is capable of evaluating compliance with national and international material accounting requirements; and

- routinely and systematically share information about its nuclear material stockpiles, including those materials designated for military use, and about how it accounts for and controls those materials on a daily basis with an international authority or directly with other states.

Lacking from previous efforts to improve nuclear material accounting standards and technological capabilities was sufficient guidance and support from national policy makers who have thus far failed to appreciate the potential nuclear risk-reduction benefits of having more continuous and detailed information about nuclear material holdings. By prioritizing efforts to expand material accounting capabilities today and to build a comprehensive, global material accounting system with which states could increase transparency and provide greater international assurance, policy makers would make a substantive contribution to reducing overall nuclear risk for the foreseeable future.

Section 1.

Introduction

In the aftermath of World War II, the scientists who developed the nuclear weapons used against Japan and U.S. diplomats proposed that all subsequent development of nuclear technology be managed by an international consortium that would maintain strict accounting of all the weapons-usable nuclear materials produced. At the time, that aspiration was technically feasible, but it quickly proved to be politically unacceptable.

In the decades that followed, eight additional national governments developed nuclear weapons for military application and 44 applied nuclear technology to other purposes. Accounting for the nuclear materials produced has been done by national governments and international and supranational authorities that do not comprehensively aggregate or share the information. As a result, uncertainties about global material inventories range in the many thousands of weapons equivalents.

During the Cold War period, uncertainties of this magnitude in nuclear weapons states were not thought to be strategically significant. In the current context, every single weapon and equivalent amount of weapons-usable nuclear material poses a risk of potentially catastrophic proportions. The legacy of inadequate national accounting is distinctly ominous in this context; higher standards can and should be achieved.

The opportunity that existed in principle in 1945 cannot be recaptured, and the ensuing production of nuclear material by multiple, mutually suspicious national governments will impose large accounting uncertainties for many decades to come. Nonetheless, the technology for achieving meaningfully higher standards of nuclear material accounting is available, and the impediments to achieving those standards have mostly to do with institutional inertia and political attitudes.

The status quo in accounting for and controlling nuclear materials and their production needs to be improved upon as states attempt to fulfill the promise of the nuclear nonproliferation regime's central tenets—that the technology and infrastructure for the production of nuclear energy and other peaceful uses is widely available, that those states that have pledged not to acquire nuclear weapons employ International Atomic Energy Agency (IAEA) safeguards to confirm that their nuclear programs are purely peaceful, and that those states with nuclear weapons decrease and ultimately eliminate their reliance on those weapons. Nuclear material control and accounting (MC&A) needs to transition from ensuring the non-diversion of nuclear materials to military uses to providing *positive inventory control* of nuclear materials, whereby national and international authorities can actively account for all designated nuclear materials on a continuous and detailed basis. These improvements would also help to provide reliable assurance that nuclear materials designated for peaceful use in nuclear weapons states have not been diverted to weapons use or stolen by non-state actors.

This transformation requires at least two related steps:

(1) In the short term, the IAEA needs to reevaluate and tighten MC&A requirements in non-nuclear weapons states to address a broader set of nonproliferation and nuclear security objectives, and all nuclear weapons states need to commit to maintaining MC&A systems for civilian materials that at a minimum meet these improved IAEA requirements.

(2) In the long-term, *all* states should be expected to maintain national accounting systems for *all* of their designated nuclear materials—both civilian and military-use materials—that meet improved IAEA requirements. They should also be expected to maintain sufficient transparency about their operational practices and material holdings in support of a broad nuclear risk reduction agenda. This requires the development of a comprehensive, global nuclear material accounting system.

While the latter step is admittedly aspirational, in that it would require significant political and security transformations, this study argues that continuous and detailed accounting of all nuclear materials is necessary to reduce the risk of both state-level and non-state level nuclear proliferation and to undergird efforts to reduce global nuclear weapons arsenals. International security could benefit significantly today if the former goal is achieved. International cooperation aimed at developing the necessary technical, regulatory, and political infrastructures for the short-term goal also presents an opportunity to speed the necessary long-term transformations.

In developing the rationale for a comprehensive, global system of accounting for nuclear materials; envisaging how such a system would function; and laying out the near-term steps states could take to begin moving in this direction, this study addresses several issues. Section Two summarizes changes in the international security environment since MC&A systems were first developed and describes the set of priorities that these systems will need to address during the coming decades in order to support nuclear risk-reduction efforts. Sections Three and Four provide background about the development and requirements of current MC&A systems, including international, regional, and national systems. Section Five describes how states could begin to develop a comprehensive system of nuclear material accounting that includes all designated nuclear materials and provides increased international confidence in national managerial practices. Section Six summarizes what states can do to begin to improve nuclear material accounting capabilities today.

Section 2.

A 21st century approach to nuclear material accounting

During the Cold War, nuclear weapons, their attendant production complexes, and the alliance structures that developed around them were most often justified as a means to deter the use of nuclear weapons by others. In other words, nuclear weapons were an asset in an uncertain and dangerous world. In this context, reducing risks involved maintaining managerial control of weapons stockpiles and ensuring that states didn't inadvertently launch nuclear attacks.

With the end of the Cold War, the net value of nuclear weapons has decreased significantly. Nuclear weapons are financially costly to maintain and secure, and they have less military value than they previously did. This is why the states with the most nuclear weapons—the United States and Russia—have significantly reduced their nuclear weapons stockpiles during the last 20 years, and why the United Kingdom and France have reduced their stockpiles as well. In other words, these states are reducing the liabilities that nuclear weapons present, even as they continue to enjoy whatever residual benefits they offer. Other states, most notably Pakistan and India, have continued to develop their nuclear weapons stockpiles and capabilities, but these states have considerably fewer weapons and considerably smaller stockpiles of materials than the United States and Russia.

Enhanced nuclear material control and accounting capabilities can help to:

- ensure the nonproliferation of *all* nuclear materials and technologies in *all* countries to state-level nuclear weapons programs;
- restrict non-state actor access to nuclear materials and technologies in *all* countries;
- enable nuclear weapons states to reduce their nuclear arsenals in a manner that doesn't introduce instability; and
- provide states with the systems and tools to continuously maintain confidence that all of these risks are being appropriately addressed.

The nuclear nonproliferation regime that developed alongside nuclear weapons arsenals and deterrence strategies has focused on a separate goal: keeping states that didn't already have nuclear weapons from developing them, and providing assurances to all states that peaceful nuclear activities, including the development and use of nuclear energy, remained peaceful. Under this regime aimed at reducing the risk of nuclear weapons proliferation, states that possessed nuclear materials saw them as assets to develop economically and technologically, but others worried about the risk that non-weapons states with nuclear infrastructures and certain types of nuclear materials could use them to develop nuclear weapons.

To manage these proliferation risks, the international community developed institutions—namely, the IAEA—and detailed management practices—namely, IAEA safeguards—that provided assurances to all states. These practices have been strengthened over time and continue to evolve to address the risk of state-level weapons proliferation.[1]

States with nuclear weapons didn't develop ways to provide this type of international assurance about the managerial control exercised over their stockpiles of weapons and materials or the composition and status of these stockpiles. Indeed, states with nuclear weapons generally kept information secret about their nuclear production complexes; the amounts, types, and statuses of materials they produced and stockpiled; and the operational practices they employed to manage their materials and warheads. These secretive practices were accepted in part because these countries already possessed nuclear weapons, and their nuclear development activities were focused on preserving deterrence.

The risk of state diversion from civilian nuclear programs to nuclear weapons acquisition remains an important concern for the nonproliferation regime today, but the risk that nuclear materials in all states could also be diverted to non-state actors has emerged as an additional priority. Instances of dangerously lax nuclear material security measures and nuclear material smuggling have been well documented, as has been the stated intent of non-state organizations to acquire nuclear materials and develop nuclear weapons.[2] Concern about individuals with official access to nuclear materials using their access to divert materials, the so-called insider threat, has also risen.

The current goal of IAEA safeguards is "the timely detection" of state diversion of nuclear materials and "deterrence of such diversion by the risk of early detection."[3] Can IAEA safeguards be expanded to better ensure the timely detection of *non-state* diversion of materials and the deterrence of such diversion

1 IAEA, "The Evolution of IAEA Safeguards," IAEA International Nuclear Verification Series 2, 1998.

2 The IAEA maintains a list of incidents involving unauthorized access to nuclear materials. See also Matthew Bunn, *Securing the Bomb 2010* (Cambridge, Mass., and Washington, D.C.: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, April 2010), which is one of many publicly available reports that document and characterize the threat of nuclear terrorism.

3 IAEA, "The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," INFCIRC/153 (corrected), June 1972.

by the risk of early detection?[4] Reevaluating and expanding IAEA safeguards would not be a trivial process, but the tools and practices of traditional safeguards, including MC&A, are capable of bearing this additional burden by, for example, ensuring stronger *national* regulatory structures, requiring more frequent and timely material inventorying and reporting, and extending certain material accounting requirements to less attractive materials.

The larger challenge is confronting the risks posed by nuclear weapons states' sizeable civilian and military-use stockpiles of nuclear materials and their weapons arsenals. Most of these materials and all of these weapons remain outside of regular international oversight. Domestic regulators and policy makers oversee these material and warhead stockpiles, but the full extent of the risks associated with their current maintenance is uncertain. For example, some nuclear weapons states don't know how much nuclear material they have with an acceptable level of certainty; some materials have not been properly characterized; and communication about the status and whereabouts of materials from the facility level to national authorities is infrequent and often short on detail.

At a minimum, the lack of transparency and accountability in managing the large materials stockpiles in civilian and military use and storage in these countries provides little to no international assurance about how materials are used and secured. Opportunities are lost to make clear to friends and potential adversaries alike the full nature of national capabilities and practices—and avoid unwarranted suspicions and undesired conflicts. The practices of weapons states also obscure the risk of non-state diversion or theft. Without additional oversight, the risk also remains that some of these materials could be moved back into existing state-level weapons programs.

As nuclear weapons states seek to reduce their nuclear arsenals further, the large stockpiles of remaining warheads (including operational and reserve warheads, and those awaiting dismantlement) and the lack of transparency about their security, status, etc. potentially undermine these efforts.[5] This lack of transparency ultimately limits how low nuclear weapons states can reduce their weapons arsenals and how they move toward the goal of complete nuclear disarmament.

The basic tools and processes of MC&A hold the potential to play a significant role in reducing many of the present-day risks posed by nuclear materials in

4 Martha Williams, "On the Importance of MC&A to Nuclear Security," CISSM Working Paper, February 2014.

5 For instance, none of the nuclear weapons reduction treaties ratified by the United States and Russia, including the most recent accord, New START, contain limits on total stockpiles of nuclear warheads, including reserve warheads or those awaiting dismantlement.

weapons states, as well as in non-weapons states.[6] MC&A is only a single piece of the broader effort to ensure nonproliferation and nuclear security—other essential parts include physical security, personnel reliability, etc.—but it is the linchpin of the daily management of nuclear materials, and its mechanisms enable the most detailed understanding of materials' characteristics and whereabouts. Put another way, MC&A is the nervous system of the nonproliferation and nuclear security corpus. Indeed, MC&A capabilities are what enable nuclear operators and regulators to adequately address one of the most important questions that confronts policy makers in both nuclear weapons states and non-nuclear weapons states: "Are nuclear materials missing?"

Strengthened IAEA MC&A requirements could help to ensure that nuclear materials in non-weapons states are not diverted to either state-level weapons programs or non-state actors. For all states to be assured that materials and warheads in nuclear weapons states are not at risk of non-state diversion, these states will have to submit their stockpiles of materials (both civilian and military) and their management practices to additional oversight. Such oversight will inevitably involve the use of MC&A systems to gather information about nuclear materials and a system by which at least some of that information is then shared either with an international authority or directly with other states.

The process of drawing down nuclear weapons stockpiles also stands to benefit from expanded MC&A capabilities. As they decrease their nuclear weapons stockpiles, nuclear weapons states will want to maintain confidence that other weapons states are complying with their arms reduction commitments. They will also want to be sure that those weapons states' latent weapons capabilities—in the form of reserve or retired warheads, or significant quantities of weapons-usable materials—*remain* latent. Achieving these objectives will require access to information about the status and location of certain forms of nuclear material and warheads, and confidence in the daily management practices of the operators of facilities with warheads and weapons-usable nuclear materials.

