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FM(C)T Meeting Series

Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions

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Note

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Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions

Pavel Podvig

How to deal with existing stocks of fissile material is one of several contentious issues that have emerged from the discussions of a treaty that would prohibit the production of fissile material for nuclear weapons, an FM(C)T. There has been consistent and growing support for a treaty that, in addition to limiting production, also includes existing material in its scope.[1] This issue is likely to remain controversial, especially since it cannot be separated from other steps toward nuclear disarmament and the broader context of international security. It is important, however, to recognize that aside from the general political question of whether an effective arrangement that bans the production of fissile material should also cover existing stocks, there are a number of practical and technical issues that would have to be addressed for such an expansion of the treaty's scope to become viable. One of these issues is declarations of fissile material holdings.

It has been widely recognized that declarations of the amount of weapon-usable fissile material held by States would be an important confidence-building measure (CBM) and could represent a significant step toward reductions and the eventual elimination of nuclear weapons. This issue has been repeatedly raised during the Nuclear Non-proliferation Treaty (NPT) review process as part of an effort to increase transparency in nuclear disarmament.[2] In expressing their views on the future fissile material ban treaty, a number of States advocated the inclusion of measures that would increase transparency of existing stocks.[3] A number of important technical studies supported the

1 United Nations, *Report of the Group of Governmental Experts to Make Recommendations on Possible Aspects That Could Contribute to but Not Negotiate a Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices*, A/70/81, 7 May 2015, Paras 6, 7.

2 Preparatory Committee for the 2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, *Transparency of Nuclear Weapons: The Non-Proliferation and Disarmament Initiative*, NPT/CONF.2015/PC.I/WP.12, 20 April 2012.

3 United Nations, *Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices. Report of the Secretary-General* , 16 July 2013, www.unog.ch/80256EDD006B8954/(httpAssets)/3FA91170E91A8E83C1257CAF00303C49/$file/A-68-154.pdf.

idea of declarations and explored various implementation options.[4] In a very important step, the United States took the initiative in releasing detailed information about past production of military fissile material and its current stocks. The United Kingdom has also published an account of fissile material in its military programme.

Despite the significant progress that has been made over the past twenty years, a number of political and technical issues remain unresolved. The international community has yet to develop a model for declaring existing stocks of fissile material that would make a meaningful contribution to nuclear disarmament and that would be accepted by all States that have fissile material in their possession. One of the challenges is to make sure that the declarations can be verified for correctness and completeness. Given that a significant amount of fissile material remains in active inventories—including deployed nuclear weapons—verifiability of declarations presents a serious challenge to the future fissile material treaty.

Proceeding on the assumption that the FM(C)T will include provisions for the limitation or control of existing stocks of fissile material (which is far from certain), this paper assesses a range of potential approaches to verification of initial declarations.

The role of initial declarations in an FM(C)T

Initial declarations are essential elements of virtually any arms control and disarmament agreement. Since such declarations provide a baseline for limitations and reductions, they play an important role in implementation. The FM(C)T should include a mechanism for verification of initial declarations. This would allow relevant actors to detect and deter actions in violation of the treaty obligations.

Initial declarations of existing fissile material stocks could play different roles in a future FM(C)T. First, it has been suggested that even if the treaty does not include provisions on existing stocks, issuing declarations could be a valuable confidence-building measure. Such declarations could also provide a broad measure of progress toward nuclear disarmament. In this case, however, the treaty would not necessarily have to include a mechanism for verifying initial declarations. After all, the declarations would have no bearing on the central obligation of the treaty, i.e. to stop the production of fissile material for weapons. It is likely that verification activities designed to monitor a ban on production would help increase confidence in initial declarations, for example by granting access to facilities involved in past production, but unless the treaty includes specific provisions that address existing stocks and past production, declarations will remain essentially unverifiable.

4 International Panel on Fissile Materials, *Global Fissile Material Report 2009: A Path to Nuclear Disarmament,* Fourth Annual Report of the International Panel on Fissile Materials, 2009, ipfmlibrary.org/gfmr09.pdf; Nuclear Threat Initiative, "Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks. Verifying Baseline Declarations of Nuclear Warheads and Materials", *Cultivating Confidence Verification Series*, July 2014, www.nti.org/media/pdfs/WG1_Verifying_Baseline_Declarations_FINAL.pdf.

Another role that declarations might play in the FM(C)T context also applies to the case when the treaty does not directly address existing stockpiles. Discussions thus far of the verification provisions of the future treaty have demonstrated that there is some support for the idea that specific verification objectives, such as quantity of diverted material to be detected or timeliness of detection, may depend on the size of the fissile material stock in the inspected State.[5] According to this view, diversion of several kilograms of fissile material would have different consequences in States with tens of tons or tens of kilograms of material in their inventory. It is also assumed that the verification objectives will become universal as States reduce their fissile material holdings. Although it is far from certain that this approach will receive support at the negotiations, it should be noted that its implementation would require parties to formally declare the amount of fissile material in their arsenals.[6] As these declarations will have legal consequences for the monitoring provisions to be applied in a State, they would have to be open to verification.

Finally, in the most ambitious proposals, the FM(C)T would include an obligation to eliminate all existing stocks of weapon-usable fissile material or to place all such material under safeguards comparable to the International Atomic Energy Agency (IAEA) safeguards accepted by non-nuclear-weapon States Parties of the NPT. Strictly speaking, it is possible to design elimination arrangements that would not require initial declarations of stocks. However, declarations would significantly enhance the integrity of the process and are probably critical for its success. If the treaty does include an obligation to declare existing stocks, it would be essential to also include a mechanism for verifying those declarations.

As mentioned earlier, a number of States have indicated their opposition to extending the scope of the future treaty to existing stocks. These States have expressed serious doubts about the feasibility of designing a system that provides effective verification of initial declarations. At the same time, the technical work in this area suggests that there are no fundamental reasons why such a system cannot be created.

Current status of declarations

The information about global stocks of fissile material currently available is incomplete and extremely fragmented. The global inventory of weapon-usable material was estimated to be 1370±125 tons of highly enriched uranium and 506±10 tons of separated plutonium at the end of 2014.[7] The large uncertainty of these estimates reflects the lack of accurate information about the world's largest fissile material stock, which is that of the Russian Federation. That said, it should be noted that the accuracy of estimates is rather low for almost all States that possess nuclear weapons.

5 For example, the US-Russia-IAEA Trilateral Initiative considered using one per cent of the inventory as a significant quantity of a material. "Verifying Baseline Declarations", op. cit., p. 61.

6 See, for example, the discussion in "GGE Report", op. cit., paras 44-45.

7 International Panel on Fissile Materials, *Global Fissile Material Report 2015,* 2015, http://fissilematerials.org/library/ipfm15.pdf; International Panel on Fissile Materials, "Fissile Material Stocks", 2016, http://fissilematerials.org.

In NPT non-nuclear-weapon States, all fissile material is subject to IAEA safeguards, so the Agency has full access to the information about quantities of the material and the material-handling facilities. However, the IAEA is not allowed to disclose this information or share it with other Member States.[8] The only information that is released publicly by the IAEA is the total amount of material under safeguards by the type of material and the type of agreement.[9] The Agency does not provide country-specific information.

A number of States provide information about some of their fissile material stocks on a voluntary basis. In 1998, nine States—Belgium, China, France, Germany, Japan, the Russian Federation, Switzerland, the United States and the United Kingdom—agreed to abide by voluntary plutonium management guidelines, including to submit annual reports on the amount of civilian plutonium that they possess.[10] These reports include information on the amount of separated plutonium owned by the State or stored on its territory as well as an estimate of the amount of plutonium in the irradiated fuel of nuclear reactors. The scope of these declarations vary from country to country. Non-nuclear-weapon States report all their plutonium. Of the nuclear-weapon States, France and the United Kingdom include information about material under IAEA/Euratom safeguards. The United States reports as civilian military-origin plutonium declared as excess to military needs. The Russian Federation and China report the plutonium separated from irradiated fuel of civilian power reactors.[11] Three of the INFCIRC/549 States—France, Germany and the United Kingdom—also include information about civilian stocks of Highly Enriched Uranium (HEU) covered by the IAEA/Euratom safeguards.

In addition to its INFCIRC/549 report submitted to the IAEA, Japan publishes an underlying annual national report on the status of its plutonium management.[12] The national report provides a more detailed account of the amounts of plutonium and facilities that handle it than the report submitted to the IAEA. The United Kingdom also publishes an annual national plutonium report that is identical to the one it submits to the IAEA.

Only two nuclear-weapon States have released information about their military fissile material stocks. The Unites States has published detailed accounts of its production and

8 The model safeguard agreement specifies that "the Agency shall not publish or communicate to any State, organization or person any information obtained by it in connection with the implementation of the [Comprehensive Safeguards] Agreement." See "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)]", International Atomic Energy Agency, 1972, para. 5.

9 International Atomic Energy Agency, *IAEA Annual Report 2014*, 2015, p. 127, www.iaea.org/sites/default/files/gc59-7_en.pdf.

10 International Atomic Energy Agency, "INFCIRC/549. Communication Received from Certain Member States Concerning Their Policies Regarding the Management of Plutonium", 16 March 1998, www.iaea.org/sites/default/files/infcirc549.pdf.

11 "2014 Civilian Plutonium (and HEU) Reports Submitted to IAEA", *IPFM Blog*, 12 October 2015, http://fissilematerials.org/blog/2015/10/2014_civilian_plutonium_a.html.

12 Japan Atomic Energy Commission, "Current Situation of Plutonium Management in Japan", www.aec.go.jp/jicst/NC/iinkai/teirei/plutonium_management.htm.

use of plutonium and HEU, and has subsequently issued a number of updates.[13] The United Kingdom also published a report on its military HEU production and use as well as some information about its military plutonium stock.[14] No other State that possesses nuclear weapons has released information about fissile material produced by its military programme.