Since the end of the Cold War, a few nuclear weapons states have introduced some transparency into their nuclear material and warhead holdings. By providing information about historical production of highly enriched uranium (HEU) and plutonium and about the disposition and use of those materials over time, the United States and the United Kingdom have cracked open the door to their otherwise protected and opaque nuclear complexes and capabilities. Yet the role

6 Robert Elwood and Charles Roche, "Insider Threat: Material Control & Accountability Mitigation," 10th Central Asia MC&A Conference, Astana, Kazakhstan, January 2011. See also, IAEA, "Preventive and Protective Measures Against Insider Threats," IAEA Nuclear Security Series No. 8, Implementing Guide, 2008.

of these disclosures in addressing the nuclear risks identified in this paper is ultimately limited. They could help identify the scope of risk, but such general disclosures provide little detail about the present-day distribution of these materials, how they are being used, and how they are being managed. Done inadequately, these efforts at transparency and confidence building raise more questions than they answer.[7]

Policy makers from across the globe have recognized the potential importance of MC&A to addressing concerns about the diversion or theft of nuclear materials to non-state actors, but the emphasis of current initiatives has been on necessary improvements to national laws and regulations—and primarily in states without nuclear weapons.[8] Best practices have been devised and technical cooperation programs launched, but states have yet to develop comprehensive requirements that are capable of addressing the full scope of nuclear risks and that are meant to be adopted by all states.[9]

The nature of current nuclear risk reduction efforts, primarily arranged on implicit and explicit bargains between nuclear weapons states and non-nuclear weapons states, suggests that the development of a comprehensive nuclear material accounting system will ultimately necessitate the participation of all states with nuclear materials. Perceptions of discrimination and the failure of nuclear weapons states to fulfill their nuclear disarmament commitments under the Nuclear Non-Proliferation Treaty (NPT) make it unlikely that non-weapons states will submit to additional MC&A requirements unless weapons states also agree to submit to additional requirements. Much as information exchanges have been a part of

7 A May 2010 U.S. press release noted that the U.S. stockpile "consisted of 5,113 warheads," a number that included active warheads that were deployed on weapon systems; "responsive" warheads that could be deployed on short notice and serve as a strategic hedge; and inactive warheads, which have had their limited-lifetime components removed but are otherwise intact and stored at Department of Defense installations. A subsequent State Department release noted that, as of December 2009, 1,968 of this total were deployed strategic weapons. Of the remaining 3,145 weapons, it was unknown precisely how many were included in the "responsive" force, which could be deployed on short notice, and how many were inactive. Officials were also vague in describing that "several thousand additional nuclear weapons are currently retired and awaiting dismantlement." These ambiguities can cause suspicion among U.S. adversaries and partners alike.

8 U.N. Security Council Resolution 1540 requires all states to "develop and maintain appropriate effective measures to account for and secure such items in production, use, storage, or transport." The communiqué from the 2010 Nuclear Security Summit recognizes that "highly enriched uranium and separated plutonium require special precautions and [we] agree to promote measures to secure, account for, and consolidate these materials, as appropriate." The statement of principles from the Global Initiative to Combat Nuclear Terrorism implores its members to "develop, if necessary, and improve accounting, control and physical protection systems for nuclear and other radioactive materials and substances."

9 For instance, see: World Institute for Nuclear Security (WINS), "Material Control and Accountancy in Support of Nuclear Security," WINS International Best Practice Guide, Revision 1.0.

nuclear weapons reduction agreements to date, nuclear weapons states will likely require additional, more detailed information sharing as part of nuclear weapons reductions agreements that address warhead numbers and material stockpiles.

In order to *get* assurance from non-nuclear weapons states and other nuclear weapons states in the risk-reduction enterprise, nuclear weapons states will be obliged to *give* assurance in the form of information and access. This will be a significant challenge, as these states have historically not been asked to submit their nuclear enterprises to the type of oversight that non-nuclear weapons states have. But in order to function as intended and to genuinely reduce the broad range of nuclear risks, a comprehensive, global nuclear material accounting system will need to operate on equitable rules that are applied fairly.

Arrangements that set comprehensive national MC&A requirements for all states and are accompanied by mechanisms for the international sharing of information would likely take years, if not decades, to gain the confidence of their participants. States will never be able to have complete confidence in such arrangements, but if such a system were developed in coordination among states and allowed to operate over the course of years, confidence could grow to levels that would support the goal of deep cuts to nuclear weapons arsenals or the elimination of nuclear weapons. Absent these types of international arrangements, states could still benefit from improvements in national-level systems that enable them to continuously account for all nuclear materials within their borders. This level of awareness and accountability is also liable to have international benefits and provide a level of assurance to international partners.

Section 3.

The development of nuclear material control and accounting

From the outset of the nuclear age, national governments with stockpiles of nuclear materials recognized the need to account for them. One of the primary initial motivations was financial, as states poured billions of dollars into developing and operating the facilities necessary to produce certain nuclear materials. But states also understood the intrinsic proliferation and safety risks associated with certain nuclear materials, and material accounting played a major role in guarding against the potential misuse of or an inadvertent accident involving nuclear materials. The processes and tools used in these early material accounting systems laid the groundwork for material accounting practices that are used today.

Early U.S. nuclear material management systems were intended to be able to answer a number of questions about nuclear material holdings: How much material is there? Where is it? What form is it in? How accurate is the knowledge of the quantities? What is the monetary value? Has any blending occurred?[10] These systems focused almost exclusively on internal, national objectives. Government and commercial entities had interests in managing materials with high monetary value and in complying with national safety regulations. During this early period, there was little effort to use nuclear material accounting or other aspects of nuclear material management to directly address international security concerns.

The passage of the 1954 U.S. Atomic Energy Act; efforts by the United States, the Soviet Union, and other countries to export nuclear technology and materials abroad; and the founding of the International Atomic Energy Agency in 1957 began the process of repositioning nuclear material accounting practices in the context of international security efforts. The United States and Soviet Union were keen to share the benefits of nuclear energy with the world and wield nuclear energy as a tool of influence. They were also eager to ensure that materials and technologies they made available to other countries for peaceful purposes were not used to develop nuclear weapons. The founding IAEA statute, for instance, prioritized the application of "safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities, and information made available

10 D. F. Musser, "Philosophical and Practical Basis," in Ralph Lumb, ed., *Management of Nuclear Materials* (Princeton, NJ: Nostrand Company, 1960), p. 7. Musser was the director of the U.S. Atomic Energy Commission's Division of Nuclear Materials Management.

The ABCs of nuclear material accounting

The concept of nuclear material accounting was based on the principles of financial accounting. These principles have persisted, and nuclear material accounting systems today share many of the same basic features. The IAEA's "Nuclear Material Accounting Handbook" and its report on the evolution of IAEA safeguards outline the basics of these traditional methods, elements of which are summarized below.

In order to account for nuclear materials, a facility establishes **material balance areas** or MBAs, discrete physical areas within which material accounting occurs. A facility can have multiple MBAs or only one; an entire facility or only a small part of one can comprise an MBA. Facility operators maintain records of how much of what kind of nuclear material is introduced into a specific balance area and also any **changes in the inventory** of materials within a specific balance area. When materials enter or leave a material balance area, they are typically subject to measurement at a **key measurement point** (KMP), where the quantity and composition of the material are noted within a specified level of uncertainty. Records of initial inventories and inventory changes make up the **book inventory** of a balance area—how much material *should* be in a given location at any given time.

At prescribed frequencies, facility operators conduct physical inventories, where they measure some or all of the materials within a balance area and generate a **physical inventory listing** (PIL), which notes how much material *actually* is in a given location. A PIL is used to construct a **material balance report**, which details the initial inventory in a particular balance area, any changes in inventory over the given material balance period, the book and physical inventories at the end of the period, and the **inventory difference**—the difference between the book and physical inventories.

Nuclear material accounting records typically reflect the amount and types of materials present in a material balance area, but they can also reflect the accounting of specific items within a balance area. **Item-level accounting** keeps track of discrete quantities or containers of materials that are not undergoing processing, have a measured element and isotope quantity, and have been assigned a unique indentifier. When states submit nuclear material accounting reports to the IAEA, they do so in terms of **batches**, portions of nuclear material, each handled as a single unit, for which "the composition and quantity are defined by a single set of specifications or measurements." A batch can include bulk materials or items and might only include a single item.

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by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose." These priorities necessitated the further development and wider application of nuclear material accounting requirements and practices.

In the process of developing the IAEA's founding statute, some states pushed back against the idea of applying safeguards, including material accounting, to certain types of nuclear materials, particularly source materials, and for the duration of their lifetimes. They believed that this practice would favor states with natural uranium deposits and would lead to the involvement of the IAEA in sovereign affairs in perpetuity.[11] Concerns have continued to this day about preserving sovereign rights; the impact of safeguards on the economic competitiveness of commercial mining, processing, and fuel fabrication entities; and the equitable treatment of all states. As such, most states remain unwilling to share more nuclear material accounting information with the IAEA or other parties than they are required to, and many national and commercial operators remain resistant to what they view as interference in operational practices. Therefore, information that could benefit security, nonproliferation, or nuclear weapons reduction objectives goes uncollected or unreported.

The entry into force of the NPT in 1970 had a profound effect on the development of MC&A systems. The treaty requires that all non-nuclear weapons states parties develop comprehensive safeguards "with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices."[12] A major component of these safeguards is the development of a state system of accounting for and control of nuclear material (SSAC), which is intended to allow a state to account for all safeguarded nuclear materials within its borders and to enable the state to report information about its nuclear materials to the IAEA.[13] The IAEA then uses this information to verify state compliance with its safeguard commitments, and to detect and deter a diversion of a significant quantity of material before it can be made into a weapon.

Rather than specifying exactly how an SSAC should be set up, the IAEA only specifies the type of information that an SSAC should collect and the reporting requirements that a state needs to meet. As a consequence of the IAEA's focus on SSAC capabilities and of the variety in states' nuclear-related activities, nuclear material accounting systems and capabilities have developed differently in different countries. States that have a multitude of facilities with nuclear materials often have facility-level nuclear material control and accounting systems that feed information into a broader, national-level system. These facility-level systems can serve multiple purposes. They can allow a state to meet its IAEA safeguard

11 David Fischer, *A History of the IAEA: The First 40 Years* (Vienna: IAEA Division of Publications, 1997), p. 48.

12 See Article III of "Treaty on the Non-Proliferation of Nuclear Weapons." The treaty is reproduced in IAEA INFCIRC/140, "Treaty on the Non-Proliferation of Nuclear Weapons: Notification of Entry into Force," April 22, 1970.

13 IAEA, "The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," INFCIRC/153 (corrected), June 1972, paragraph 7.

commitments, but they can also help a facility ensure compliance with national or regional nuclear safety and security regulations. In states with only a handful of facilities containing nuclear materials or a limited range of activities, or in states where national regulations are limited, the SSAC's sole function is to help that state meet IAEA material accounting and reporting requirements for all IAEA safeguarded materials. Despite the differences in SSACs, IAEA safeguards agreements contain the most widely adhered to MC&A requirements.

In the process of negotiating and ratifying the NPT, a few of the states that were categorized as nuclear weapons states under the terms of the treaty agreed to make available for safeguards many of their civilian nuclear facilities and materials under voluntary offer safeguards agreements. IAEA safeguards were intended to detect and deter the diversion of nuclear material to non-peaceful purposes—not an immediate concern about those states that had already developed nuclear weapons. Yet, the offer was meant in part to assuage concerns that commercial interests in nuclear weapons states would benefit economically from the absence of IAEA safeguards and in part to address the sense among some non-nuclear weapons states that they were being discriminated against with the application of safeguards. Putting some of the most advanced nuclear fuel cycle facilities in these states under safeguards would also help the IAEA develop its safeguard capacities.[14]

While most non-nuclear weapons states developed national nuclear material accounting systems—SSACs—with the explicit purpose of meeting IAEA safeguards requirements, weapons states developed their national systems independently and according to their own national requirements; these systems were then adapted as necessary to fulfill their limited IAEA safeguards commitments. As such, there is great variety among nuclear weapons states in the requirements placed on civilian facilities with nuclear materials and on national systems that gather this information. And nuclear weapons states have all maintained separate and distinct accounting and management systems for nuclear materials assigned to military use, including nuclear warheads.

MC&A-related technological capabilities

In meeting their material control and accounting requirements, states (non-weapon states and weapon states) employ a range of technologies without which MC&A capabilities would be severely limited. As MC&A technologies have advanced, they've enabled facilities to implement capabilities with greater efficiency than before.

14 David Fischer, *A History of the IAEA: The First 40 Years,* p. 96.

Measurement capabilities. Central to any MC&A system is the ability to measure material—its mass, density, isotopic composition, and other characteristics. Without accurate measurements of materials, it is difficult to have an accurate accounting of materials. When a material balance area accepts new materials, the first step an operator takes is to measure the new materials. This process permits the operators to verify that the materials are what the transferrer/shipper says they are and to rule out the possibility that materials were diverted or lost in transit. These initial measurements also serve as the basis for future material balance calculations. If these initial measurements are inaccurate or contain too much uncertainty, then it will be difficult to reconcile future physical inventories with accounting records.

Fortunately, nuclear material measurement capabilities have steadily improved over time. One good indication of this change is the improvement of international standards for measuring nuclear materials. Starting in 1991, the IAEA developed a set of International Target Values (ITVs) that established a standard of measurement uncertainties for a range of material types, processes, and measurement technologies. These target values did not reflect the capabilities of the most sophisticated and advanced measurement systems at the time, nor did they assume that measurements were being taken under ideal circumstances; instead, they reflected the "measurement performance observed in the IAEA's verification activities."[15] In other words, the ITVs reflected the accuracy and uncertainties inherent in measurement systems in operational settings. Today, IAEA ITVs are used by facilities containing nuclear materials all around the world as the benchmark for their own material measurement capabilities.

When released in 1993, the initial set of ITVs reflected "an improvement by a factor 2 to 2.5 [sic] in the accuracy achievable in practice in the analysis of uranium products and spent fuel solutions" over standards set only five years earlier.[16] Subsequent versions of the IAEA ITVs include standards for additional types of measurement technologies and demonstrate further improvement in measurement performance for certain types of materials and processes. For example, the 2010 ITVs demonstrate a marked improvement over standards from 2000 in the ability of operators to measure the abundance of U-235 (the fissile isotope of uranium) in uranium hexafluoride using portable detectors and multi-channel analyzers—among the most common non-destructive measurement tools

15 S. Deron, E. Kuhn, M. Yousif, "International Target Values for the Quality of Measurements for Safeguards," *ESARDA Bulletin*, no. 23, 1994, p. 459.