Table 1 lists estimates of the amount of weapon-usable fissile material in NPT nuclear-weapon States and States that are not NPT members.

Table 1. Estimated national stocks of fissile material

	HEU, tons	Non-civilian Pu, tons	Civilian Pu, tons
Russian Federation	679	128	52.8
United States	599	87.6	0
France	30.6	6	61.9
United Kingdom	21.2	3.2	104.2
China	18	1.8	0.025
India	3.2	5.7	0.4
Pakistan	3.1	0.19	0
Israel	0.3	0.86	–
North Korea	0	0.03	–
Others	15	–	52.8
TOTAL	1370	234	272

Numbers for the United States and the United Kingdom are based on their official reports. Most numbers for civilian plutonium are based on INFCIRC/549 declarations submitted to IAEA and reflect the status as of 31 December 2014. Other numbers are non-governmental estimates, often with large uncertainties. Source: Global Fissile Material Report 2015.

13 United States, Department of Energy, "Plutonium: The First 50 Years. United States Plutonium Production, Acquisition, and Utilization from 1944 through 1994", February 1996; Department of Energy, "The United States Plutonium Balance, 1944-2009. An Update of Plutonium: The First 50 Years, DOE/DP-0137, February 1996", June 2012, http://fissilematerials.org/library/doe12.pdf; United States, Department of Energy, "Highly Enriched Uranium: Striking a Balance. A Historical Report on the United States Highly Enriched Uranium Production, Acquisition, and Utilization Activities from 1945 Through September 30, 1996", January 2001, http://fissilematerials.org/library/doe01.pdf; The White House, "Transparency in the US Highly Enriched Uranium Inventory", 31 March 2016, www.whitehouse.gov/the-press-office/2016/03/31/fact-sheet-transparency-us-highly-enriched-uranium-inventory.

14 United Kingdom, Ministry of Defence, *Historical Accounting for UK Defence Highly Enriched Uranium. A Report by the Ministry of Defence on the Role of Historical Accounting for Highly Enriched Uranium for the United Kingdom's Defence Nuclear Programmes*, March 2006, http://fissilematerials.org/library/mod06.pdf; United Kingdom, Ministry of Defence, *The United Kingdom's Defence Nuclear Weapons Programme*, n.d., http://fissilematerials.org/library/mod00b.pdf.

The challenge of verifying fissile material declarations

At the most basic level, a declaration of existing stocks should include numbers for the total amount of plutonium and HEU in a State's inventory.[15] A simple declaration, however, would not accurately reflect the history of the fissile material inventory and would therefore have limited practical value, especially from the point of view of its verifiability. To increase confidence in the information provided in the declaration, a State would have to disclose details of the material balance process that was used to obtain the reported amount of fissile material, such as the records of material production and removals from the inventory.

To understand the challenge of verifying initial declarations, it is instructive to consider the IAEA's process for the establishment of comprehensive safeguards in States that had substantial stocks of fissile material in their possession upon the adoption of the safeguards, such as certain post-Soviet States. In the case of South Africa, the State had a significant history of fissile material production. At the beginning of this process a State submits an initial nuclear material inventory report, which contains a detailed physical inventory listing for each material balance area within its facilities that handle fissile material.[16] This report provides a starting point for a cooperative verification programme that establishes correctness and completeness of the listing. During this process, the IAEA carries out physical inventory verification at all declared facilities that handle fissile material and, when necessary, examines the historical operating records of all active and decommissioned production facilities.[17] This verification process is expected to discover discrepancies between the initially submitted physical inventory list and the actual verified physical inventory. It is also expected to identify some material unaccounted for (MUF or inventory difference), which is the difference between the measured inventory and the amount of material held according to material accounting records. Inventory differences are a common occurrence in the material accounting process and they do not necessarily indicate an actual loss (or gain) of material. They would, however, require an investigation if the verification procedure is expected to provide assurances of non-diversion of material.

The United States' and the United Kingdom's fissile material inventory accounts provide an illustration of the potential magnitude of the challenge of closing the material balance on a State-wide scale in a programme with a long history of fissile material production.

15 *Global Fissile Material Report 2009*, op. cit., p. 35. It is normally assumed that the amounts of plutonium and highly enriched uranium would be reported separately. Should the FM(C)T include other isotopes, such as neptunium or americium, in its scope, amounts of these materials would be reported separately as well.

16 International Atomic Energy Agency, *Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols,* IAEA Services Series, no. 21, May 2016, www-pub.iaea.org/MTCD/Publications/PDF/SVS-21_web.pdf.

17 Adolf von Baeckmann, Garry Dillon and Demetrius Perricos, "Nuclear Verification in South Africa", *IAEA Bulletin*, no. 1, 1995, pp. 42-48; Olli Heinonen, "Verifying the Dismantlement of South Africa's Nuclear Weapons Program", in *Nuclear Weapons Materials Gone Missing. What Does History Teach?*, ed. Henry Sokolski, The Nonproliferation Policy Education Center, 2014, pp. 89-95, www.belfercenter.org/sites/default/files/legacy/files/Verifying%20the%20Dismantlement%20-%20Heinonen%20Chapter%208.pdf.

In its most recent plutonium account, the United States reported a difference of 2.4 tons of plutonium out of the total measured inventory of 95.4 tons.[18] In another example, the United Kingdom reported the audited stock of HEU at 21.86 tons. At the same time, the United Kingdom's material balance amount was 21.64 tons—suggesting a gain of 0.22 tons of material.[19] As can be expected, most inventory differences arose during the early stages of nuclear programmes.[20]

In general, for the purposes of assessing the prospects of verifying fissile material declarations submitted by States with nuclear weapons, it is useful to distinguish between two different challenges. First, verification would have to involve taking a detailed physical inventory of the entire fissile material stock to provide a basis for a conclusion about correctness of the declaration. Second, verification would have to examine material balance records to ensure both correctness and completeness of the declared data.

The most difficult problem with taking physical inventory in a State that maintains an active arsenal of nuclear weapons is that it would require having at least some access to material in nuclear warheads, including those in operationally deployed weapons. It is highly unlikely that any State would grant this kind of access to any verification body. Indeed, in the current practice, even such information as the average fissile material content in active nuclear weapons is considered sensitive from both the national security and nuclear proliferation points of view.

Another problem related to physical inventory is the difficulty of carrying out accurate measurements of fissile material content in some forms, especially the material in waste or abandoned material. Some of this material can be considered disposed of for the purposes of national accounting, even if its recovery is within the capability of the host State. For example, the US standard for terminating domestic safeguards requires that the removed material is protected from theft and diversion. The IAEA, by contrast, requires that the material should be "practically irrecoverable".[21] In fact, the US standard includes provisions for returning once terminated material to the active inventory.[22]

An example of material that has been removed from inventory but may still be considered recoverable is material left behind at nuclear test sites. In Kazakhstan, significant amounts of plutonium (and HEU) were left behind at the Semipalatinsk test site by the extensive underground nuclear test programme carried out there by the Soviet Union. Although the cost of recovering this material would be quite substantial, the plutonium was apparently considered to be vulnerable to recovery by non-State actors. To prevent diversion, the United States, in close cooperation with Kazakhstan and the Russian Federation, launched

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18 This means that the measured inventory was 2.4 tons less than the amount reflected in the records. "The United States Plutonium Balance, 1944-2009", op. cit., 4.

19 *Historical Accounting for UK Defence Highly Enriched Uranium*, op. cit.

20 According to the US plutonium report, "68% of the inventory difference occurred during the period prior to the late 1960s". "Plutonium: The First 50 Years", op. cit., 53.

21 International Atomic Energy Agency, *IAEA Safeguards Glossary*, 2002, para. 2.12.

22 United States, Department of Energy, *Nuclear Materials Control and Accountability. DOE Standard DOE-STD-1194-2011*, June 2011, p. 39, www.energy.gov/sites/prod/files/2013/09/f2/DOE-STD-1194-2011_CN2.pdf.

a dedicated programme, completed in 2012, to secure this material. Yet the material has never been declared to the IAEA and apparently has not been included in any national inventory.[23]

Verification of material balance records would also present a very difficult problem. Most nuclear weapon programmes have been running for more than fifty years, so it is possible that some operating records are no longer available. Many fissile material production facilities have been modified, converted, decommissioned or demolished, making verification of production records extremely difficult. Fissile material production history can to some extent be reconstructed with the help of nuclear archaeology, however. Nuclear forensic analysis can also provide valuable help by verifying the amount of material produced at a facility. This effort, however, would require physical access to the production sites and material, as well as significant degree of cooperation from the host State.[24]

Verifying removal of material from accountable inventory may prove even more challenging. For example, according to the US reports, most of the plutonium removed from the inventory was discarded as waste. In the case of HEU, a large quantity of material was used in naval reactor fuel. Nuclear tests also consumed very large amounts of US plutonium and HEU. Unlike production, removals in most cases leave no physical evidence that can be independently examined and therefore can be extremely difficult to verify.

Potential approaches to verification

The difficulty of getting access to fissile material inventories and material balance records suggests that full validation of initial declarations would be an extremely complex undertaking. It would require the full cooperation of the host State. In countries with large fissile material stocks and a significant history of production, verification could take decades and might never be fully completed.

The most common approach to addressing the verification challenges calls for a gradual introduction of transparency. On this model, States would begin by releasing limited information about their fissile material inventories, such as the aggregate amount of fissile material in their possession. They would then move to increase the amount of disclosed information, granting inspectors access to key facilities and historical records in a manner that would build confidence in the correctness and completeness of the released data. It is also important that this process would allow the international community to develop an understanding of past production activities and to build the technical and institutional

23 See Eben Harrell and David E. Hoffman, "Plutonium Mountain: Inside the 17-Year Mission to Secure a Legacy of Soviet Nuclear Testing", Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, 15 August 2013, www.belfercenter.org/sites/default/files/legacy/files/Plutonium%20Mountain-Web.pdf.

24 "Nuclear Archaeology", in *Global Fissile Material Report 2009*, op. cit., pp. 52-62.

capacity that would support effective verification of the data.[25] In the end, it is generally understood that a conclusion about correctness and completeness of declarations would have to be based on the record of openness and cooperation demonstrated by the inspected State as well as on the analysis of technical data.

The gradual approach to verification is probably the only solution that would be acceptable to States that possess nuclear weapons. However, it may not be fully compatible with the requirements of a legally binding treaty that includes existing stocks in its scope. Such a treaty would presumably have to include specific reporting and verification provisions that would be applied upon entry into force.

There are several ways of addressing existing stocks. First of all, initial declarations of fissile material inventories could be a valuable element of the treaty even if the treaty does not provide a mechanism to verify them. The absence of verification provisions does not mean the absence of verification. The history of arms control and disarmament has examples of treaties that did not include verification provisions, relying instead on national technical means for verification. Although inventories of fissile material cannot be easily verified by national technical means, the value of this approach should not be underestimated. As the analysis conducted by independent experts demonstrates, in most cases the size of national fissile material stocks can be estimated based on publicly available data, so even simple declarations of aggregate amounts of material can be checked for consistency.[26] Information available to national governments would probably significantly improve the accuracy of these estimates. Detailed reports on the inventories, similar to the ones released by the United States and the United Kingdom, would further increase confidence in the data provided. As long as the limitations of this approach are well understood, it could meet some requirements of the treaty.

Other approaches to verification of initial declarations of fissile material inventories could no doubt be developed, including ones that would provide greater confidence in the accuracy of the declarations. This would support the goals of verified reduction and elimination of military fissile material stocks. These proposals must address the verification challenges outlined earlier in this paper, namely the lack of access to fissile material in active inventories and the difficulty of verifying historical material balance records accurately.

One possible arrangement of this kind, which may be called “deferred verification”, would take advantage of the fact that fissile material inventories and the facilities that handle them can be separated into two distinct segments. The first segment would include material in active inventory as well as all the facilities that handle the material. Nuclear warheads—whether deployed, in active arsenals or in reserve—would also be assigned there. The amount of fissile material in this segment would most likely be known with very high accuracy by the host State. The material in this segment would be reported

25 “Declarations of Fissile Material Stocks and Production”, in in *Global Fissile Material Report 2009*, op. cit., 32-41; “Verifying Baseline Declarations”, op. cit.

26 International Panel on Fissile Materials, *Global Fissile Material Report 2010: Balancing the Books: Production and Stocks*, 2010, http://ipfmlibrary.org/gfmr10.pdf.

as one part of the initial declaration of the inventory. However, the segment would not be available for any verification or monitoring activity, such as an independent physical inventory. The subsequent discussion will refer to it as a “closed segment”.

The second, “open”, segment would include the rest of the nuclear complex and, importantly, all current and former production facilities as well as all sites that may have waste containing fissile material or abandoned fissile material. As discussed earlier, the material in the open segment could only be known with limited accuracy; it will be reported in the initial declaration with the understanding that this number may be updated and corrected over the course of the verification process. And as the name implies, the key characteristic of the open segment is that it would be open for verification.[27]

If a State is concerned that a declaration of the amount of material in the closed segment might disclose sensitive information about its active nuclear arsenal (such as the amount of fissile material in individual warheads), it could “mask” that sensitive information by adding some additional material there. As long as the overall quantity of material in the closed segment is known with high accuracy, the exact amount it contains is not particularly important. Once the material in the closed segment is declared, however, it would be necessary to design arrangements that would ensure that no new material is added there. Removals, on the other hand, would be allowed. Any fissile material that becomes excess for military purposes could be removed from the closed segment as long as it is done in a verified manner. That way, the amount of material remaining in the closed segment is always known with high accuracy.

Verification of the initial declarations would be done in different ways for the open and closed segments of the nuclear complex, although in each case it would probably take a considerable period of time.

For the closed segment, the definitive check of the accuracy of the initial declaration would be deferred until the time when all material is removed from that part of the nuclear complex or when it is made available for a complete physical inventory. Since any removals from the closed segment would be independently verified, it should be possible to close the material balance for the entire segment with very high accuracy and guarantee that all material is accounted for.

Providing a similar guarantee for the open segment would be a more difficult task because of the uncertainties described earlier. Verification activities in this part of the nuclear complex would probably follow the gradual approach outlined above. An initial declaration of the amount of material would be followed by a release of a more detailed account of the structure of the inventory and the uses of that material, the history of

27 Activities associated with production and use of fissile material for military non-weapon purposes, such as naval fuel, would have to be assigned to the open segment. These activities would be generally open for verification, although specific verification procedures may be different from those applied to civilian material. See Pavel Podvig, “Fissile Material (Cut-off) Treaty: Elements of the Emerging Consensus”, UNIDIR, 2016, www.unidir.org/files/publications/pdfs/fissile-material-cut-off-treaty-elements-of-the-emerging-consensus-en-650.pdf.

production and removals. Access to former and current production facilities as well as to the material storage and disposition sites would gradually increase confidence in the absence of undeclared material outside of the closed segment, even if the accurate verification of the initial declaration would be technically impossible.

The deferred verification approach is one of many ways to deal with the inherently difficult issue of initial declarations. It has yet to demonstrate that it could serve as a basis for a practical verification mechanism. It does suggest, however, that problems such as the lack of access to material in active inventories and the uncertainty associated with past production may not present an insurmountable obstacle to effective arrangements for verifying initial declarations of fissile material inventories.

In conclusion, it should be noted that although development of effective verification measures presents a considerable challenge, getting political support for comprehensive declarations of fissile material inventories would probably be a more difficult task. It is possible that this issue will not be resolved during the FM(C)T negotiations and that the treaty will not cover existing stocks of fissile material at all. It is nevertheless important to understand that the international community will eventually have to address this issue and establish a system that would account for all fissile material and ensure that it is managed safely and securely. The FM(C)T negotiations process could make an important contribution toward this goal.

Pre-Existing Stocks of Weapons-Usable Fissile Material in the FM(C)T: Analysis of Baseline Declarations and Verification Challenges

Anatoly S. Diakov[1]

Introduction

Banning the production of fissile material for nuclear weapons or other nuclear explosive devices has been a long-sought objective of nuclear non-proliferation and arms control efforts. But despite broad international support for the Fissile Material (Cut-off) Treaty (FM(C)T), talks at the Conference on Disarmament have remained blocked for nearly 20 years. One of the major stumbling blocks in negotiations is the scope of the treaty. There are deep divisions among States over the question of what fissile material should be covered. While some States insist that the treaty should only cover future production, the majority argue that it should also include material produced prior to entry into force.[2]

Some States have argued that inclusion of already produced material does not correspond to a strict interpretation of the "Shannon Mandate" (the mandate contained in General Assembly resolution 48/75L and in document CD/1299), and therefore the treaty should deal only with material produced after entry into force.[3] Others have argued that inclusion of existing stocks could result in the FM(C)T not receiving sufficient support and could lead to difficulties in ensuring effective verification.

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1 The author was one of the contributors to the Nuclear Threat Initiative "Innovating Verification" study. This paper is largely based on the results of that study. See: Nuclear Threat Initiative, "Innovating Verification: New Tools & New Actors to Reduce Nuclear Risk. Verifying Baseline Declarations of Nuclear Warheads and Materials", *Cultivating Confidence Verification Series*, July 2014, www.nti.org/media/pdfs/WG1_Verifying_Baseline_Declarations_FINAL.pdf.

2 General Assembly, *Group of Governmental Experts to Make Recommendations on Possible Aspects That Could Contribute to but Not Negotiate a Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices*, A/70/81, 7 May 2015, paras 6, 7.

3 Conference on Disarmament, *Report of Ambassador Gerald E. Shannon of Canada on Consultations on the Most Appropriate Arrangement to Negotiate a Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices*, CD/1299, 24 March 1995.

Although there is no clear consensus on the reasons for including existing stocks in the treaty scope, the general goal is to reduce and eliminate these stocks and thereby to prevent nuclear-armed States from using their accumulated fissile material for weapon purposes.[4] Supporters of such an approach argue that, in the absence of measures that would address the existing stocks, the treaty would neither advance nuclear disarmament *effectively* and *irreversibly* nor provide adequate incentives for non-weapon States to join the treaty.

Thus, if existing stocks are to be covered by the FM(C)T, States with nuclear weapons would be required first to declare their entire inventory of relevant nuclear material, and then, at some point, to accept the application of verification measures on declared material to ensure that these are not used for producing nuclear weapons.

Declarations will be an integral part of the application of any verification arrangements—or, in other words, declarations and verification are two sides of the same coin.

Baseline declarations

If agreement is achieved on the inclusion in the treaty of past production of relevant nuclear material, each State will be required to declare the totality of its weapons-usable material inventory. The initial statement of the quantity of relevant material is defined as a baseline declaration. It is obvious that a baseline declaration would be the starting point for an agreed process.

To meet goals of the treaty, baseline declarations should satisfy two principal requirements: *correctness* and *completeness.*

Correctness refers to the accuracy of a declaration—that the declaration accurately shows the current holdings (physical inventory) of nuclear material to which the declaration relates, setting out quantities, locations, isotopic composition, and physical and chemical forms.

An essential objective of baseline declarations should also be to assist in establishing *completeness* of verification, i.e. that the State has no additional *undeclared* nuclear material in quantities significant for the objectives of the treaty. This means that along with a declaration of their entire inventory of nuclear material, all States should accept the application of verification measures on declared material to ensure that it is not used for the production of nuclear weapons. The process of preparing material declarations

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

in a way that permits the verification of their accuracy and completeness is even more important.

Material and inventory information to be included in baseline declarations. The basic requirement will be to include material defined for arms control and disarmament purposes as being weapons-usable, such as highly enriched uranium (HEU), plutonium and uranium233.