16 Ibid.

at facilities with these types of nuclear materials.[17] And measurement uncertainties continue to be the lowest for the most attractive forms of materials, such as HEU in metal or alloy form. The target uncertainty values associated with the non-destructive measurement systems used for these forms of uranium and separated plutonium oxide are about 1 percent; for destructive measurement systems the uncertainty is less than .1 percent.[18]

In general, the more nuclear processes conducted and the more forms of nuclear materials present at a facility, the more types of measurement technologies will be needed to support material control and accounting operations. Materials "in process"—e.g., in enrichment centrifuges, being fabricated into fuel pellets, or in a dissolving tank—generally pose the greatest measurement uncertainties because they are often very difficult if not impossible to physically measure. For this reason, operators have historically included a category of "in-process" materials when conducting physical inventories based on measurements.[19] Under this practice an operator measures and inventories feed materials, intermediate and scrap materials, and outputs from processes—but *not* the actual in-process materials; this material is instead listed in the general category of "in process." This practice, though still common, is being supplanted by attempts to develop technologies to more actively and accurately account for materials in process, without requiring their destruction.[20]

Process monitoring. The implementation of the measures developed in the early 1980s as part of the Hexapartite Safeguards Project—an effort involving the IAEA and a handful of nuclear supplier nations—began increasing safeguards at uranium enrichment facilities, including more frequent physical inventories and some in-process measurements. The most recent updates to the IAEA safeguards approach at enrichment plants involve even more process monitoring techniques, including actively monitoring the flow of uranium hexafluoride, using load cells to measure the amount of feed material and waste that enters and exits a centrifuge cascade, and continuously monitoring the enrichment levels of

17 IAEA Department of Safeguards, "International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Materials," STR-368, November 2010.

18 Ibid. Bulk sampling uncertainties add to the overall uncertainty of measurements.

19 James Lovett, *Nuclear Materials: Accountability, Management, Safeguards* (American Nuclear Society, 1974), p. 85.

20 Joseph F. Pilat, "IAEA Safeguards: The Role of Advanced Safeguards Technologies in Meeting Tomorrow's Challenges," LA-UR-07-7848, November 2007. This paper was first presented at the JAEA-IAEA Workshop on Advanced Safeguards Technology for the Future Nuclear Fuel Cycle held in November 2007.

materials in cascades.[21] The IAEA believes that these tools, coupled with innovative information management systems, "will yield a clear picture of the U-235 and U-total nuclear material balance for the whole [enrichment] facility."[22] If these tools can be set up to function unattended, this stream of material accounting information can be continuously available.[23]

Similar efforts have aimed to integrate process monitoring techniques into spent fuel reprocessing plants. Near-real-time materials accountancy at reprocessing facilities involves measuring material streams with non-destructive tools and coupling this information with analytical models of the process to obtain accurate inventory differences for the nuclear materials involved, including plutonium.[24] Such systems have been developed for facilities that rely on a range of reprocessing techniques with the goals of not only providing a more continuous stream of material accounting data, but also of reducing the costs associated with plant shutdowns that are often required to complete physical inventories of materials at these facilities.

Containment and surveillance. The IAEA employs containment and surveillance tools at facilities with nuclear materials to supplement material accounting practices by "providing means by which access to nuclear material can be controlled and any undeclared movement of nuclear material detected."[25] The most common IAEA surveillance tools are specially designed and tested video cameras that monitor, for example, key measurement points, entrances and exits to enclosures, and the materials themselves. These monitoring systems are capable of maintaining continuous, 24-hour vigilance over an area, so that, for instance, all movements of materials in and out of a monitored area are recorded.

The tools of containment include seals that are applied to containers with nuclear materials inside. The seals are designed and implemented so that operators and third parties are able to determine if they have been tampered with and

21 C. Charlier, et al., "Conceptual Approach for Applying Safeguards at a Large Gas Centrifuge Enrichment Plant," Japan-IAEA Workshop on Advanced Safeguards Technology for the Future Nuclear Fuel Cycle, Tokai-mura, Japan, November 2009. See also: J. M. Whitaker, et al., "Using Process Load Cell Information for IAEA Safeguards at Enrichment Plants," paper presented at the 2010 IAEA Safeguards Symposium, IAEA-CN-184/116.

22 C. Charlier, et al., "Conceptual Approach for Applying Safeguards."

23 L. Eric Smith, et al., "Potential Roles for Unattended Safeguards Instrumentation at Centrifuge Enrichment Plants," *Journal of Nuclear Materials Management*, vol. 42, no. 1 (Fall 2013), pp. 38-56.

24 Steve M. Brion, et al., "The Commercial Application of Near Real Time Accountancy," paper presented at 2001 IAEA Safeguards Symposium, IAEA-SM-367/8/04/P.

25 IAEA, "Safeguards Techniques and Equipment," International Nuclear Verification Series, No. 1 (Rev. 2), 2011, p. 55.

Efforts to improve material accounting

Since the end of the Cold War, the United States and other nations have attempted to upgrade the MC&A capacities of other countries.

Starting in the early 1990s, the U.S. government began investing hundreds of millions of dollars in securing direct-use nuclear material (separated plutonium and highly enriched uranium) throughout the former Soviet states. A small part of this effort was aimed at improving the ability of Russia and other former Soviet states to account for their current holdings of nuclear materials. This included projects to improve Russia's ability to accurately measure and characterize its nuclear material stockpiles, to maintain accurate and up-to-date records of material holdings, to ensure that records reflected physical inventories, and to enable stringent control of all direct-use materials, including discrete items.

Other states were also involved in improving Russian MC&A capabilities. For instance, Swedish officials worked with officials at the Chepetsk Mechanical Plant, a uranium production and conversion facility, to install measurement and detection equipment. The Swedes are also prepared to install a new material accounting system at the facility, according to Swedish officials, though Russian officials are uncertain if they plan to keep this facility open.

Swedish authorities have also been involved in efforts to establish national nuclear material accounting systems in the former Soviet republics of Kazakhstan, Ukraine, and Lithuania—and some facility-level systems at particular reactor sites. In large part, these efforts have involved installing material accounting systems that were initially developed and deployed in Western states to assist these states in fulfilling their IAEA safeguards obligations. This cooperation has boosted the material accounting capacity of these states, but because these systems were developed and have been maintained with Western support, sponsoring states have struggled to hand off responsibility for maintaining them to domestic authorities.

In 1994, the U.S. Department of Energy initiated a "lab-to-lab" program between U.S. and Chinese scientists aimed at boosting cooperation on nuclear arms control and nonproliferation. A main accomplishment of this effort was the joint demonstration of material protection, control and accounting technologies at a Chinese nuclear safeguards laboratory, which led to improvements in Chinese material accounting capabilities. Though the lab-to-lab program ended in 1998, the United States has since agreed to establish a center of excellence on nuclear security in collaboration with China, and will organize training and share best practices with Chinese nuclear technicians, including on MC&A.

The IAEA maintains perhaps the most expansive effort to improve nuclear material control and accounting capabilities. It organizes training through its safeguards and nuclear safety and security departments for both IAEA member states and non-member states, and its technical cooperation department also focuses on providing assistance to states looking to address safety and security challenges.

containers opened without authorization. These tools are most often employed to monitor materials that are in storage or not in use for months or years at a time.

Other IAEA systems can continuously and remotely monitor the movements and measure the contents of individual items, such as fresh or spent fuel assemblies.[26] Though these tools are not directly applicable to nuclear material accounting systems, they capture and transmit information that could be used to support a comprehensive nuclear material accounting system. Another surveillance tool that could be useful in this way is radiofrequency identification (RFID) tracking. Scientists have successfully pilot-tested systems in which RFID devices are attached to containers holding nuclear materials and tracked in real-time during transport and storage.[27] Although these tracking devices are not capable of continuously and accurately measuring the nuclear contents of such containers, if coupled with remotely monitored seals, they could provide some level of assurance to regulators or other states about the location and integrity of nuclear materials stored in containers.

26 Ibid., p. 42.

27 Yung Liu and James Shuler, "ARG-US RFID: Real-Time Tracking System," presentation to INMM International Workshop, Containment and Surveillance: Concepts for the 21st Century, Oak Ridge, Tennessee, June 7-11, 2010.

Section 4.

Current requirements and capabilities

IAEA material accounting and reporting requirements

Under their safeguards commitments, NPT non-nuclear weapons states are required to meet certain material accounting standards and to report back to the IAEA with specific information about their nuclear materials. These requirements are spelled out in the subsidiary arrangement that a state agrees to as part of its comprehensive safeguards agreement. Subsidiary arrangements vary from state to state, but the publicly available model subsidiary arrangement outlines the general requirements for SSACs and for the provision of information to the IAEA.[28]

According to the most recent version of the model subsidiary agreement, a state's SSAC should be able to:

- measure the quantities of nuclear materials it receives, produces, ships, or otherwise removes from its inventory;
- evaluate the precision and accuracy of its measurements and estimate measurement uncertainties;
- conduct a physical inventory, whereby a part, a sample, or all material holdings are measured to compare against a book inventory;
- evaluate accumulations of unmeasured materials or unmeasured losses;
- identify and evaluate differences in shipper/receiver measurements;
- maintain records that show, for each material balance area, the inventory of materials and the changes in that inventory;
- provide material accounting reports to the IAEA; and
- ensure that accounting procedures and arrangements operate as intended.

28 IAEA, "Subsidiary Arrangement to the Agreement Between the Government of […….] and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," Fifth Revision, SG-FM-1170, February, 22, 2011.

The IAEA's general requirements for SSACs leave much to the discretion of a member state. For instance, states are not required to maintain facility-level material accounting systems; they are not required to maintain computer-based accounting systems; they don't have to submit their reports to the IAEA electronically; and they can opt to submit information directly from facilities to the agency.

When a state agrees to a comprehensive safeguards agreement, it is expected to make an initial report to the IAEA that describes all nuclear material within its national boundaries "in peaceful nuclear activities" and all nuclear material in "peaceful non-nuclear activities, if it is recoverable or is directly usable for a nuclear activity."[29] In addition, as a state's inventory changes—as it produces more materials that fall under safeguards, as materials move from material balance area to material balance area, etc.—that state is required to provide the IAEA with "inventory change reports" documenting these changes. After it takes physical inventories of materials, a state is also required to file with the agency a "material balance report," which attempts to match the book inventory—the amounts of materials as reported in the material accounting system—with the physical inventory listing.

There is the potential for a considerable time lag between when inventory changes are made and when the IAEA requires reporting. The model subsidiary arrangement requires that states file inventory change reports "as soon as possible, but within 30 days after the end of the month in which the inventory change(s) occur(s)." In theory, if an inventory changes in the first week of a month, it could be nearly 60 days before that change is required to be reported to the IAEA. The same potential lag exists between a physical inventory taking and the filing of a material balance report to the agency. Here, states are required to file material balance reports with physical inventory listings "as soon

Materials not subject to IAEA detailed nuclear material accounting requirements

- All quantities of source materials (e.g., natural uranium, uranium ore concentrate, thorium) and other nuclear materials not "suitable for fuel fabrication or for being isotopically enriched."
- Nuclear materials designated as "non-nuclear use" materials.
- Waste containing nuclear material that is typically safeguarded but which is "diluted in such a way that it is no longer usable for any nuclear activity . . . or has become practicably irrecoverable."
- Nuclear materials exempted from safeguards.

29 This latter category of material refers primarily to nuclear materials that are used in industrial processes. The IAEA's "Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols," IAEA Services Series 21, March 2012, spells out the many IAEA safeguards requirements of member states.

as possible, but within 30 days of completion of physical inventory taking." The required frequency of physical inventories is not specified in the model subsidiary arrangement and likely varies depending on the type and form of material being accounted for.

A state is also required to prepare a special report for the IAEA in the event that a facility loses more than a specified limit of nuclear material or if any unusual incident or circumstance leads it to believe that "there is or may have been loss of nuclear material, including the occurrence of significant delay during an international transfer." The model subsidiary agreement requires these reports to be sent within 72 hours of a state reaching a specified loss limit and "immediately" after an incident or circumstance is known.[30]

When a state or entity with an IAEA safeguards agreement transfers more than 1 kilogram of nuclear material to another country, it is required to notify the agency two weeks prior to shipment. A country receiving more than 1 kilogram of material is to notify the agency of receipt of that material "not later than seven days before the nuclear material is to be unpacked." While the material is in transit, it is most often on the books of the receiving state; thus there is a period during which the material is not on the books of the sending state and when it is not physically held by the recipient state. If a book or physical inventory were taken during this period, the material would appear on the recipient books but not be present in its physical inventory.

There are limits to the types and quantities of materials to which IAEA safeguards and detailed nuclear material accounting are applied. Nuclear materials not "suitable for fuel fabrication or for being isotopically enriched" are not subject to detailed nuclear material accounting; only import and export data about these materials is reported to the IAEA.[31] While the IAEA "prefers to receive such information . . . within 30 days after the import or export occurs," states are only required to include this information in their annual report to the agency.[32] The initial requirements for these types of materials excluded nuclear materials exported and imported for "non-nuclear uses," such as when the aircraft industry uses thorium as a counterweight. The Additional Protocol introduces

30 IAEA, "Subsidiary Arrangement to the Agreement Between the Government of [.......] and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons."