Baseline declarations should be extensive enough to make sure that subsequent refinements, elaborations and verification efforts reduce uncertainties rather than add to them. Accordingly, baseline declarations should also provide information on current *holdings,* total *production* and *disposition* of weapons-usable material.

Clearly, the information of greatest interest to the negotiating parties is each party's current holdings of HEU, plutonium and U-233. These holdings should be an essential part of the baseline declaration. But if declarations were limited to current holdings of HEU, plutonium and U233 alone, this would not be sufficient to address the *completeness* issue. Therefore, along with information about current material holdings, the starting point for baseline declarations should be the inclusion of information that is as complete as possible about the total production and use of this material over the entire lifespan of the State's nuclear programme. In accordance with arrangements that would need to be negotiated (including applicable timelines), current holdings would be verified for *correctness* and total production would be reconciled with current holdings, thus supporting conclusions about *completeness*. To facilitate reconciliation of current holdings with total production, baseline declarations would also need to contain information on the use or disposition of material, i.e. transactions that result in changes to the inventory of the particular material. In accordance with nuclear material accountancy principles, *current holdings* should be the sum of *total production* and *inventory changes* (increases and decreases), e.g. nuclear transformation, losses, nuclear decay, consumption and transfers (shipments and receipts). Any significant anomalies identified through material accountancy and/or verification would require investigation.

A State's declaration that it has a current holding of Z metric tons of weapons-usable material becomes verifiable if it includes (1) all historical production (P), i.e. the sum of material production at N identified sites including substantial details of the methods and specific history of production, (2) the sum quantity of material used in tests (T), (3) waste (W), (4) non-weapons purposes (NW) and lastly the overall errors attributed to the estimates.

This can be expressed as: $Z = P - (T+W+NW)$

Only clear and detailed declarations, as well as supporting records and documentation, provide sufficient grounds and conditions for verification.

Inclusion of information on specific categories of nuclear material. Another set of questions related to the content of baseline declarations and subsequent verification is whether the declarations should include a breakdown by specific categories of weapons-usable material and whether the quantities of material in these categories should be identified.

Nuclear material in warheads. Inclusion in baseline declarations of information on holdings of weapons-usable material in weapons will present a major problem for baseline declarations. For many reasons, States that possess nuclear weapons oppose the idea of providing information on the amount of material in weapons. Protecting weapon-design information is one of the most important reasons cited. Given the scale of weapons production in the United States and the Soviet Union/Russian Federation, and to a lesser extent in the other nuclear-armed States, exclusion of such information would create significant uncertainty about the possibility of diversion of material outside a monitoring regime. If the total mass of nuclear material in a State's nuclear weapons is excluded from the nuclear material baseline declaration, the declaration will be incomplete in its description of the very material that is of greatest importance for the declaration process. This would undermine the value of the declaration.

Weapons-usable material in naval propulsion programmes. Most nuclear submarines, as well as other nuclear-powered vessels, use HEU of various enrichment-levels including so-called weapons grade. Because of the large quantity of HEU involved in the naval sector and the need to ensure that this material is not diverted to nuclear weapons, accounts of naval reactor fuel use would be an important component of any declaration and, in due course, verification process.

The United States has set aside 128 tons of HEU for future naval use. If it is assumed that the Russian Federation has reserved a similar naval stockpile, that would suggest global naval HEU stocks of some 250 tons—enough for over 10,000 nuclear weapons. This is comparable to the number of assembled nuclear weapons in the world today and, as United States–Russian Federation arms reductions proceed further, naval stocks may become the largest category in the stocks of weapons-usable material.

While States' sensitivities about disclosing details about their naval-fuel design will complicate verification approaches, such sensitivities should not present a problem for the inclusion in baseline declarations of aggregated information on holdings of weapons-usable material in naval propulsion programmes.

Weapons-usable material in civilian programmes. Weapons-usable material in civilian programmes (e.g. power generation and scientific research) is important to the disarmament process for two reasons:

- First, it will be essential for arrangements to be in place to ensure that this material never becomes available for weapons use.
- Second, when the material has come from dual-use processing facilities, information about the material may be needed to enable accounting of material flows through those facilities.

Where weapons-usable material in civilian programmes are adequately covered by International Atomic Energy Agency safeguards, this is likely to be sufficient for disarmament verification purposes. For the sake of completeness of baseline information, it would be desirable to include all such material in the initial baseline declarations.

Baseline declarations—challenges. As was pointed out above, the overriding principle for declarations should be *completeness*, i.e. that all material available, or potentially available, for weapons use should be declared and, in due course, appropriately verified or otherwise accounted for. This requires declarations of full inventories, with detailed accounts of material produced by type and use.

However, as a result of several factors, achieving completeness of declarations would be a significant challenge even for the declaring States themselves.

The principal such factor is (in some cases) the very long period of production operations—over 50 years in the cases of the United States and the Soviet Union/Russian Federation. Over this period, both production technology and accounting methods have changed many times over at each production site. Taking into account the fact that maintaining accurate records was often not a priority, especially at the beginning of production operations, it is not clear whether detailed records of the operation of enrichment facilities, plutonium production reactors and reprocessing plants have been adequately preserved. It is also likely that at the beginning of an agreed declaration/verification process, nuclear-armed States will resist declaring information on the *amount of material* in weapons.

These difficulties could be overcome if the negotiating parties would accept a lower level of completeness at the initial stage. As the first step, each State could declare the *total current inventory* of all weapons-usable material. While such a minimalist declaration may serve some transparency functions, however, its value will be limited in terms of the verification task. But as States gain confidence in the process over time, the initial baseline declarations would be followed by further declarations in order to update or correct information provided in the initial declarations and expand on them by providing more detail. Also, verification would not necessarily apply immediately to all holdings, but would apply initially to less sensitive material and be extended progressively in accordance with successive agreements.

The detailed arrangements of this phased process, including applicable timelines for future declarations and verification protocols, would need to be negotiated.

Verification

There is a common understanding that an FM(C)T must be effectively verifiable. If existing stocks are to be included in the scope of such a treaty, this would mean that along with declarations of their entire inventories of nuclear material, nuclear-armed States would have to accept the application of verification measures on declared material to ensure that this material is not used for the production nuclear weapons. This verification would be an integral part of the treaty. However, several factors—the length of time military programmes have been running, the huge scale and complexity of these programmes, national security issues and differences in nuclear material accounting practices among States—mean that verification of nuclear material in military programmes would be very difficult to undertake from a practical point of view. Therefore, verifying past production will be extremely complex and challenging.

Designing a verification approach. A verifiable fissile material control treaty is intended to protect against the risk that a party retains a secret and strategically significant stockpile of material. As mentioned above, only a clear and detailed declaration, as well as supporting records and documentation, provides sufficient grounds and conditions for verification.

Correctness and completeness. In safeguards terminology, verification is required to address the correctness and completeness of declarations and associated records. These concepts are also applicable to verifying baseline declarations.

Correctness refers to the accuracy of a declaration, i.e. that the declaration accurately shows the current holdings (physical inventory) of nuclear material to which the declaration relates ("Z" in the example discussed above), setting out quantities, locations, isotopic composition, and physical and chemical forms. Verification of correctness for current holdings, conceptually at least, is relatively straightforward—the accuracy of the declaration is confirmed by measurement, sampling and analysis of the physical material that the State presents to the inspectors as being included in the declaration.

Completeness concerns the inclusion in a declaration of *all* the material that the State is required to declare, i.e. that no *undeclared* material remains in contravention of the relevant agreements.

Assessing completeness involves analysing the entire history of a State's nuclear programme, examining questions such as:

- Is the history as declared consistent with the current situation as observed by inspectors?
- How well can past records be validated?
- Could anomalies, such as unresolved differences between declarations and the verified inventories, conceal material withheld from the verification process?
- Could material that has not been declared exist?

Achieving completeness for the inspecting party due to the potential for greater measurement errors and the difficulty of integrating information over several sets of production eras, facilities and technologies is a far greater challenge than achieving completeness of the declaration by the declaring State.

As noted earlier, large programmes, such as those of the United States and the Russian Federation, have long and extraordinarily complex production histories, stretching over decades. As time passes, locating the original production and operating records will be increasingly difficult and many of the operators who could have helped explain those records will no longer be available. These records include information concerning:

For HEU production:

- enrichment technology used;
- cascade configurations and separative work produced by the cascades;
- operating temperatures and pressures;
- amounts and types of feed material and waste products;
- breakdown of HEU production by enrichment level.

For Pu production:

- reactor type;
- coolant and moderator;
- the make-up of the reactor core and various fuel designs;
- operating records, including cooling water throughput;
- inlet and outlet operating temperatures;
- burn-up of the discharged fuel;
- type of reprocessing method;
- the flowsheet and list of reagents used in each process;
- the amount and type of feed material, including fuel design;
- batch origin and fuel burn-up and waste products;
- total mass and isotope composition of the separated plutonium.

In the context of verification of production history, all these factors impede achievement of the completeness requirement. This gives grounds for the belief that completeness of verifications will never be achieved and therefore that verification can never be truly effective.

Uncertainties. Even if material accounting records exist, these records contain some inherent uncertainties as a result of practical difficulties in taking measurements, possible measurement errors and accounting errors in relation to material handling processes. Nuclear material accounting involves: recording when material is produced, consumed, altered or "lost"; tracking when material enters or exits a particular facility; taking periodic physical inventories, whereby material holdings are measured for quantity and composition; and reconciling records of material transactions with records of current inventories and physical inventories.

The problems facing States in preparing baseline declarations are similar to the problems that will arise during verification, because both the baseline declarations and the verification estimates that have been derived from a reconstructed record of production history will contain uncertainties. The accuracy of these estimates can vary from country to country due to different practices and methods of material accounting. Even if it were possible to ensure that uncertainties are small as a percentage of total material stockpile, in absolute terms such uncertainties could still be extremely significant. For example, if the inventory difference for a declaration by the United States or the Russian Federation of HEU in percentage terms was about one per cent, in terms of quantity this would represent 8 and 12 tons, respectively.[5] That would be enough for 400–600 nuclear weapons.

In some cases, material accountancy and validation of production can be improved by using nuclear archaeology methods.[6]

The physical methods for confirming historical plutonium production are based on the fact that neutrons alter the isotopic composition of the moderator and structural materials of plutonium production reactors. Examination of the isotopic compositions of samples taken from graphite and structural materials can be correlated with cumulative local neutron flow and cumulative local plutonium production in specified parts of the reactor core. For graphite production reactors, the data obtained and knowledge of reactor physics and records of their operations allow estimates to be made of cumulative plutonium production in the entire core over its whole life cycle, with standard errors of less than 2 per cent. The accuracy of the final estimate of cumulative plutonium production combined with the uncertainties of estimated reprocessing losses is expected to be within 3–7 per cent.[7] However, there is currently no validated method for estimating plutonium production in heavy water production reactors, and some plutonium production reactors previously in use have been dismantled.

Auditing of HEU production at enrichment plants will also require access to the operational records of uranium entering the plant as feed, records of each product shipment, including quantity and enrichment, and records of quantity and enrichment of the tails over the whole period of the plant's operation. Validating the records will be complicated by factors such as use of different enrichment technology (gaseous diffusion and centrifuge), enrichment of recycled uranium, production of low enriched uranium (LEU) for power reactor fuel, enrichment of tails and the fact that U-235 concentration in enriched material and tails varies extensively. As a result, record keeping of the quantities and concentrations of input and output flows for such operations is not always complete. This could lead to a significant gap between declared HEU production and the results obtained from auditing historical records, especially for the United States and the Russian Federation, where HEU production has been substantially larger than in other nuclear-weapon States.

The physical method for confirming historical HEU production is based on the fact that in addition to U-238 (93.7 per cent) and U-235 (0.7 per cent), natural uranium contains traces of U234 (0.0055 per cent). Measurements of the ratio of U-234 to U-235 in tails from enrichment plants can be used to determine the product enrichment level. To ensure high accuracy of estimates, samples need to be taken for each type of tail (tails

5 Russia has produced about 1200 tons of HEU and the United States about 800 tons. See International Panel on Fissile Materials, *Global Fissile Material Report 2010: Balancing the Books: Production and Stocks*, 2010, http://ipfmlibrary.org/gfmr10.pdf.

6 Steve Fetter, "Nuclear Archaeology: Verifying Declarations of Fissile-Material Production", *Science & Global Security* 3, vol. 3, 1993, pp. 237-59.

7 Thomas W. Wood, Bruce D. Reid, John L. Smoot and James L. Fuller, "Establishing Confident Accounting for Russian Weapons Plutonium", *Nonproliferation Review*, vol. 9, no. 2, 2002, pp. 126-37, doi:10.1080/10736700208436898.

from LEU, slightly enriched uranium and HEU) produced by enrichment plants over their life cycle.

This method has at least two major drawbacks, both of which complicate estimation. The first is that the concentration of U-234 in natural uranium can vary by more than 10 per cent from sample to sample. The second is the possibility that uranium used as enrichment feed may be recycled, i.e. recovered by reprocessing reactor fuel. In this case the isotopic composition of the uranium feed will be different to that of natural uranium, and therefore estimation requires that the composition of the feed uranium be available. The United States National Academy of Sciences has concluded that improvement of nuclear material accountancy for historic production and disposition, both for the declaring State and inspectors, requires additional work by international experts to develop a method for accurate estimation of HEU production based on physical measurements.[8]

Conclusions

On the assumption that States that possess nuclear weapons will agree to the inclusion of existing stockpiles of fissile material in the scope of an FM(C)T, three conclusions can be drawn from the discussion above:

1. Because of national security concerns, and because of the time required for historical research in preparing baseline declarations, States are unlikely to be prepared to declare all details of their nuclear material inventories initially. Given these political and technical challenges it would be reasonable to expect a *phased approach to declarations*. It is expected that the baseline declarations would be followed by further declarations—some updating or correcting of information in the initial declarations and some expanding on this information through the provision of more detail. It is anticipated that the specifics of the declarations would change over time, as verification is phased in and experience gained, nuclear reductions proceed and confidence in the overall process increases.
2. There is a need for *international scientific cooperation* to address all the technical and political obstacles related to the development of mechanisms for recording and sharing material inventories and to detailed provisions for their verification, especially concerning material in sensitive forms. Collaboration on verification methods and techniques should be complemented by a sustained dialogue among international experts on practical and technical approaches to achieving effective baseline declarations and verification arrangements.
3. *Uncertainties can probably never be eliminated by verification*: It is unreasonable to expect that verification procedures can provide absolute confidence in the reliability of the submitted declarations. This is due to a variety of reasons, such as the extremely long duration of military programmes, their scale and complexity, the absence of rigorous nuclear accounting practices in their early stages, the inherent inaccuracy

8 National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials*, National Academies Press, 2005.

of declarations, losses of information and the existence of contradictory information in the historical record as well as questions over the reliability and accuracy of measurements and associated uncertainties..

But how much confidence will be enough is ultimately a political judgement that policymakers will have to make, based not only on technical analysis, but also on the overall level of trust among participating States as well as the perceived benefits of the proposed agreement.

Fissile Material Stockpile Declarations and Cooperative Nuclear Archaeology

Alexander Glaser and Malte Göttsche

Background

With the beginning of the Cold War, the United States and the Soviet Union quickly began to produce fissile material (plutonium and highly enriched uranium, HEU) for military purposes on an industrial scale. By the mid-1950s, both countries were already making ton-quantities of fissile material per year to supply their growing nuclear arsenals. They were soon joined by the United Kingdom (1951), France (1955), China (1964), and Israel (1965)—and later by India, Pakistan, and finally North Korea. By the time most of these production efforts ended in the early 1990s, the global stockpile of military fissile material had reached fantastic levels. While the combined global nuclear weapon inventory had peaked at about 64,000 in 1986,[1] the military fissile-material stockpile ultimately reached almost 2200 tons (240 tons of plutonium and 1960 tons of highly enriched uranium), which is sufficient to make about 200,000 simple nuclear weapons.[2] Since the end of the Cold War, almost 700 tons of highly enriched uranium have been down-blended and other material is now reserved for naval fuel. Overall, the military material available for weapon purposes today is sufficient for more than 150,000 weapons (Figure 1).

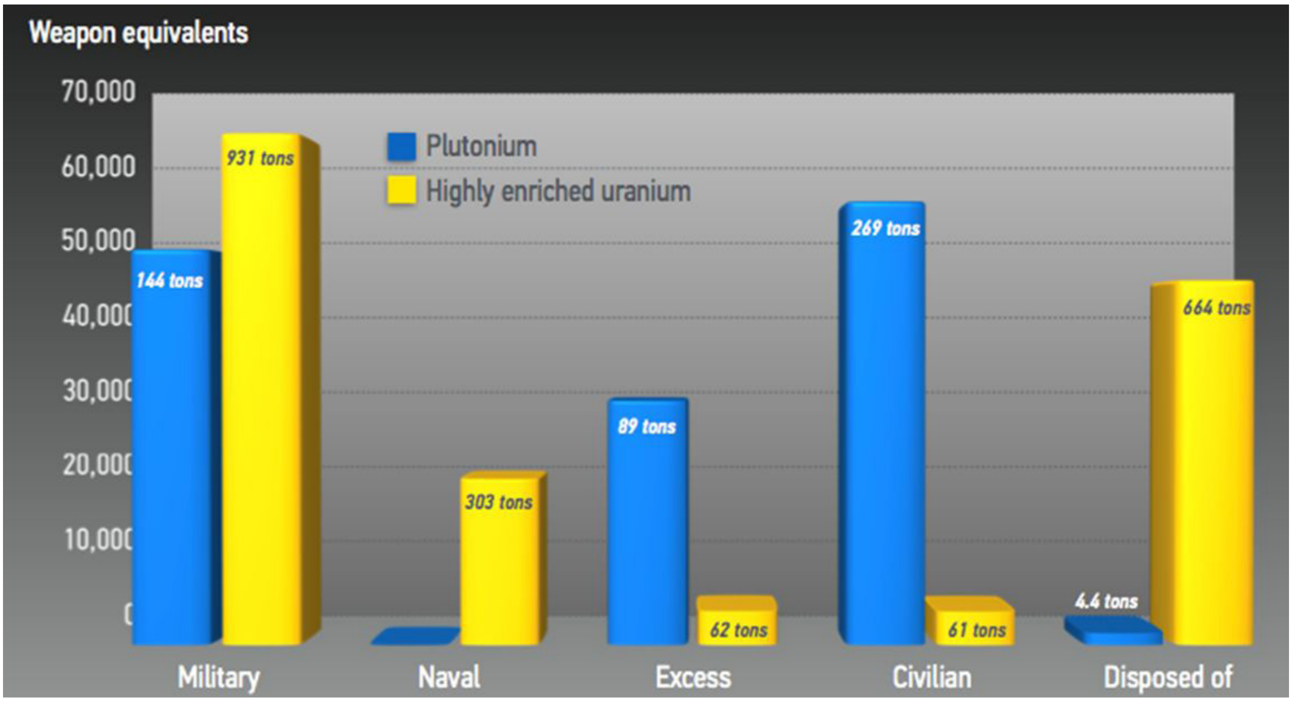
Most large-scale fissile-material production programs were driven by a sense of great urgency and typically shrouded in secrecy. It is generally believed that accounting and record-keeping for these military operations was poor, especially, when compared to similar production activities (i.e., plutonium separation and uranium enrichment) carried out in non-nuclear weapon states for civilian purposes under IAEA safeguards. The uncertainty can be much larger than the amount required to build a single weapon, and weapon-States have had difficulty reconciling their production records with physical

1 The United States and Russia reached their peak weapon inventories at different times. While the US inventory peaked in 1966 at 31,175 warheads, the Soviet inventory peaked later (around 1986) at an estimated 40,000 warheads. Hans Kristensen and Robert Norris, "Global Nuclear Weapons Inventories, 1945-2013," *Bulletin of the Atomic Scientists,* vol. 69, no. 5, 2013.