31 These types of materials include source materials, such as natural uranium, uranium ore concentrate, or thorium.

32 IAEA, "Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols," p. 38.

new thresholds for which import and export reporting is required for these “non-nuclear use” materials: above 10 tonnes of uranium or 20 tonnes of thorium.

Though IAEA safeguards require import and export reporting on those materials not “suitable for fuel fabrication or for being isotopically enriched,” in practice, the IAEA doesn’t have the resources to match all of these import and export records.[33] As a consequence, there is no way of knowing whether all exports of these materials reach their specified destination.

Other nuclear materials not subject to IAEA safeguards include nuclear waste in which material that is typically safeguarded has been “diluted in such a way that it is no longer usable for any nuclear activity . . . or has become practicably irrecoverable.” States with Additional Protocols must provide information on changes “regarding the location or further processing of intermediate or high-level waste containing plutonium, high enriched uranium or uranium-233 on which safeguards have been terminated,” but these materials, like the source materials noted above, are not subject to detailed material accounting. IAEA safeguards (and thus nuclear material accounting requirements) can also be exempted for relatively small quantities of nuclear materials, as long as the total amount of exempted material in a country does not exceed “one kilogram in total of special fissionable material” (a quantity that is determined by combining total plutonium with the U-235 content of both highly enriched and low-enriched uranium), 10 tonnes of natural or depleted uranium enriched to .5 percent U-235 or greater, 20 tonnes of depleted uranium enriched to .5 percent U-235 or below, and 20 tonnes of thorium. Should IAEA member states determine that any of these materials need to be subject to more detailed nuclear material accounting, then they would have to revisit model safeguards agreements requirements.

Material accounting and reporting requirements in nuclear weapons states

None of the five states designated as nuclear weapons states under the NPT has comprehensive international nuclear material accounting and reporting requirements. Each of these states has negotiated a voluntary offer agreement with the IAEA that makes certain materials and facilities within their nuclear complexes available to nuclear safeguards, but due partly to IAEA resource constraints, very few materials and facilities in these states are subject to ongoing IAEA safeguards. For instance, during 2011 and 2012, only four U.S. facilities were selected for IAEA safeguards, and only one facility, the K-Area Material Storage

33 Cindy Vestergaard, “Governing the (Very) Front-End of the Fuel Cycle,” presentation given at CISSM Workshop on Comprehensive Nuclear Material Accounting, October 18, 2013, Washington, D.C.

(KAMS) at the Savannah River Site, was directly subject to IAEA oversight, and a majority of the inspections of this facility were done remotely. In China, materials at only three facilities (Qinshan Nuclear Power Plant, HTR-10 research reactor, and Shaanxi enrichment plant) were directly under IAEA safeguards.[34] In total, the amount of material subject to IAEA safeguards and therefore detailed nuclear material accounting in nuclear weapons states represents a small fraction of the total nuclear material holdings of these countries—around 18 percent of separated plutonium and less than 1 percent of highly enriched uranium in these countries.[35] Nuclear materials in NPT nuclear weapons states are subject to national safeguards, and these domestic systems include their own separate nuclear material control and accounting standards and reporting requirements. These standards and requirements vary from state to state, but one commonality is that national nuclear material systems do not include detailed accounting of nuclear materials assigned to nuclear weapons use or nuclear materials assigned to military non-weapons use. Military authorities maintain separate accounting systems for these materials.

Little is publicly known about the nuclear material accounting and reporting practices of the four states that possess nuclear weapons outside of the NPT: India, Israel, North Korea, and Pakistan. Each of these states has (or had) a separate safeguards agreement with the IAEA that places (or placed) some of its nuclear materials and facilities under international safeguards and subjected them to IAEA material accounting and reporting requirements. But each of these countries (with the exception of North Korea) maintains more facilities and materials outside of IAEA safeguards than under them.

United States. The United States has maintained a national nuclear material accounting system since the passage of the 1954 Atomic Energy Act. The ability of U.S. officials to account for nuclear materials at U.S. civilian facilities has improved considerably since then. Currently, the most comprehensive U.S. nuclear materials accounting system is the Nuclear Materials Management and Safeguards System (NMMSS), which is run out of the Department of Energy's semiautonomous National Nuclear Security Administration (NNSA). All civilian U.S. facilities with nuclear material holdings provide accounting reports to NMMSS, and all generate these reports using their facility-level nuclear material accounting systems. (NMMSS also maintains aggregate information about nuclear materials

34 The IAEA lists the facilities under IAEA safeguards in its annual reports.

35 These estimates are based on IAEA statements about materials under IAEA voluntary offer agreements and International Panel on Fissile Material estimates of weapons states' nuclear material holdings.

assigned to military uses.) U.S. facility-level accounting systems are intended to meet standards and requirements set forth by either the Department of Energy or the Nuclear Regulatory Commission (NRC). NRC regulations pertain primarily to nuclear reactor and nuclear fuel cycle facilities (including waste facilities), while Department of Energy regulations pertain primarily to U.S. research facilities and those facilities that work to develop and maintain nuclear weapons.[36]

Both NRC and Department of Energy material accounting requirements are graded, meaning that materials that could be more easily used in nuclear weapons are given extra scrutiny and require more frequent inventories on the facility level. But NMMSS, as a national system, sets the same requirements on accounting and reporting for all facilities with nuclear materials. Like IAEA safeguards requirements, NMMSS requires transaction reporting, physical inventorying, material balance reporting, etc., but NMMSS also accepts aggregate data on materials from some facilities, meaning that discrete items aren't always accounted for separately. There is also a lag between when a transaction occurs and when it is reported to NMMSS. NMMSS requires that "data on all transactions occurring during a calendar month is submitted no later than eight working days following the end of the month during which the transactions occurred." It also requires that a facility that is shipping nuclear material to another facility report the transaction to NMMSS no more than one day after the shipment. When a facility receives a shipment, it has 10 days from the point of receipt to submit a transaction report to NMMSS. The same requirements are in place for domestic and international material transactions.[37] NMMSS does not necessarily require a transaction report if a facility operator moves material from one material balance area to another within the same facility.[38]

NMMSS reconciles its nuclear material accounting records—based on transaction reports from a facility—with a facility's material balance report, which is prepared after a facility conducts a physical inventory. This reconciliation process is done at least annually for most facilities. And although the NMMSS user guide expresses a preference for electronic submission of material accounting reports from facilities, it also accepts "manual/paper" submission, and some

36 See Department of Energy, "Nuclear Material Control and Accountability," DOE O474.2, approved June 26, 2011; see also "Material Control and Accounting of Special Nuclear Material," Code of Federal Regulations, Title 10 (NRC Regulations), Part 74.

37 Department of Energy, "Nuclear Materials Management and Safeguards System: User Guide-Rev. 2.0," April 2013, p. 3-1.

38 Interviews with U.S. Department of Energy officials and facility operators.

facilities still fulfill their reporting requirements this way.

One of the fundamental weaknesses of NMMSS, indeed of most national nuclear material accounting systems, is that it relies on facility operators to manually report material accounting data accurately and in a timely manner. The NRC and Department of Energy have processes in place to ensure compliance with facility-level nuclear material control and accounting requirements. But for a variety of reasons, facility operators don't always comply with NMMSS reporting requirements in a timely fashion.[39]

China. Compared to other nuclear weapons states, China maintains much smaller stockpiles of nuclear materials. Prior to the 1980s, all facilities with nuclear materials were the sole purview of the Chinese military, which ensured control of the materials through methods of social control and worker loyalty.[40] Under this system, materials were accounted for with a rudimentary, paper-based "ledger system."[41]

China agreed to a voluntary offer safeguards agreement with the IAEA in 1988, which ushered in the use of IAEA MC&A requirements and practices at some Chinese facilities. In 1990, China also issued a regulatory document, "Rules for the Implementation of the Regulations on Nuclear Materials Control," which outlined the MC&A requirements that *all* facilities needed to meet in order to be licensed to use nuclear materials. The regulation and licensing of facilities with nuclear materials is currently managed through the Chinese Atomic Energy Authority's Office of Nuclear Material Control.

The 1990 rules require each facility to: assign personnel to be responsible for the custody of nuclear materials; establish accounting and reporting systems; measure materials as they enter a balance area and at the close of balance periods; and record internal and external transfers of materials.[42] Facilities are required to conduct physical inventories of their nuclear materials at least annually, and at least twice annually for those materials containing plutonium 239, uranium 233, and uranium 235 in concentrations greater than 20 percent.[43] Operators are expected to record and analyze inventory differences and regularly

39 Interviews with U.S. Department of Energy officials.

40 Hui Zhang, "Evaluating China's MPC&A System," paper presented at the INMM 44th Annual Meeting, Phoenix, Arizona, July 13-17, 2003.

41 Nathan Busch, "China's Fissile Material Protection, Control, and Accounting: The Case for Renewed Collaboration," *The Nonproliferation Review*, Fall/Winter 2002, p. 94.

42 Wu Jun, "The Regulation and Technology of Chinese Nuclear Material Accounting," CISSM Working Paper, February 2014.

43 Ibid.

assess the reliability of measurement systems.

With the assistance of the United States (see “Efforts to Improve Material Accounting,” p. 32) and the IAEA, China has been able to introduce computerized nuclear material accounting systems at many of its facilities. Yet there are questions about whether the adoption of these systems and the requirements stipulated in the 1990 rules are sufficient to detect or prevent the diversion of nuclear materials by “insiders” and non-state actors.[44] Similar questions remain about whether China has an accurate baseline accounting of nuclear materials on which to conduct accurate and complete material accounting.[45]

Russia. During the Cold War, the Soviet Union’s nuclear accounting efforts relied primarily on assigning personal responsibility for nuclear materials to facility operators and technicians.[46] In other words, individuals working with nuclear materials were responsible for staying under targets for allowable losses of materials that were set for each type of activity that they conducted. As long as the amounts of materials, or records of material losses, were within limits of allowable losses, the material accounts were considered adequate. Rarely if ever did facility operators measure material stockpiles to determine inventory differences based on empirical data.

The Soviet Union began to introduce a more conventional form of nuclear material accounting in the mid-1980s after it signed a voluntary offer safeguards agreement with the IAEA.[47] Two Russian facilities—a research reactor and a power reactor—developed MC&A systems that met IAEA requirements. The many other Russian facilities with nuclear materials didn’t begin to see this type of improvement in material accounting until the mid-1990s, when U.S. and Russian officials initiated cooperative threat reduction projects within the former Soviet states. As part of these efforts, Russia instituted a range of new, more stringent national regulations aimed at governing the use of nuclear material.[48] The

44 Nathan Busch, “China’s Fissile Material Protection, Control and Accounting.” Busch suggests, “It is [not] clear that China has undertaken the extensive designing and testing necessary to assemble MC&A equipment into an integrated system capable of detecting the thefts of fissile materials.”

45 Ibid.

46 Alexander Rumyantsev, “State System for Accounting and Control of Nuclear Materials and Radioactive Substances in Russia,” *Yaderny Kontrol* (Nuclear Control), #15, March 1996. This article provides a broad overview of Soviet-era material accounting practices.

47 IAEA, “The Text of the Agreement of 21 February 1985 Between the Union of Soviet Socialist Republics and the Agency for the Application of Safeguards in the Union of Soviet Socialist Republics,” INFCIRC/327, July 1985.

48 Dmitry Kovchegin, “Developing a Nuclear Material Control and Accounting System in Russia,” CISSM Working Paper, December 2013.

most important for nuclear material accounting purposes was, "Basic Rules for Accounting for and Monitoring of Nuclear Materials."[49] This order doesn't specify requirements for inventory change reporting, but it does require operators to confirm the characteristics of a nuclear material shipment and enter them into the facility-level material accounting system within 10 days of receiving the material. It also requires that physical inventories be conducted every two months for the most sensitive nuclear materials and at least once every 12 months for the least sensitive nuclear materials.

Missing from Russian material accounting requirements was and is the requirement for an initial material accounting report from each facility that is based on measurements of material holdings. In many cases, Russian officials have decided to accept as accurate Soviet material accounting records as the baseline for balancing material accounts.[50] The lack of initial measurement-based physical inventories at many Russian facilities undercuts efforts to ensure the security of all materials at those facilities.

Along with the reform in regulations that came as part of the cooperative threat reduction program, U.S. officials worked with Russian officials to establish a new national nuclear material accounting system that could serve a role equivalent to that of IAEA SSACs or other weapons states' national systems. The Federal Information System (FIS), as the Russian national system is known, was intended to include detailed information about all nuclear materials from all material balance areas at all civilian facilities. By 2000, however, Russian officials conceded that this ambitious goal was impractical because it would be too costly economically.[51] Instead of reporting material accounting information from every material balance area, a standard requirement under IAEA safeguards and most other national material accounting systems, the FIS adopted "organization-level" reporting, where many of the approximately 60 Russian civilian organizations would report on the aggregate material holdings of their entire system. Summaries of material inventories for an entire organization would be sent to the FIS once a year; summaries of all inventory changes within an organization would be reported quarterly. This standard proved insufficient to the management team overseeing the FIS's development: "The organization-wide reports provided too little information to perform several different nuclear

49 This regulation, best known by its Russian acronym, OPUK, has gone through several versions. The most recent version, NP-030-12, was adopted on April 17, 2012.

50 Dmitry Kovchegin, "Developing a Nuclear Material Control and Accounting System in Russia."

51 Rusty Babcock, "U.S. and Russian Cooperation on the Russian Federal Information System (FIS)," presentation at NMMSS Users Annual Training Meeting, May 23-25, 2006, p. 7.

material management tasks."[52]

As an alternative, officials decided to organize "reporting zones"—which could be made up of a single MBA, many MBAs, or an entire organization—and that these zones would regularly provide detailed accounts of material holdings to the FIS. According to Russian officials, this shift would permit an increase in material accounting reporting as compared to organization-level reporting, but wouldn't require as many inventory reports as would be required under a system that counted each MBA as a separate reporting unit. Under this scheme, referred to as the "universal reporting method," the reporting zones with the most sensitive material would submit inventory listings and inventory change reports to the FIS monthly.[53]

France and the United Kingdom. Since 1973, when the European Atomic Energy Commission (Euratom) concluded a safeguards agreement with the IAEA, Euratom has served as a clearinghouse of nuclear material accounting information from members of the European Commission, including France and the United Kingdom. Euratom maintains its own material accounting database to which civilian nuclear facilities within Europe submit accounting reports on their nuclear material holdings. In most cases, this information is then passed along to the IAEA in fulfillment of European states' international safeguards commitments.

Euratom material accounting and reporting requirements are similar to those in the United States. Euratom safeguards are also graded for material attractiveness, and Euratom data collection relies on facility-level compliance. Euratom member countries are expected to maintain nuclear material accounting systems at all facilities that house nuclear materials, to set up material balance areas, to measure and characterize materials as they come and go, to report on transactions between material balance areas, to conduct regular physical inventories, and to reconcile differences in book and physical inventories. Euratom also conducts site visits to verify both that material accounting systems are organized as required and that accounting records reflect current holdings.

Each Euratom facility is expected to submit all transaction reports regarding materials entering or leaving each material balance together. According to Euratom regulations, these reports, "shall be sent monthly, at the latest 15 days

52 A. Martiyanov, V. Pitel, L. Kasumova, R. Babcock, and C. Heinberg, "Proposals for the Future Development of the Russian Automated Federal Information System for Nuclear Material Control and Accounting: The Universal Reporting Concept," presentation at INMM Annual Meeting, June 24, 2004, UCRL-CONF-204879.

53 Ibid.

after the end of the month, and shall state all inventory changes which have occurred or become known during that month."[54] Physical inventories are required at least once every calendar year and "the period between two successive physical inventory takings shall not exceed 14 months."[55] If a facility operator believes there has been an "unusual occurrence," such as a loss of material, he or she is required to bring this loss to Euratom's attention as soon as possible. Facilities are required to notify Euratom of exports of material to other states at least eight days "before the material is to be packed for transfer." Facilities that receive shipments of material from foreign facilities must report the transaction by the date of receipt at the latest. When it revised its nuclear material accounting regulations in 2005, Euratom also developed a new streamlined electronic data transmission system. All Euratom facilities are expected, if possible, to use this system when transmitting accounting data to Euratom.

As NPT nuclear weapons states, France and the United Kingdom have a number of facilities and materials that are excluded from Euratom safeguards. These military-related facilities and materials are subject to separate domestic accounting and reporting requirements.

Accounting for military-use nuclear materials

Each of the five NPT nuclear weapons states reserves a sizeable stockpile of nuclear materials for use in nuclear weapons or for other military purposes, including the fueling of nuclear-powered submarines. None of these states makes publicly available detailed information about how these military-use materials are accounted for on a daily basis.

The Trilateral Initiative between the United States, Russia, and the IAEA attempted to begin the process of applying international safeguards to U.S. and Russian materials deemed in excess of military needs, but the initiative ended in 2002 when political leaders in each country decided that coordinated efforts had gone as far as they could and that each state ought to pursue further implementation of safeguards on excess military materials with the IAEA, and only the IAEA.[56] The U.K.-Norway Initiative attempted to demonstrate the

54 "Commission Regulation (Euratom) No. 302/2005 on the Application of Euratom Safeguards," *Official Journal of the European Union*, February 8, 2005.

55 Ibid. Commission recommendations for the implementation of Regulation (Euratom) No. 302/2005 specify particular requirements related to the submission of physical inventory listings and material balance reports that are compiled before the end of a month, so that these reports do not create inconsistencies when the data is reported to the IAEA.

56 Thomas E. Shea, "The Trilateral Initiative: A Model for the Future?," *Arms Control Today*, May 2008.

possibility of verifying nuclear warhead declarations and dismantlement, but it was a demonstration project and did not involve accounting for the materials assigned to operational or reserve warheads. Safeguards experts have explored yet other ways to extend IAEA safeguards to materials in nuclear weapons states, including materials designated for military use or in-excess of military use.[57] Yet, these efforts have not made it off the drawing board, as nuclear weapons states, by and large, have yet to fully embrace the perceived benefits of having more detailed accounting of other states' nuclear material stockpiles and to prioritize bolstering IAEA capabilities.

The United States and the United Kingdom have made public declarations that include information about the amount of weapons-usable nuclear materials currently held by their militaries.[58] But these declarations provide only snapshots of material holdings and include little to no information about how these materials are accounted for and managed on a day-to-day basis. In accordance with arms control agreements, Russia and the United States have also shared with each other information about the number and location of operationally deployed strategic nuclear weapons; a subset of this information is also released publicly. However, these information exchanges are relatively infrequent, and they don't address which nuclear materials are present in each warhead or in what quantities and composition. These agreements also do not address non-deployed strategic warheads, tactical nuclear weapons, or reserve military stockpiles of weapons-usable materials.

The branches of the U.S. armed services that manage nuclear weapons and materials (the U.S. Air Force and the U.S. Navy) have made publicly available some of their regulatory guides for nuclear material and warhead handling. These documents describe the general requirements for the accounting and control of U.S. nuclear weapons, weapons assemblies, and some weapons-related items, and they provide a general sense of how some military-use nuclear materials are accounted for.

Each nuclear weapon or item under the control of the U.S. Air Force, for instance, is assigned an account number, and a single munitions accountable systems officer (MASO) is assigned responsibility for a set of items; this officer

57 For example, see John Carlson, "Expanding Safeguards in Nuclear-Weapons States," presentation, 2011 Annual Meeting of the Institute of Nuclear Materials Management, July 17-21, 2011.

58 See Department of Energy, "Plutonium: The First 50 Years," February 1996, DOE/DP-0137; Department of Energy, "Highly Enriched Uranium Inventory," January 2006; U.K. Ministry of Defence, "Historical Accounting for UK Defence Highly Enriched Uranium," March 2006; U.K. Ministry of Defense, "Plutonium and Aldermaston: An Historical Account," 2000.

is "responsible for the accuracy of accountable records (manual or automated) generated within his/her area of responsibility."[59] The Department of Defense maintains the Defense Integration and Management of Nuclear Data Services (DIAMONDS) system, an "automated end-to-end information infrastructure" for managing its nuclear stockpile, including operational and non-operational nuclear warheads.[60] The accountable officer is required to document in DIAMONDS changes in the status of each item within his or her control, changes in the configuration of items, transfers of custody of items, and the shipment or receipt of items.[61]

Any time an accountable officer is changed for a set of items, both the old and the new officers are required to conduct a "100 percent [physical] inventory of the account." A complete physical inventory is also required of the entire U.S. stockpile of nuclear weapons and weapons subassemblies at least semiannually; this semiannual process "creates an independent inventory that reports the status, location, and configuration of the national nuclear weapon stockpile by serial number and quantity for each location." This independent semiannual inventory listing is then sent to DIAMONDS, where the Defense Threat Reduction Agency, which maintains the system, reconciles the inventory with its most up-to-date records. Special "rapid" inventories can be requested by the president of the United States, secretary of defense, and the Joint Staff to "promptly verify all or selected portions of the DoD stockpile of nuclear weapons are in the possession of authorized DoD agents."[62] It is unclear if any of these inventories involve measuring and reporting the nuclear materials present in an item or whether they are simply exercises in counting items.

In the absence of detailed publicly available information about how they account for and control all military-use nuclear materials and nuclear warheads, the militaries of the five NPT nuclear weapons states and the four additional nuclear weapons states have provided public assurances about how

59 Department of the Air Force, "Nuclear Accountability Procedures," Air Force Instruction 21-203, November 23, 2009. While this document outlines some accounting and control procedures, public access to other documents that presumably provide significantly more detail about accounting for nuclear weapons and military-use materials—directives such as "11N-100-4 Custody, Accountability, and Control of Nuclear Weapons and Nuclear Material," "11N-3150-8-1, USAF DIAMONDS Policy and Procedures," and "11N-100-3150, Joint Reporting Structure: Nuclear Weapons Reports"—remains restricted. Previous iterations of some of these documents have been released publicly, though they are heavily redacted.

60 *FBO Daily*, DIAMONDS "sources sought" notice, December 15, 2002, FBO #0378.

61 Department of the Air Force, "Nuclear Accountability Procedures."

62 Ibid.

seriously they take the responsibility of accounting for and controlling these materials.[63] This type of assurance might have sufficed in a world where the primary concerns of national and international officials were the prevention of proliferation to non-weapons states and the preservation of strategic nuclear deterrence, but it is unlikely to suffice under current security demands. Indeed, assurances about the level of national control of nuclear weapons and their components have been severely undermined by accounts of nuclear weapons states' operational failures.

For instance, Russian experts believe that as the Soviet Union began to fall apart in 1991, Russian officials did not have complete control over nuclear weapons deployed to republics other than Russia. As one expert put it, "nuclear weapons quickly became hostage to political struggle between the governments of emerging independent states and Soviet leadership.[64] While this lack of control was a problem, an even greater problem would have been if these weapons and the materials included in them would have been unaccounted or misaccounted for. Experts don't know if this was ever the case, but it's unclear if the Soviets even had the accounting infrastructure in place to know if this had occurred.

More recently, in 2007, U.S. pilots mistakenly flew six nuclear-armed cruise missiles from Minot Air Force Base to Barksdale Air Force Base. Neither the officers at Minot or at Barksdale were aware for 36 hours that the nuclear weapons were transferred; in other words, whatever system that was used to manage those nuclear weapons failed to account for or control them in a timely manner. The mistake was noticed only when officers at Barksdale offloaded the weapons. On two occasions a year earlier, in October and November 2006, the Air Force mistakenly shipped several forward-section assemblies of U.S. Minuteman intercontinental ballistic missiles to Taiwan. While this mistake did not involve a failure of accounting for nuclear material, it did involve highly sensitive weapons components—in this case, the part of the missile that holds

63 For example, in his briefing about the 2007 mistaken transfer of 6 nuclear weapons from Minot Air Force Base to Barksdale Air Force Base, Michael Wynne, Secretary of the Air Force, attempted to reassure the public about Air Force accounting and control of nuclear weapons thusly: "The American public has placed great trust and confidence in its Air Force to safeguard our country's strategic weapons. We have for the past 60 years and will continue to execute this important mission of providing security for all weapons." Department of Defense, "DoD Press Briefing with Maj. Gen. Newton from the Pentagon, Arlington, Va.," October 19, 2007.

64 Nikolai Sokov, "Controlling Soviet/Russian Nuclear Weapons in Time of Instability," paper prepared for a Nonproliferation Policy Education Center meeting, "Securing Nuclear Arsenals for the Next Half Century: What Does History Recommend?" February 28, 2012.

Comparing international and national nuclear material accounting standards

	Inventory change and transaction reporting	Physical inventory taking
IAEA Safeguards	Changes in material balance area inventories are required to be reported **within 30 days** after the end of the month in which change occurs. Reporting for international transactions is required **two weeks** prior to shipment and **one week** prior to unpacking a received shipment.	Varies by material type and form; required **at least annually**.
U.S. Nuclear Materials Management and Safeguards System (NMMSS)	According to U.S. regulations, transaction data is required within **eight days** of the end of the month in which the transaction occurred. Reporting on inter-facility or international transfers is required within **one day** of material shipment and within **10 days** of material receipt.	Varies from **every two months to every two years** for Department of Energy facilities and **at least annually** for NRC licensees.
Euratom Safeguards	Transaction data is required within **15 days** after the end of the month in which transaction occurs.	Required **at least once every calendar year** and not more than 14 months after previous physical inventory.
Russia's Federal Information System (FIS)	Transaction data is required within **10 days** of material receipt.	Required **at least every two months** for most sensitive materials and **at least annually** for other materials.
U.S. Air Force Accountability System/ DIAMONDS	At the time of the change.	Required when a new officer assumes responsibility for items; complete inventory required **at least semiannually**.

Sources: IAEA, "Subsidiary Arrangement to the Agreement Between the Government of [.......] and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," Fifth Revision, SG-FM-1170, February, 22, 2011; Department of Energy, "Nuclear Materials Management and Safeguards System: User Guide-Rev. 2.0," April 2013; Russian Federation, "Adoption of the Federal Rules and Regulations Regarding the Use of Atomic Energy—Basic Nuclear Material Control and Accounting Rules," Federal Environmental, Industrial, and Nuclear Regulatory Authority Order № 255, April 17, 2012; "Commission Regulation (Euratom) No. 302/2005 on the Application of Euratom Safeguards," *Official Journal of the European Union*, February 8, 2005; Department of the Air Force, "Nuclear Accountability Procedures," Air Force Instruction 21-203, November 23, 2009; and other sources.

the nuclear warheads—that had previously been accounted for in a manner similar to how nuclear weapons with materials included are accounted for.