2 For this estimate, a pure fission weapon with a nominal yield of 10-20 kilotons of TNT is assumed. A typical, moderately sophisticated device might include 3-4 kilograms of plutonium or 12-15 kilograms of highly enriched uranium.

inventories.[3] In the United States, for example, estimated plutonium acquisition exceeded the actual inventory by 2.4 tons. It is not clear if this material ever existed.[4]

Figure 1. Fissile material inventories and their nuclear-weapon equivalents, 2015



Assumptions for weapon equivalents: 3 kg of weapon-grade plutonium, 5 kg of reactor-grade plutonium, 15 kg of highly enriched uranium. Including civilian stocks, as of 2015, the global stockpile of fissile material corresponds to almost 220,000 weapon-equivalents. Source: Global Fissile Material Report 2015, *International Panel on Fissile Materials, Princeton, NJ, December 2015.*

Large as these uncertainties in existing fissile material inventories are, they will have to be understood and gradually reduced as nuclear arsenals are reduced and as further progress toward nuclear disarmament is made. In particular, a solid understanding of fissile material holdings is needed to give future arms-control initiatives a meaningful degree of predictability and irreversibility. Given that a moderately sophisticated nuclear device can contain as little as 3-4 kilograms of plutonium or 12-15 kilograms of highly enriched uranium, speculations about fissile material stockpiles unaccounted for, possibly equivalent to hundreds of nuclear weapons, could make progress in this area very difficult.

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3 In 2006, the United Kingdom reported: "A major problem encountered in examining the records was that a considerable number had been destroyed for the early years of the programme. There is only a legal requirement for the companies to keep such records for 30 years. In some cases older records were destroyed when they reached this age. There is a greater awareness now of the need to keep these records and this past practice has now been stopped, but too late for the purposes of this review." The report goes on to highlight specific problems that have been encountered even where records survived. United Kingdom, Ministry of Defence, *Historical Accounting for UK Defence Highly Enriched Uranium,* March 2006, www.ipfmlibrary.org/mod06.pdf.

4 United States, Department of Energy, *The United States Plutonium Balance, 1944-2009*, June 2012, www.ipfmlibrary.org/doe12.pdf.

Declarations of fissile material holdings are the logical first step to lay the basis for such initiatives; indeed, it is hard to imagine a process that would be viable without initial declarations and subsequent updates. As further discussed below, some precedents for fissile material declarations exist. While these ad hoc efforts have been welcome as a confidence-building measure, as part of a formal arms-control process, fissile material (and nuclear warhead) declarations would not be credible if no efforts were made to agree on provisions that would help establish confidence in the correctness and completeness of these declarations. As there is a fairly wide range of possible declarations of existing stockpiles, a range of verification concepts can be envisaged, mainly differing in comprehensiveness and intrusiveness.

Declarations of fissile material stockpiles

To date, only the United States and the United Kingdom have issued public declarations of their respective plutonium and HEU inventories, accounting for both production (uranium enrichment and separation of weapon-grade plutonium) and removals (for example, the use of HEU in naval reactor fuel or use of fissile materials in tests). The US Department of Energy issued its plutonium declaration in 1996[5] and updated it in 2012;[6] HEU holdings were declared in 2006 and updated the same year.[7] The US declarations provided detailed information on annual production rates, breakdown by sites and some information about isotopics (uranium-235 content in HEU and plutonium-239 in plutonium). The United Kingdom made its first declaration in 1998, essentially in a single sentence: "Our current defence stocks are 7.6 tonnes of plutonium, 21.9 tonnes of highly enriched uranium and 15,000 tonnes of other forms of uranium."[8] The United Kingdom released somewhat more detailed declarations on historical plutonium and HEU accounting in 2000 and 2006.[9]

A number of States provide information about their civilian plutonium holdings by regularly submitting voluntarily updates according to the IAEA INFCIRC/549 guidelines.[10] All nuclear-weapon States Parties to the Non-Proliferation Treaty (NPT) provide such declarations. In recent years, the United Kingdom and France have also declared civilian HEU holdings.

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5 United States, Department of Energy, *Plutonium: The First 50 Years,* DOE/DP-0137, 1996, www.ipfmlibrary.org/doe96.pdf.

6 *The United States Plutonium Balance, 1944-2009, op. cit.*

7 United States, Department of Energy, *Highly Enriched Uranium: Striking a Balance (Revision 1)*, 2001, www.ipfmlibrary.org/doe01.pdf; United States, Department of Energy, *Highly Enriched Uranium Inventory: Amounts of Highly Enriched Uranium in the United States*, 2006, www.ipfmlibrary.org/doe06f.pdf.

8 United Kingdom, Ministry of Defence, *Strategic Defence Review: Modern Forces for the Modern World,* July 1998, Section 72, www.ipfmlibrary.org/mod98.pdf.

9 United Kingdom, Ministry of Defence, *Plutonium and Aldermaston—An Historical Account,* 2000, fissilematerials.org/library/mod00.pdf and *Historical Accounting for UK Defence Highly Enriched Uranium, op. cit.*

10 International Atomic Energy Agency, *Communication Received From Certain Member States Concerning Their Policies Regarding the Management of Plutonium*, INFCIRC/549, 16 March 1998.

Assuming that existing fissile material stocks are to be covered by the FM(C)T, it will be necessary to make provisions for declaring such stocks. Current proposals for the design of such provisions vary greatly. In the most modest proposals, declarations would be made through a voluntary agreement outside of the FM(C)T.[11] Such voluntary measures could also be directly included in the FM(C)T. For instance, the French draft treaty includes voluntary declarations of fissile material deemed excess to defence needs.[12] A slightly more ambitious proposal, discussed by the Group of Governmental Experts (GGE), proceeds from the notion that an FM(C)T should "seek to prevent any increase in the amount of fissile material assigned for use in nuclear weapons or other nuclear explosive devices." Some GGE participants argued that this could only be achieved by issuing baseline declarations of fissile material holdings to assess diversion.[13]

Fissile material declarations have also been discussed in the NPT-context. Action 21 of the Action Plan on Nuclear Disarmament agreed at the 2010 NPT Review Conference stated that, "as a confidence-building measure, all the nuclear-weapon States are encouraged to agree as soon as possible on a standard reporting form and to determine appropriate reporting intervals for the purpose of voluntarily providing standard information without prejudice to national security."[14] The NPT nuclear-weapon States submitted reports to the 2014 Preparatory Committee, but very little quantitative information was included.[15] In contrast, the Non-Proliferation and Disarmament Initiative, a cross-regional group of non-nuclear-weapon States Parties to the NPT, has developed a more extensive reporting model for the nuclear-weapon States to consider.[16]

All nuclear-weapon States could make public their total plutonium and HEU holdings. They could also inform which portions are available for IAEA Safeguards under their Voluntary Offer Agreements. As an example, Figure 2 shows how declared material could be further broken down into categories.

Declarations could be checked by other States through independent assessments, for example comparing the data with information previously made public or obtained through intelligence. However, verification activities agreed by the parties would offer more credibility. Some possible options are outlined below.

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11 Pavel Podvig, "Fissile Material (Cut-off) Treaty: Definitions, Verification, and Scope", *UNIDIR Resources*, 2016.

12 French Foreign Ministry, *Projet français de Traité interdisant la production de matières fissiles pour les armes nucléaires ou d'autres dispositifs explosifs nucléaires (FMCT),* 9 April 2015, www.delegfrance-cd-geneve.org/Draft-fissil-material-cut-off-treaty.

13 United Nations General Assembly, "Group of Governmental Experts to make recommendations on possible aspects that could contribute to but not negotiate a treaty banning the production of fissile material for nuclear weapons or other nuclear explosive devices", A/70/81, 7 May 2015, p. 9.

14 2010 NPT Review Conference Final Document, vol. 1, NPT/CONF.2010/50, New York, 2010.

15 UNODA, Repository of information provided by nuclear-weapon States, www.un.org/disarmament/wmd/nuclear/repository.

16 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, "Recommendations for consideration by the 2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons", NPT/CONF.2015/WP.16, 20 March 2015.

Figure 2. Possible reporting form for a fissile material (baseline) declaration

	HEU	Plutonium
Inventory as of (DATE)	....	....
Military, available for weapons	....	....
Military, reserved for non-weapon purposes	....	....
Military, in irradiated fuel	....	....
Excess military, not available for IAEA safeguards	....	....
Civilian, not available for IAEA safeguards	....	....
Civilian, available for IAEA safeguards	....	....
Excess military, available for IAEA safeguards	....	....

Specifying average isotopics (uranium-235 content in HEU and plutonium-239 in plutonium) would enable further consistency checks of the declarations.

Verification of baseline declarations

Will it ever be possible to verify, i.e. confirm the correctness *and* completeness, of fissile material declarations made by the nuclear-weapon States? Even assuming an ideal cooperative environment, uncertainties would remain. Inaccuracies—largely a product of uncertainties in the nuclear-weapon States' own assessments—could translate into an order of hundreds of warhead equivalents. Nevertheless, while it may not be possible to obtain reliable results from verification activities directly after a declaration has been issued, such uncertainties do not necessarily mean that States can't become more confident over time that declarations are correct and complete: If verification activities are conducted and continued after the initial declaration, the understanding of the State's nuclear activities will grow over time. Over time, facilitating verification activities in good faith, including cooperatively attempting to resolve inconsistencies that may arise, will build confidence that no cheating has occurred.