The Department of Defense conducted several reviews of the specific circumstances that led to these mistakes and of nuclear weapons handling procedures in general. One of the reviews, the Report of the Secretary of Defense Task Force on Nuclear Weapons Management (otherwise known as the Schlesinger Report, after the task force chairman, former defense and energy secretary James Schlesinger), pointed to changes that had been made in the mid-1990s to the accounting procedures for nuclear weapons-related materials as a source for the errant shipments to Taiwan. As a part of military base consolidation and procedural "streamlining," 12,000 nuclear weapons-related items—sensitive components that do not include nuclear materials—were transferred to "a system that managed them as regular commodities," effectively eliminating "special material handling requirements."[65]

In response to finding an "atrophy" of the Air Force's nuclear mission, the task force recommended a review of all Air Force nuclear weapons handling procedures and endorsed Air Force efforts to elevate the accounting requirements for nuclear weapons-related items. The Air Force defines its goal as obtaining "positive inventory control" of all nuclear weapons-related items. This requires "the ability to identify and account for the condition and location of material *anywhere* in the supply chain, including storage, movement, maintenance, use, and disposal by a responsible agent at *any point in time* [emphasis added]."[66] Indeed, the Department of Defense added a module to its DIAMONDS system for the explicit purpose of providing "tracking and accountability of Nuclear Weapons-Related Materials."[67]

Accounting for foreign-obligated materials

As states began to trade nuclear technology and material with other countries in the 1950s, they had to consider what material accounting requirements they would apply to these "foreign-obligated" materials. In most cases, particularly since the adoption of the NPT, states have relied on their trading partners' or the IAEA's ability to account for these nuclear materials. As most nuclear-exporting states limit trade of nuclear materials and technologies to other states with IAEA

65 Department of Defense, "The Report of the Secretary of Defense Task Force on DoD Nuclear Weapons Management, Phase I: The Air Force's Nuclear Mission," September 2008, p. 24.

66 Ibid., p. 66.

67 The Department of Defense FY2011 Budget Request explains in greater detail the requirements for this additional DIAMONDS module.

safeguards agreements, this ensures that these exported materials are at least subject to IAEA safeguards requirements.

In relying on other national or international material accounting systems, states give up direct knowledge of the whereabouts of the material they supplied and how the materials are being used. In the United States, this lack of knowledge has been perceived as reason for concern.[68] While not having access to detailed material accounting information about foreign-obligated materials is not the same as those materials not being accounted for properly, there is reason for states to work toward greater and more predictable accounting of foreign-obligated materials. Without frequent access to information about where foreign-obligated materials are and what they are being used for, states forfeit the ability to ensure the application of safeguards and material accounting to *all* materials in those states. The IAEA and other regulatory bodies work to ensure a state's compliance with safeguards commitments, but it is in the interests of supplier states to be able to exercise additional leverage to ensure compliance. This would require more frequent access to detailed nuclear material accounting information about foreign-obligated materials.

Achieving this objective would require reorienting the nature of nuclear cooperation to achieve both economic and security objectives.[69] Applying additional material accounting requirements to nuclear trade could steer states seeking nuclear technology and material to suppliers with less stringent requirements. This is why it is important for all supplier states to work toward specific and consistent nuclear material accounting and reporting requirements for all of their nuclear cooperation agreements. Doing so would set a new baseline for commerce in nuclear materials above and beyond what organizations, such as the Nuclear Suppliers Group, currently require.

68 U.S. Government Accountability Office, "Report to the Committee on Foreign Affairs, House of Representatives: U.S. Agencies Have Limited Ability to Account for, Monitor, and Evaluate the Security of U.S. Nuclear Material Overseas," GAO-11-920, September 2011.

69 Nickolas Roth and Jonas Siegel, "Improving Accounting and Reporting of Foreign-Obligated Nuclear Materials," unpublished working paper, June 2013.

Section 5.

Envisaging a comprehensive system

Setting more stringent requirements and establishing new capabilities for the accounting and control of nuclear materials in all states requires a great deal of forethought. The systems currently in place have developed over time and reflect the security, safety, and commercial concerns of governments, businesses, and international organizations. But it's also because current systems and practices predominantly reflect legacy arrangements, in response to outdated security concerns and economic conditions, that these requirements and operating capabilities need rethinking.

The primary risk posed by nuclear materials today is not simply that non-nuclear weapons states will divert materials to develop nuclear weapons, though this does remain a concern. Policy makers and security experts are equally, if not more, concerned about the diversion of nuclear materials to non-state entities, particularly as the use of nuclear energy and the international trade in nuclear materials expands. A third concern is ensuring international security as states decrease their nuclear weapons arsenals and adjust their nuclear postures. This is a considerably more complex and demanding set of priorities for nuclear material accounting and control systems and practices to serve.

As the above summaries of national and international material accounting requirements demonstrate, current nuclear material accounting standards vary from country to country. Though many nuclear material accounting systems serve their stated purposes adequately, taken together they are ill equipped to address emerging nuclear security and nonproliferation objectives, as well as to support further nuclear weapons reductions. Put more directly, legacy systems are not as accurate or as timely as they could be made to be with reasonable adjustments.

To achieve expanded objectives, *all* states will have to employ comprehensive nuclear material accounting systems and practices that enable them to account for the most dangerous types of materials on a near-continuous basis and less dangerous material more frequently than they currently do. They will also need to develop information systems that allow for the coordinated management of all accounting information about all nuclear materials within their national borders. And *all* states will need to subject their systems to international monitoring and transparency mechanisms, such that states will have confidence in other states' accounting and control of their materials.

In order to achieve these objectives, it is not necessary for material control and accounting systems to function identically in every state, but they all need to meet the same internationally agreed-upon requirements. The nature of past and current arrangements to reduce nuclear risks suggests that further risk reduction efforts will need to involve more equitable rules. Building such a comprehensive, global nuclear material accounting system will require international coordination and considerable political effort. For states to have confidence in such a system—confidence that the system permits them to assess other states' compliance with their nuclear risk reduction commitments—the system will have to operate for a number of years and be refined to address emergent concerns. This section identifies the components of a comprehensive nuclear material accounting system that will help states meet emerging global security objectives.

Materials subject to comprehensive accounting

Nuclear material accounting requirements typically differ according to the attractiveness, quantity, and form of the materials being safeguarded. Requirements are graded in this way to reflect the lower security risk that certain quantities and forms of materials present and also the financial cost associated with accounting for materials. As accounting requirements for more attractive materials typically require more frequent physical inventories and sometimes more technologically advanced measurement and control mechanisms, they can be more time consuming and expensive to fulfill. On the other hand, some attractive materials are relatively easy to account for because they are kept in item form and can be secured in containers and continuously monitored, while less attractive bulk materials can be more time-consuming to account for.

Accounting for all nuclear materials—from HEU assigned to nuclear warheads to cylinders of uranium hexafluoride—in the same stringent manner would likely lead to the misallocation of finite national government and commercial resources. Yet, requirements for each type and form of material can be improved and standardized across national borders to better address the risks identified in this study and the shortcomings of current systems.

Special nuclear materials. While there are differences in specific requirements, most national regulatory bodies and the IAEA agree on the basic types of materials that should be subject to detailed nuclear material accounting. These materials include: plutonium 239, uranium 233, uranium enriched in the isotope 235, and any material containing one or more of these materials (to include nuclear waste). The IAEA terms this type of material "special fissionable material," the United States calls it "special nuclear material," Euratom "special fissile material," etc.[70]

The IAEA breaks down special fissionable material into two additional categories: direct-use material and indirect-use material. Direct-use special fissionable materials are those that can be used in a nuclear weapon "without transmutation or further enrichment."[71] This includes uranium enriched to 20 percent or greater U-235, plutonium containing less than 80 percent Pu-238, and uranium 233. Indirect-use materials include all other special fissionable materials: low-enriched uranium, etc. This latter distinction is important because the IAEA sets different standards for detecting the diversion of direct- and indirect-use materials. At a minimum, it aims to detect the diversion of unirradiated direct-use materials (such as fresh HEU reactor fuel, separated plutonium, etc.) within one month of a diversion, while it aims to detect the diversion of irradiated direct-use materials (such as spent reactor fuel) within three months of diversion and all indirect-use material within one year of diversion.[72]

As part of a comprehensive nuclear material accounting system, direct-use special fissionable nuclear materials should be subject to the most stringent requirements. In a world with low numbers of nuclear weapons, the risk of a nuclear weapons state reconstituting a weapon or of a non-nuclear weapons state or non-state actor developing a weapon requires that all direct-use materials be subject to MC&A requirements similar if not the same to those used for intact nuclear weapons.

The U.S. Department of Defense's emphasis on positive inventory control of all nuclear weapons-related materials could serve as a minimum standard for all direct-use materials in both item and bulk form. As a reminder, positive inventory control requires "the ability to identify and account for the condition and location of material anywhere in the supply chain, including storage, movement, maintenance, use, and disposal by a responsible agent at any point in time." Such a stringent requirement will necessitate significant changes in how facility-level nuclear material accounting systems function (see below for a discussion of frequency of inventory change, transaction, and material balance reporting).

Positive inventory control for nuclear materials classified as items is currently achievable given the evolution of safeguards technologies. If items are stored in

70 IAEA, "Statute of the IAEA," Article XX, entered into force on July 29, 1957.

71 IAEA, "Safeguards Glossary," International Nuclear Verification Series No. 3, 2001, p. 28.

72 Ibid., pp. 24-25.

"smart" containers that can be sealed, continuously monitored, and remotely interrogated, then the condition and location of those materials can be continuously available to operators and regulators. Positive inventory control of all direct-use special fissionable materials might pose particular challenges for bulk materials in storage or in process. Yet, if bulk materials in storage are subdivided and containerized as they currently are at Savannah River's K-Area Materials Storage site and at the Mayak Fissile Material Storage Facility, accounting for them can be similar to accounting for specific items.

In-process special fissionable materials pose less of an immediate security or proliferation risk than, say, bulk metallic HEU because they are not immediately accessible. It is conceivable that positive inventory control requirements can be relaxed for these types of materials by reducing the frequency of inventorying and reporting. But states will want to know on a regular basis if and to what degree other states are reprocessing spent nuclear fuel or enriching uranium. The use of in-process monitoring and accounting tools (described earlier) holds the potential to fulfill more stringent national-level accounting requirements than are currently in place. Rather than reporting inventory changes on a monthly basis, for instance, operators could be expected to make in-process accounting information for special fissionable materials available to national authorities on a weekly or even daily basis.

The IAEA currently permits some quantities of special fissionable materials to be exempt from safeguards and material accounting. For instance, the model comprehensive safeguards agreement permits quantities of special fissionable material less than 1 kilogram in total to be exempted from detailed nuclear material accounting. The IAEA would make a trade-off in terms of efficiency and cost if it were to require all states to subject all gram quantities of special fissionable materials to detailed nuclear material accounting, but for the purposes of addressing concerns about the diversion of materials to non-state actors or the "insider" threat, the agency ought to consider tightening these requirements, and a comprehensive system ought to consider adopting them.[73]

Source materials. While all special fissionable materials are subject to IAEA safeguards and national material accounting regulations, not all source materials, or materials that can be used to produce special fissionable materials, are. As noted earlier, the IAEA makes the distinction between source material "of a composition and purity suitable for fuel fabrication or for being isotopically

73 Martha Williams, "On the Importance of MC&A to Nuclear Security."

enriched" and source material that has not yet reached this form.[74] This latter category is not subject to detailed material accounting in the same manner as the former. Standard IAEA safeguards, the Additional Protocol, and most national regulations require commercial operators at uranium mines, concentration facilities (where uranium ore is crushed and processed to make uranium concentrate or "yellowcake"), and conversion plants (where uranium is purified and made into a gaseous form) to measure and report estimates of materials that enter and leave their facilities, but as discussed earlier, the IAEA doesn't routinely transit match these numbers and operator compliance with these requirements can be low.[75]

The logic behind the distinction drawn by the IAEA and many national regulators between special nuclear materials and source materials is generally sensible, as there are a relatively small number of uranium enrichment and fuel fabrication plants where source materials can be made into forms that present greater security risks. If regulators are able to safeguard those facilities and all of the materials that come in and out of them, then they can be relatively certain that materials that would be attractive for state diversion to unauthorized uses or for non-state diversion are subject to detailed nuclear material accounting.

Yet, there are still good reasons for national regulators and the IAEA to extend more stringent accounting requirements to some forms of source materials. For instance, if analysts are concerned about the risk that a state (or a non-state actor) is building an undeclared uranium enrichment facility, then they will also want to know with greater certainty than they currently do that all of the uranium concentrate that leaves uranium mines is properly accounted for. Without a steady stream of uranium concentrate, undeclared conversion and enrichment facilities would be without material to process. And, if each drum of uranium concentrate that leaves a mine is monitored to a minimum standard, by being assigned a barcode and tracked via an inventory control system, then a significant number of missing or unaccounted-for drums of uranium concentrate would draw the necessary attention. It is unnecessary to characterize all of the uranium in a particular drum to the fullest extent possible, but making a mass calculation for each drum, assigning each a unique identifier, and recording its destination could serve the larger purpose of ensuring confidence in the control of the material. The national or international regulators whose goal it is to ensure compliance with nonproliferation and security objectives will require additional resources to

74 This distinction is drawn in paragraph 34 of INFCIRC/153, the model comprehensive safeguard agreement.

75 Cindy Vestergaard, "Governing the (Very) Front-End of the Fuel Cycle."

comprehensively match transit records of these drums.

More stringent accounting requirements are currently in place for uranium hexafluoride cylinders than for drums of uranium concentrate. But these requirements should be tightened as well. Operators should be required to employ systems to track cylinders of uranium hexafluoride during shipment and prior to the contents of the cylinders being introduced into, for instance, a centrifuge cascade. Indeed, a uniform global tracking system for these cylinders, an idea that has been consistently advocated for during the past decade, would fit well within the idea of a comprehensive nuclear material accounting system.[76]

Facility-level requirements

Inventory change and transaction reporting. To be capable of reporting to national nuclear material accounting systems on a daily basis, facilities will need to maintain facility-level systems capable of compiling changes to their nuclear material holdings on a daily basis. In MC&A parlance, this would require facility operators to be able to compile book inventories daily. Depending on the scheme whereby information is reported or shared with a national-level material accounting system, inventory change or transaction reports would need to be submitted on the day that they occur, rather than within a week or a month of a change in material inventory or a material transaction.

Indeed, the IAEA has developed a similar idea, "near-real-time accountancy," to enable this type of awareness of material stockpiles. Near-real-time accountancy, which is primarily used in bulk material balance areas, involves operators making available inventory and inventory change data to the IAEA on a near-real-time basis so that inventory verification can be carried out and material balances can be closed more frequently than, for example, at the time of an annual physical inventory taking.

Daily reporting on some materials will be relatively easy. Operators should be able to report if a single container of material is moved from one material balance area to another, or if a fuel rod is moved from a reactor to a spent fuel pool. However, it will be difficult to conduct daily reporting for some types of materials undergoing particular processes. For instance, if operators at an enrichment facility introduce uranium hexafluoride into a cascade of centrifuges on a particular day, that material will not be easily accounted for absent an in-process accounting capability. Yet even then, it should be possible to report on a daily basis

76 Peter Friend, et al., "A Concept for a World Wide System of Identification of UF6 Cylinders," paper presented at the 2009 Institute for Nuclear Materials Management Annual Meeting.

how much material of what concentration is introduced into a cascade, and how much material, and of what concentration, is removed. By tracking in-process inventories of materials over time, national and international inventories should be able to assess compliance with risk-reduction commitments, even in the absence of in-process monitoring capabilities.

Frequency of physical inventories and material balance reports. The process of conducting a physical inventory is central to verifying that facility and national accounting records match the amounts and characteristics of materials within a balance area. A material balance report is assembled after a physical inventory taking and represents the most complete accounting of material stockpiles. It also serves as a baseline for future material accounting efforts.

In general, the physical inventory process is time-consuming and costly. During a physical inventory taking, facility operators typically cease all operations, count and measure all or selected materials, and compile material balance reports of their findings. Physical inventories in material balance areas that contain only items are more straight forward, as there should be no material unaccounted for in these areas, unless an entire item or a number of items are missing. Conducting physical inventories of material balance areas that house bulk or in-process materials is more complicated, as it often involves sampling and measuring bulk materials, some of which are difficult or dangerous to access.

In a comprehensive nuclear material accounting system, physical inventory taking would be central to ensuring confidence in the more regular operator reporting of changes in inventories and of book inventories. Even if it is possible to remotely verify that containers holding nuclear items have not been moved or tampered with, it will still be necessary to conduct occasional physical inventories of these materials. The more frequently that physical inventories match (or are within the uncertainty limits of) the accounting records that are updated with each inventory change or transaction, the more confidence users and observers will have in material accounting practices and systems.

In item material balance areas, some of which contain the most sensitive nuclear materials (e.g., intact nuclear warheads and the nuclear components of nuclear warheads), operators should be required to conduct frequent (at least monthly if not weekly) physical inventories (under the oversight of national regulators) that confirm the status and location of items and help to ensure the accuracy of accounting records. National nuclear material accounting records should be expected to reflect the findings of these physical inventories relatively quickly (within days at most, if not in near-real-time) to ensure timely information sharing with third parties (other states or international authorities). For physical inventories to have the greatest effect, third parties should be involved in a random selection of physical inventory takings each year, as is current IAEA practice.

Material balance area arrangements. States with large stockpiles of nuclear materials have generally been reducing the number of facilities and material balance areas in which nuclear materials are stored.[77] This move has the potential to streamline the process of accounting for nuclear materials within these countries. However, the creation of material balance areas with larger stockpiles of materials also poses challenges, as physical inventory taking could be more time-consuming and costly, depending on the types and configuration of the materials.

As part of its guide on using MC&A to achieve nuclear security objectives, the IAEA suggests that operators subdivide material balance areas and record when materials are moved between sub-areas.[78] These arrangements could help to address the challenge of accounting for materials in large balance areas and thus the challenge of consolidating materials into larger balance areas, without requiring the same personnel and technical infrastructure needed to operate additional material balance areas.

In addition to reporting movements within a balance area, all facilities should be required to report to national regulators movements of materials from balance area to balance area within a facility. This type of detailed reporting to a national accounting system is particularly important for nuclear weapons states where some facilities maintain several types and statuses of materials. For instance, the primary U.S. weapons assembly and disassembly facility, the Pantex Plant, houses a range of types and forms of materials: retired warheads (with their limited-lifetime components removed), assemblies and subassemblies removed from warheads, bare pits, etc. Some of these forms of nuclear material can be more easily and more quickly weaponized than others; thus it is important for a national material accounting system to be able to account for how much of each type of material is in each specific balance area, and when materials move from one balance area to another. This type of information will be particularly relevant in verifying nuclear weapons reductions and dismantlement.

While these changes would likely move facilities toward maintaining positive inventory control of their most attractive nuclear materials, an even more fundamental change to material balance areas might be necessary to achieve the requisite security and nonproliferation gains. Rather than trying to find

77 For instance, see Pavel Podvig, "Consolidating Fissile Materials in Russia's Nuclear Complex," report of the International Panel on Fissile Materials, May 2009.

78 Martha Williams, "On the Importance of MC&A to Nuclear Security."

the optimal size and arrangement of material balance areas, in some facilities, operators could begin conceiving of each separate container as an individual balance area, in which a separate material accounting record is kept, a separate physical inventory process is conducted, and separate continuous monitoring is applied. Such a system would involve considerably more data than current material accounting practices require, but it would provide the type of fine-grain accounting that will be necessary for significant quantities of weapons-usable nuclear materials and intact or partially intact nuclear weapons.

Unique item identifiers. As part of a previous attempt to strengthen U.S. nuclear material management systems, U.S. scientists focused on a basic problem in the way that nuclear material items are currently accounted for and tracked. When U.S. operators ship an item from one facility to another "its [unique] identifier changes because each site has its own identifiers, which are only unique within a site."[79] To address this problem, the scientists suggested that each item of nuclear material be assigned a "permanent, complex-wide unique identifier." This would ensure that data about the mass, composition, etc. of the item would not be lost as it moved from site to site. It would also enable operators to have a record of the history of the item's movements throughout the nuclear complex.

A comprehensive nuclear material accounting system would benefit from a similarly stringent and uniform system for identifying and tracking items. Having continuity in item identifiers would make it easier for a national system to identify changes in material inventories and to reconcile book and physical inventories. If adopted internationally, such a system of identifiers could also ease the process of reporting on foreign-obligated materials and make it more straightforward for states to be assured of the continuity of material control.

As discussed earlier, systems to apply a set of unique identifiers to all uranium hexafluoride cylinders around the world are under development, and similar principles and technologies could be used to identify and track containers in use with item-level nuclear materials.

National-level requirements

In defining the objectives of State Systems of Accounting for and Control of Nuclear Material (SSACs), the IAEA identifies two primary objectives, one national and one international: "to account for and control nuclear material in the State and to contribute to the detection of possible losses or unauthorized use or

79 Christopher A. Aas, et al., "Defense Nuclear Material Stewardship Integrated Inventory Information Management System (IIIMS)," Sandia National Laboratories report, SAND2004-5688, November 2004.

removal of nuclear material" and "to provide the essential basis for the application of IAEA safeguards pursuant to the provisions of an agreement between the State and the IAEA."[80] In other words, an SSAC is intended to both do the detailed, everyday work of accounting for and controlling nuclear materials so as to avoid unauthorized use, *and* to provide information about the management of materials, including material accounting data, in order satisfy the terms of international commitments. In practice, SSACs don't always perform both functions equally well. Material accounting professionals in different states and government officials who are familiar with how SSACs function confirm that some SSACs serve the latter goal of meeting international safeguards requirements without stringently safeguarding materials.[81]

In some nuclear weapons states without comprehensive safeguards agreements, the opposite is more often true. Facility operators who work with nuclear materials on a daily basis maintain facility-level MC&A systems and are capable of accounting for nuclear materials within their facilities with a relatively high degree of certainty. Yet information about changes in nuclear material inventories and about material transactions are often communicated to national systems in summarized or aggregate form and operators don't always meet reporting requirements (see earlier discussion of the U.S. NMMSS and the Russian FIS). As a result, even if states with large quantities of materials and a range of fuel-cycle facilities, such as the United States and Russia, wanted to communicate regularly with an international authority or with one another about their detailed holdings of certain nuclear materials, their national systems as presently operated would be unable to do so.

In order to address the range of risks outlined in this study, *all* states should be required to maintain a capable *national* system that draws on material accounting information from facility-level accounting systems. Instead of merely confirming that facility-level operators are meeting their regulatory requirements and accounting for financially and militarily valuable materials on an annual basis, national systems should be required to be a part of a system that can provide regular assurance to other countries and international authorities in line with larger nuclear security, nonproliferation, and weapons reduction commitments. The level and frequency of reporting and access between states and between states and international authorities that could be a part of a global comprehensive nuclear material accounting system is discussed below (see "Transparency and

80 IAEA, "Nuclear Material Accounting Handbook," IAEA Services Series 15, May 2008, p. 5.

81 Interviews with U.S. and foreign government officials and safeguards experts.

National-Facility information sharing arrangements

Central to a comprehensive nuclear material accounting system is the ability of national- and facility-level nuclear material accounting systems to share nuclear material accounting data. While material accounting and management takes place on the facility level, a national-level system with regular updates of detailed facility-level data will be necessary to fulfill international information sharing and other nuclear risk reduction goals. Absent a capable national-level system, facilities would need to develop multiple channels of communication in order to achieve the same goals—an inefficient and costly proposition.

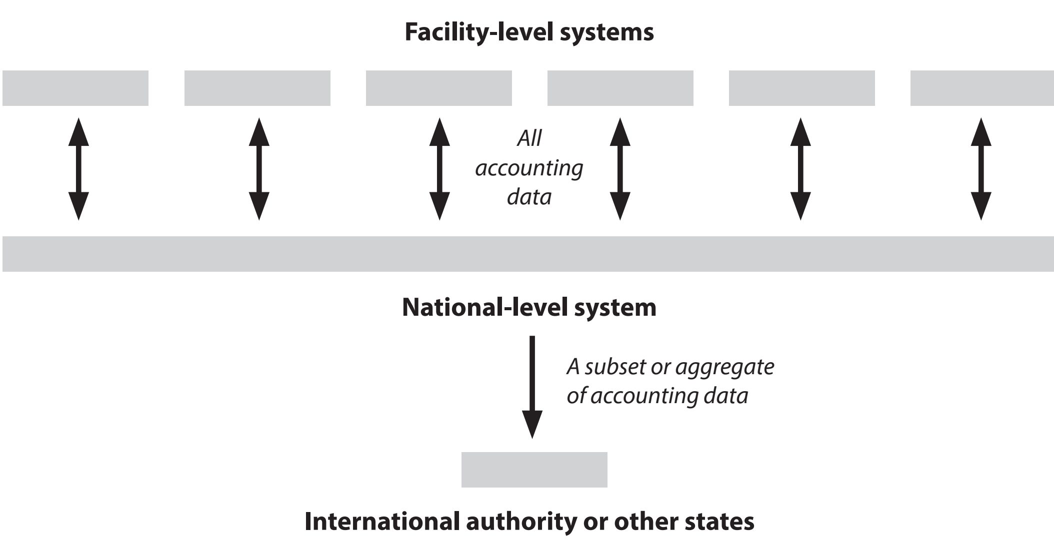
As part of a comprehensive nuclear material accounting system, facility- and national-level nuclear material accounting systems in each state would have the following capabilities:

Facility-level systems

- Ability to electronically provide at least daily updates of facility-level accounting records (book inventories) to a national system for all special fissionable materials in all material balance areas, to include location, composition, and use of materials.
- Ability to transmit physical inventory data and material balance reports to national systems as they are completed.

National-level system

- Ability to electronically receive at least daily updates of facility-level accounting records (book inventories) for all special fissionable materials in all material balance areas, to include location, composition, and use of materials.
- Ability to query facility-level accounting records on short notice.
- Ability to electronically share nuclear material accounting data—either a subset of facility-level data or an aggregate of all materials data—with an international authority or directly with other states.