Having to build confidence in the correctness and completeness of a baseline declaration that is initially not fully verified is not new and has been successful in the past: Some States—including Canada, Germany, and Japan—already had extensive civilian nuclear programmes and experience with enrichment and reprocessing when they joined the NPT as non-weapon States. With regard to accounting reports required for NPT verification, Paragraph 62 of the model Comprehensive Safeguards Agreement (INFCIRC/153)[17] specifies that "the Agency shall be provided with an initial report on all nuclear material which is to be subject to safeguards thereunder." Formal verification of these initial

17 International Atomic Energy Agency, *The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the NonProliferation of Nuclear Weapons*, INFCIRC/153 (Corrected), Vienna, June 1972.

reports (for correctness and completeness) was never envisioned; nevertheless, as the IAEA implemented safeguards over time, the IAEA gained confidence in the correctness and completeness of the declarations that these countries made upon joining the NPT.

Several models for verifying baseline declarations may be envisaged. However, stipulating the details of such models would require more research. So far, most research has focused on verifying the correctness (i.e. not the completeness) of declarations, which, in the case of declared fissile stocks, can include a combination of nuclear measurements to characterize nuclear materials, tagging and sealing and continuity-of-knowledge measures to track specific items and batches.[18] This approach requires on-site inspections and would, in the case of military materials, also require access to sensitive nuclear facilities. Depending on the scope of the agreement and associated declarations, the verification regime may envision or require access to classified items. Comprehensive verification of baseline declarations could be experienced as very intrusive, as inspectors would have to be granted access to a variety of sensitive facilities and material.

The above verification concept may not be sufficient to detect undeclared nuclear materials (i.e. verify completeness). The most promising approach to verify completeness is to reconstruct the history of fissile material production in a country, primarily using techniques of nuclear forensics. This concept was first introduced as “nuclear archaeology” in 1990.[19] Estimates of historic military production of plutonium and HEU would be obtained, corrected for removals, and the net balance compared to the declared stocks. It is important to point out that nuclear archaeology does neither require access to classified forms of fissile material nor necessarily knowledge of ongoing fissile-material-related activities.

In addition to tools to verify past production, procedures and techniques would have to be developed to assess the credibility of reported removals from the stockpile. For example, the United States has reported a total of 3.4 tons of weapons plutonium as expended in nuclear weapon tests.[20] Similarly, large quantities of HEU have been used and consumed as fuel for nuclear submarines and other naval vessels. In both cases, however, it is unlikely that measurement techniques could be identified to accurately quantify removals.[21]

18 Nuclear Threat Initiative, “Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks: Verifying Baseline Declarations of Nuclear Warheads and Materials”, *Cultivating Confidence Verification Series,* 2014, www.nti.org/media/pdfs/WG1_Verifying_Baseline_Declarations_FINAL.pdf?_=1405443895.

19 Frank von Hippel, “Warhead and Fissile-material Declarations”, pp. 61-81 in Frank von Hippel and Roald Z. Sagdeev (eds)*, Reversing the Arms Race: How to Achieve and Verify Deep Reductions in the Nuclear Arsenals,* New York, Gordon and Breach, 1990.

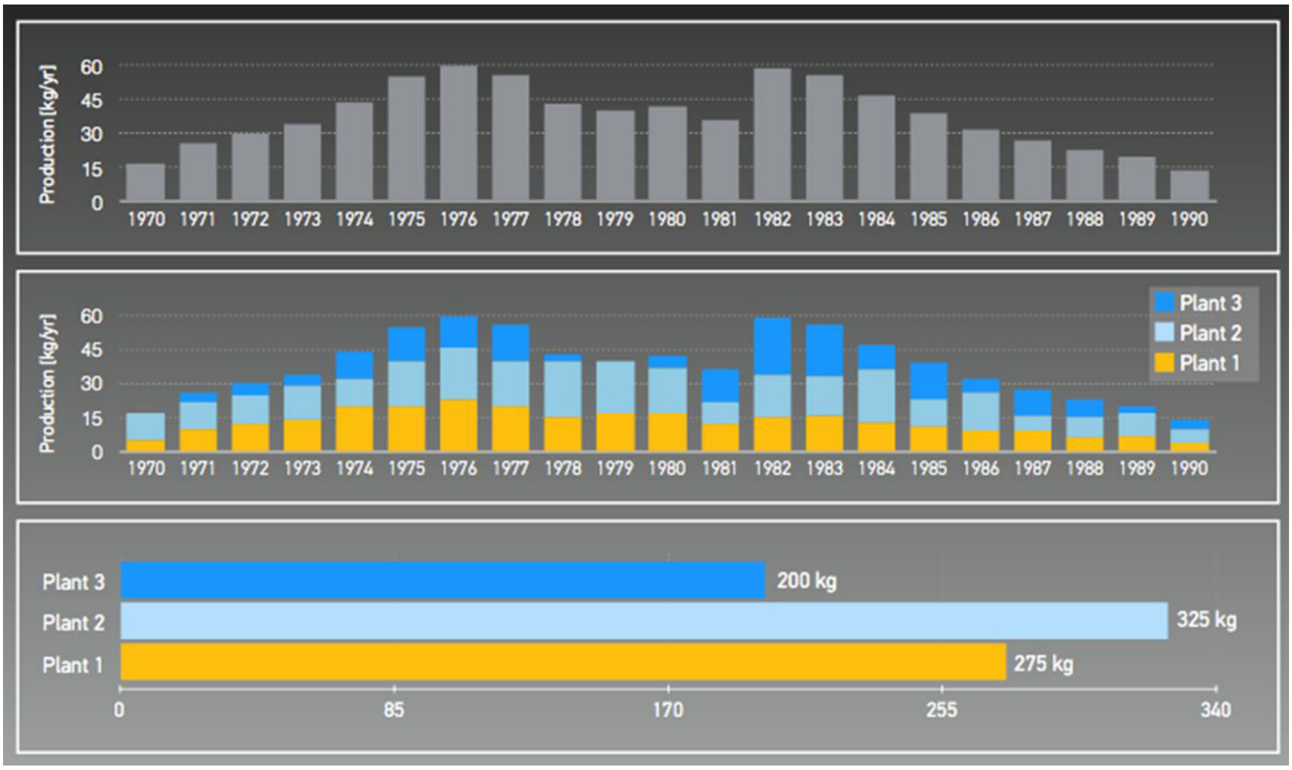
20 *Plutonium: The First 50 Years*, *op. cit.*

21 For example, the United States has provided detailed information about the 1,054 nuclear weapon tests it conducted between 1945 and 1992. It is quite possible that other countries, especially other nuclear-weapon States, would be in a position to assess the credibility of declared removals, for example, by using reported yields or yield estimates. United States, Department of Energy, *United States Nuclear Tests: July 1945 Through September 1992,* DOE/NV-209-REV 15, December 2000.

This paper focuses on the challenge of reconstructing fissile material production histories. At least three models, varying in intrusiveness, are available. The first is independent assessments, which does not require the cooperation of the State that provided the declaration. The other two variations are cooperative and more intrusive approaches. They would require access to further data and/or access to fuel-cycle facilities.

To obtain the confidence required to enable significant warhead reductions, a phased approach could be envisaged: A State could declare its complete fissile material stocks, which may not be directly verifiable, as the provided information may not be sufficient. However, independent assessments could be conducted. This would result in an initial level of confidence. At the same time or later, additional data could be provided. This could build more confidence if independent assessments turn out to confirm the data. Several options exist, some suggestions are shown in Figure 3. The total fissile material production could be broken down into production (and removals) for each year. A different approach would be to declare aggregate values of produced fissile material per production plant. Even more information would be provided if the aggregate production is broken down into values per year per plant.

Figure 3. Notional production scenario and alternative ways of declaring historic fissile material production (plutonium or highly enriched uranium)



Production rates could be made public by year (top), by year and site or plant (middle), or by site or plant only (bottom). Should a country initially have concerns about revealing its total inventory, a single-plant declaration could help lay the basis for nuclear archaeology demonstrations (as further discussed in main text).

Later, as part of a verification regime, the State could provide "metadata" and/or provide physical access to a part of the production complex to conduct measurements. Metadata are details of the fissile material production and removal history, such as detailed information about the plant operations, which can be used to reconstruct the past processes. Perhaps unwilling to provide metadata or physical access to all plants initially, the State could include further facilities as time progresses and confidence increases. At some point in the future, the entire fissile material production history could be verified in detail, and the result could be compared to the initial aggregate fissile material declaration, thereby verifying its completeness.