Information Sharing”). Any level or frequency of transparency and reporting, however, would require a national nuclear material accounting system that maintains up-to-date databases of detailed nuclear material accounting information.

How could states construct such national systems? IAEA requirements for SSACs can serve as a basis for developing them. Indeed, in some states with comprehensive safeguards agreements, facility-level material accounting operators have already implemented “mailbox” mechanisms, in which facility operators communicate nuclear material accounting information to national and international authorities at the same time that they update their facility-level systems.[82]

Alternatively, national or international authorities could be given direct access to facility-level material accounting databases so that they can have continuous access to material accounting data with little additional effort required on the part of facility-level operators. This process would be made complicated if each facility operates separately designed software systems, as many presently do, or maintains its accounting records in hard-copy form only. But in theory this arrangement is possible. The larger problem, according to those who have analyzed the possibility of establishing a more centralized U.S. national nuclear material accounting effort, is that facility security protocols would prohibit direct access to material accounting databases, as would facilities’ desires to maintain individualized security protocols.[83]

Another option is for facility-level operators to regularly provide copies of material accounting databases or a subset of raw material accounting data directly to a national system.[84] Doing so would protect the security of facility-level material accounting systems and databases and allow the national system to provide information to other states or national authorities in a manner that would maintain confidence in compliance with international nuclear risk reduction efforts. It would also limit the additional workload for facility-level operators. The frequency of such data “snapshots” could vary on the level of facility activity or material attractiveness, but weekly or daily updates could suffice to provide the necessary confidence.

Regulatory authority. To ensure that national- and facility-level MC&A

82 Patrick Burton, “Canadian Perspective on the State-Level Concept,” presentation at INMM Workshop on Evolving the IAEA State-Level Concept, May 14, 2012.

83 Christopher A. Aas et al., “Defense Nuclear Material Stewardship Integrated Inventory Information Management System (IIIMS).”

84 Ibid.

requirements are met, each state in a comprehensive, global nuclear material accounting system ought to have an independent, empowered national regulator that is capable of evaluating compliance.[85] Indeed, a comprehensive system will rely in part on states' abilities to demonstrate day-to-day compliance with system requirements. The primary way to do this is to establish an independent regulator that demonstrates its reliability over time.

Most states currently have national regulators that oversee the implementation of national MC&A requirements, but the independence of these regulators and their ability to ensure compliance vary from state to state. In some states, regulators are closely aligned bureaucratically and politically with commercial operators (in some cases these operators are state-owned enterprises) and other government agencies that oversee and sometimes promote the use and export of nuclear technologies and materials. Other states have managed to build regulatory institutions that have demonstrated over time their independence from other government agencies and commercial interests.

The IAEA Department of Safeguards works to ensure state compliance with international safeguards agreements. This involves analyzing material accounting reports and other information related to the design of facilities and the implementation of safeguards. The IAEA also conducts inspections of facilities with nuclear materials to ensure compliance with safeguards commitments. The frequency and nature of these inspections vary according a range of factors, including the types and quantities of materials held at a facility and the activities conducted a facility. Another factor is the "effectiveness of the State's accounting and control system" to include the promptness, consistency, and accuracy of material accounting reports.[86] In other words, if states are able to demonstrate the effective implementation of national and international MC&A requirements, then they can limit the involvement of international regulators.

In addition to having a regulatory infrastructure that ensures compliance with national and international MC&A requirements, all states will need to increase transparency about how regulators function and about the performance of the systems and practices being evaluated. States will want to know that facility and national MC&A systems are meeting requirements, but they will also want to know *how* they are meeting their requirements and if, for

85 U.N. Security Council Resolution 1540, for instance, singles out the need for states to "adopt national rules and regulations . . . to ensure compliance with their commitments under the key multilateral non-proliferation treaties," and to "enforce effective measures to establish domestic controls" to prevent nuclear proliferation.

86 IAEA, "Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols," p. 54.

whatever reason, they don't.

Transparency and information sharing

The value of transparency regarding nuclear material stockpiles, to include materials assigned to military uses, is much debated. Nationally sanctioned disclosures about the amount and characteristics of materials, and their locations and statuses have the potential to assure allies and reassure potential adversaries of national activities and motivations.[87] Insufficient disclosures, pressure for greater transparency without protections on how that information will be used, or too much of the wrong type of information has the potential to prove destabilizing.[88]

Assuming that all states are able to construct national nuclear material accounting systems that maintain continuous or near-continuous accounting of both items and bulk special fissionable materials, what kinds of information (and how frequently) should states be expected to make available to other states or an international authority in support of global nuclear risk reduction efforts? A comprehensive, global nuclear material accounting system would not require all states to make available information about all nuclear material holdings, even if all of that information is available in a centralized national system. Non-nuclear weapons states with comprehensive IAEA safeguards agreements do make information available to the IAEA about *all* specified nuclear material holdings, yet even here, this information is kept confidential by the IAEA.

While a range of initiatives have suggested opportunities for states to declare their nuclear material stockpiles, few have spelled out how and to what degree states should share information about nuclear material holdings on a routine basis. A 2005 U.S. National Academy of Sciences study explored the possibility of states making available information about material stockpiles and granting foreign governments or third parties access to a subset of this information using cryptographic tools.[89] The study envisioned a system that could "update declarations almost continuously," or at the very least every time an inventory change was made, and that third parties would be notified of the availability of

87 Carnegie Commission on Preventing Deadly Conflict, "Comprehensive Disclosure of Fissionable Materials: A Suggested Initiative," Carnegie Corporation of New York discussion paper, June 1995; Ashton B. Carter, William J. Perry, and John D. Steinbruner, "A New Concept of Cooperative Security," Brookings Occasional Papers, 1992, p. 38.

88 Kristin M. Lord, *The Perils and Promise of Global Transparency* (Albany, NY: State University of Albany, 2006), pp. 33-37.

89 Committee on International Security and Arms Control, National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear Explosive Materials* (Washington, D.C.: National Academies Press, 2005), pp. 56-60.

additional, more up-to-date information.

Updating international third parties or other states every time nuclear material inventories change would set a high bar, but it might be an unnecessarily high bar for some materials. If a facility's inventory changes multiple times daily, then such a requirement would mean that a facility's operators would need to make available information about their material holdings multiple times daily. This requirement might be necessary for the most attractive materials, but it would be excessive for less attractive materials that would require additional enrichment or processing to be made "weapons usable." International third parties or other states are likely to want less frequent snapshots—daily or weekly—of material databases for these less attractive materials.

For national nuclear material accounting systems to regularly make available some nuclear material accounting information to international third parties or directly to other states, they will need facilities with nuclear materials to maintain electronic material accounting databases and be both capable of and willing to either transmit material accounting data electronically or provide a national system direct access to their facility-level system. This is not currently the case for all facilities with nuclear materials.

A comprehensive nuclear material accounting system should also ensure that states make available to each other the national laws and regulations that guide national- and facility-level MC&A systems. Transparency about how facilities manage nuclear materials on a day-to-day basis will go a long way toward assuring all parties that the information about nuclear material holdings that they receive is reliable.

Section 6.

Building on current capabilities

Fulfilling the vision of a comprehensive nuclear material accounting system will require considerable political accommodation among nations. Less work is necessary to develop the technical and regulatory tools that the effort will require. This study found that if the trajectory and focus of current research into nuclear material measurement and monitoring capabilities and information management systems is sustained over time, these systems should be capable of supporting a more comprehensive accounting system over the long term.

In the short term, national and international authorities can and should build on current material accounting capabilities as a way to begin moving toward the more difficult-to-achieve objectives. By beginning to rethink the specific goals of nuclear material accounting and the current requirements on national- and facility-level systems, all states can ensure that they are equipped to meet the demands of policy makers and the public. Indeed, if states reevaluate their nuclear material accounting requirements and pursue other short-term objectives in coordination with each other, it could speed the process of adopting a global system.

By tightening material requirements and exerting more control over the management of nuclear materials in their countries, national governments have the potential to improve public confidence in nuclear-related enterprises, increase commerce in nuclear technology and materials, and reassure other states of their capabilities and intentions. Below is a brief list of action items that national governments should pursue:

For non-nuclear weapons states

IAEA member states should review whether the IAEA MC&A requirements for states with comprehensive safeguards agreements and in-force additional protocols are sufficient to meet emerging security threats, including the detection and deterrence of nuclear material diversion to state-level weapons programs and to non-state actors, and the potential for insider threats. In particular, the IAEA should consider:

- expanding the accounting and reporting requirements for certain source materials to include reporting mass measurements for uranium ore concentrate, ensuring the transit matching of uranium ore concentrate drums, and tracking uranium hexafluoride containers with the assistance of universal unique identifying numbers;

- increasing the required reporting frequency of changes to special fissionable material inventories and the frequency of physical inventories at both process and storage facilities for special fissionable materials;

- instituting advanced information management tools, including IAEA mailboxes, at all facilities with special fissionable materials to ensure the timely, electronic reporting of nuclear material accounting information from the facility level to the agency; and

- requiring all facilities with nuclear materials to maintain and operate electronic databases of nuclear material accounting information and be capable of electronically transmitting or sharing that data with national and international authorities.

These changes would necessitate increased funding for the IAEA Department of Safeguards and continued support by nuclear supplier nations to states with underdeveloped nuclear material accounting capabilities. Once they were put in place, though, they should be more efficient and cost effective than current practices.

For nuclear weapons states

All nuclear weapons states, including those outside of the NPT, should review the structure and requirements of their national- and facility-level MC&A systems in light of emerging security threats, including the possibility of diversion of nuclear materials to non-state actors, the potential for insider threats, and the need to provide international assurance that special fissionable materials are not redirected to military use.

In particular, all of these states should consider adopting MC&A requirements for civilian materials that at a minimum meet enhanced IAEA requirements. Adopting these requirements would improve international understanding of the capabilities of accounting systems in these states, and it would signal weapons states' willingness to abide by the same standards imposed on non-nuclear weapons states. Just as importantly, accounting for nuclear materials in a manner that could support further reductions in nuclear weapons stockpiles could also help to demonstrate these states' willingness to pursue their NPT Article VI commitments. These states should also consider introducing more stringent nuclear material reporting requirements into nuclear cooperation agreements as a way to further prevent the diversion or misuse of these materials.

All nuclear weapons states should also explore the potential benefits of greater disclosure about the amounts, status, and location of military-use nuclear materials and about how these materials are accounted for on a daily basis. At the very least, these states should make publicly available one-time declarations about their production and use of special fissionable materials, as the United States and the United Kingdom have already done. They should also be willing to make publicly available general information about the management systems in place aimed at accounting for and managing military-use materials.

For all states

All states should engage in cooperative research and development of technological capabilities that will feed directly into their capacities to participate and have confidence in a comprehensive nuclear material accounting system. Possible areas of collaboration include:

- development of information systems that can facilitate the secure exchange of detailed nuclear material accounting information between states or between states and an international authority;
- development of advanced in-process measurement capabilities that will enable real-time material accountancy at process facilities, including enrichment, reprocessing, and fuel fabrication facilities;
- development of containment and surveillance technologies that will enable continuous monitoring of nuclear materials, including items and bulk materials, throughout their lifetimes;
- research on how nuclear material storage and process facilities can be configured to ease the physical inventory taking and materials measurement processes; and
- research on the effectiveness of national nuclear regulators and ways to improve compliance with MC&A regulations in a manner that contributes to transparency efforts.

Many of these technical areas are currently being explored by individual national governments, but international, cooperative research and development will better ensure that all states have confidence in the operating capabilities of the many components necessary for more comprehensive MC&A arrangements.

To make the most of cooperative research and development, a nuclear weapons state (preferably the United States) should volunteer to develop a pilot initiative that seeks to demonstrate the technological feasibility of continuous, detailed accounting of both bulk and item forms of direct-use special fissionable materials. This effort should also involve the development and demonstration of information systems that are capable of securely storing nuclear material accounting information and making a subset of all this information available to an international regulator or directly to other states. This effort should seek to answer the following questions:

- What would be the financial costs—capital costs and operating costs—of implementing such a system at a variety of types facilities with nuclear materials?

- How would such a system affect the ability of commercial and government operators to perform their currently prescribed tasks?

- What adjustments could be made to lessen the impact of comprehensive nuclear material accounting requirements on facility operations, without sacrificing pursuit of broad nuclear risk-reduction goals?

The United States and other nuclear weapons states have at various points considered establishing and have started developing information systems that would permit the centralization of detailed nuclear material accounting data. The original specifications of Russia's Federal Information System and the U.S. effort to develop an Integrated Inventory Information Management System were each moves in this direction. These states and the IAEA have also invested in new technologies and capabilities that would permit continuous or near-continuous material monitoring and accounting. Lacking from these and other efforts was sufficient guidance and support from policy makers who have thus far failed to appreciate the potential nuclear risk-reduction benefits of having more continuous and detailed information about nuclear material holdings.

The loss of control or diversion of significant quantities of nuclear materials from any state, or the inability of any state to determine if *all* nuclear materials in civilian and military use are where they are intended to be during a crisis, would certainly draw attention to current shortcomings in national and international MC&A capabilities. The challenge for policy makers is to adopt policies and requirements that address these real and potentially catastrophic shortcomings today, as a way to lessen the probability of their occurrence and decrease their impact if they should occur. By prioritizing more detailed and continuous nuclear material accounting today, policy makers would make a substantive contribution to reducing overall nuclear risk for the foreseeable future.

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