Independent assessments. Even without a formal verification regime in place and without a dedicated metadata-exchange initiative, fissile material declarations could be compared with public information and/or intelligence by independent or government experts. Possible sources of data include declassified historical documents and observed facility signatures such as power levels or atmospheric emissions (Figure 4). Even countries that have historically been reluctant to release information about their fissile material production histories have recently begun to document some aspects of their military production complex. For example, Russia has made public historical documents that specify the target burnup levels for the fuel used in its plutonium production reactors. Combined with the power level of respective reactors, this information can be used to determine the amounts of plutonium and the isotopics of the material with high accuracy.[22] As suggested previously, "especially if declarations are made early, such independent assessments could provide much more confidence than the large uncertainties in the estimates might at first suggest. This informal stage could therefore provide a firm basis of confidence upon which to build the next and more rigorous stages of verification."[23]

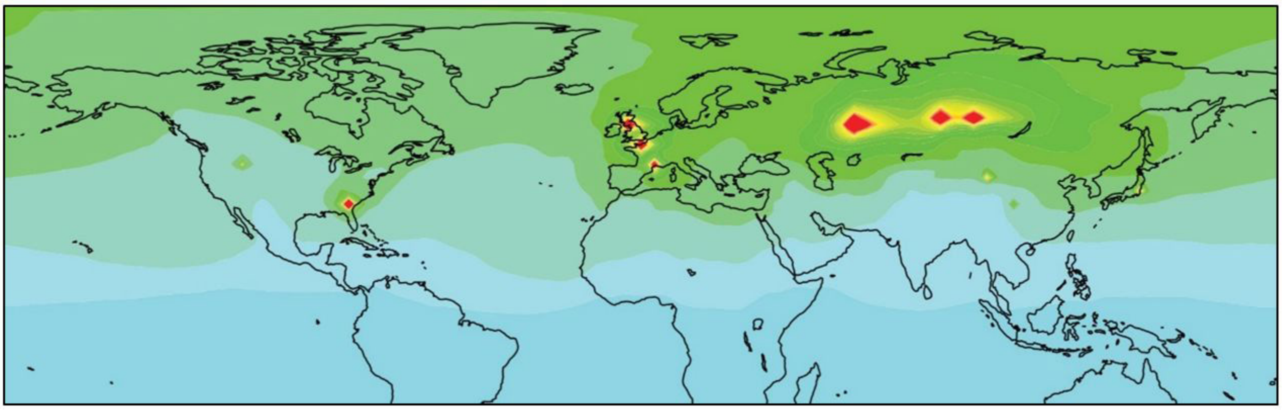
22 For the Russian case, see "Russia: Plutonium" in *Global Fissile Material Report 2010: Balancing the Books, Production and Stocks*, International Panel on Fissile Materials, Princeton, NJ, 2010, fissilematerials.org/library/gfmr10.pdf, in particular, pp. 47-48 and relevant footnotes. For a more detailed discussion of fissile material production histories using publicly available documents and information, see: *Global Fissile Material Report 2010, op. cit.,* and Harold Feiveson, Alexander Glaser, Zia Mian, and Frank von Hippel, *Unmaking the Bomb, A Fissile Material Approach to Nuclear Disarmament and Nonproliferation,* Cambridge, MA, MIT Press, 2014.

23 Alexander Glaser, "Facilitating Nuclear Disarmament: Verified Declarations of Fissile Material Stocks and Production", *Nonproliferation Review,* vol. 19, no. 1, 2012.

Figure 4. Several data sources could support independent assessments of fissile material declarations

	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Tonnage G2, G3	190	130	320	620	640	760	850	820	960	730	890
Tx de combustion . . .	100	100	100	200	200	300	300	300	400	400	450
Tonnage EDF . . . . . —	—	—	—	—	—	—	—	—	—	—	—

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Tonnage G2 G3	530	570	460	480	240	280	260	170	non connu	non connu	190
Tx de combustion . . .	450	450	500	600	700	800	1000	1200			1200
Tonnage EDF					113	8	25	120	245	280	310



Shown are two examples: In 1981, the National Atomic Energy Trade Union (SNPEA) of the French Democratic Confederation of Labour (CFDT) reported annual throughput and fuel burnup for the French plutonium production reactors G2 and G3. These numbers can be used to estimate the amount and the isotopics of plutonium produced annually in these reactors, which could be compared with officially declared data (top). When spent fuel is reprocessed to extract plutonium, krypton-85 is released from the spent fuel. During the Cold War, atmospheric concentrations of this isotope have been tracked using airborne and ground-based sensors to estimate plutonium production worldwide. Shown here are simulated results for the year 1981, which could be refined and compared against measurements once major plutonium producers make public additional information about their production histories (bottom). Sources: Le retraitement des combustibles irradiés: La situation de la Hague et Marcoule, Syndicat National du Personnel de l'Energie Atomique, 92, February 1981; Ole Ross, Simulation of Atmospheric Krypton-85 Transport to Assess the Detectability of Clandestine Nuclear Reprocessing*, PhD thesis, University of Hamburg, 2010.*

Cooperative verification approaches. If a verification regime is agreed upon, the most effective way of implementing it would be a cooperative approach where the inspecting and inspected States enter into a constructive dialogue to work together to reconstruct the production history. A non-cooperative approach would likely be unsuccessful due to the inaccuracies of the inspected State's knowledge of the production history. Inconsistencies would be found, and only by cooperation and dialogue could it be assessed whether they result from cheating attempts or from honest and unintentional inaccuracies. The cooperative approach could even result in jointly reducing existing uncertainties. This is not to say that inspecting States should trust all information they are given. While maintaining the cooperative relationship, inspecting States still need to undertake a maximum effort to reach independent conclusions on the provided information.

Two cooperative approaches could help reconstruct the production history: the exchange and analysis of metadata about past production, and cooperative measurements in facilities involved in fissile material production. Many materials, processes and sites have been involved in fissile material production. Accordingly, there are opportunities to analyse a large amount of data from several types of facilities. Several signatures could potentially be measured, for example not only from production facilities, but also from radioactive waste.

Data exchange. If sufficient metadata on past production and removals of fissile material is provided, verification may become possible in addition to independent assessments. Limited exchange of data, as discussed above, could help create confidence in the correctness and completeness of a declaration. However, if more detailed data were exchanged, perhaps at a later point, various pieces of information could be cross-checked for consistency. Such information could include design information of the various facilities (see Figure 5 for the plutonium case), their operational histories, including a range of operational parameters, as well as detailed records of the fissile material that entered and exited the facilities over time. The simplest solution would be to compare documentation of material that has been removed from one facility (e.g. spent fuel from a reactor) with documentation of material arriving at another (e.g. the spent fuel arriving in a reprocessing plant). The more details that are provided, the more confidence can be built: It will become much more difficult to make declarations that are wrong on a significant scale. The likelihood of detecting cheating would increase, especially if independent assessments and measurements are conducted as well (see below).

Simulating fissile material production histories using computer programmes can assist consistency-checks. Documented operational parameters of fuel-cycle facilities can be used as input to simulate the nuclear materials as they pass through the fuel cycle. The code(s) could calculate the composition and masses of nuclear materials at the different fuel-cycle stages for more complex fuel-cycle configurations. The results would be compared to provided records. Some tools, in particular reactor fuel-depletion codes, are widely used; others would need to be further developed.

The authenticity of certain types of documents can also be assessed. While it may be difficult to assess historically recent documents, the authenticity of older documents could potentially be determined quite reliably. Providing copies of original records would enable investigation of whether the form and content of records (for example the level of detail and presence of particular features such as stamps) are consistent with each other, with other documents from that time and with relevant documentation-regulations and practices. Exchanging original records would allow laboratory measures to confirm their authenticity, such as age dating of paper and ink. As this alone may not reveal all forgeries, it could and should also be attempted to establish the provenance of documents.[24] Provenance refers to examining a document's history, i.e. who created it, where and how was it handled and stored. This process would likely require the possibility to conduct interviews with the people who were responsible for the documents.

A difficult issue that could come up is that a State being inspected might claim that certain information, which an inspecting State has asked for, is not available. This may be particularly relevant for material removals. The inspecting State must then decide if this claim is acceptable or not. To enable the drawing of conclusions in such cases, inspected States could provide the inspecting State with information about relevant documentation laws, regulations and practices concerning fissile material production and the management of such documentation or information over time, including the possible destruction of information.

If inconsistencies arise during the consistency-checking, which is rather likely for large and complex fuel cycles, they can be discussed—and hopefully resolved. Such discussions would be facilitated by the nuclear-weapon States being open about their uncertainty assessments, including their assessments of where uncertainties come from. Inspecting States must also recognize that the inspected nuclear-weapon State may have made honest mistakes in determining its past production history.

Nuclear archaeology measurements. Measurements can be conducted in shut-down fissile material production facilities or radioactive waste to obtain estimates of the amount of fissile material produced. Such measurements are complementary to the exchange of metadata; they provide independent information. Nuclear archaeology measurements are important to obtain fissile material estimates if the extent of provided documentation and records is very small and insufficient for a reliable evaluation.

If the data about production are available, they can increase confidence in nuclear archaeology measurements by allowing comparisons of measurement results and documented data. Furthermore, the joint evaluation of measurements and provided data can potentially reduce the uncertainties of the fissile material production estimates beyond what is possible based on either approach alone. For example, it may occur that not all inconsistencies arising from provided records and computer simulations can be resolved by dialogue and joint evaluation alone. Some documented data may be inaccurate and documents alone may not provide sufficient evidence to decide which of the inconsistent data is more accurate. Measurements can help resolve such issues. In an advanced phase of warhead and fissile material reductions, an inspecting State might require the combination of both approaches to obtain sufficient confidence.

24 For example, the authenticity claim of a papyrus fragment where Jesus speaks of his "wife" could not be disproven with forensic methods such as radiometric dating. The document is now considered a forgery based on the inability to establish the provenance of the papyrus, see Karen L. King, "Jesus said to them, 'My wife …': A New Coptic Papyrus Fragment", *Harvard Theological Review,* vol. 107, no. 2, 2014, pp. 131-59 and David N. Hempton, "Statement from HDS Dean David N. Hempton on the "Gospel of Jesus' Wife", Harvard Divinity School, 20 June 2016, gospelofjesusswife.hds.harvard.edu/introduction.

Some research has been conducted on measurement concepts for nuclear archaeology in uranium enrichment plants.[25] Other techniques under development include quantitative estimates of the plutonium production in graphite-moderated reactors[26] and heavy water reactors[27] that rely on examining the graphite moderator (GIRM) or structural reactor elements. These techniques require samples to be taken from shut-down reactor cores. For accurate results, detailed information about the reactor design is required. Of all published research, only GIRM has been robustly experimentally validated. Further research is required, including looking for further helpful indicators, for example in radioactive waste.

As mentioned, both nuclear archaeology measurements and data exchange should be combined to reduce uncertainties. Some nuclear-weapon States have produced such a large amount of fissile material that even low measurement uncertainties translate into large uncertainties of HEU and plutonium stocks estimates. For example, in the case of the United States, an uncertainty in the plutonium production of 2%, a reasonable value if the estimates are based on measurement results alone,[28] corresponds to over 2,000 kg of plutonium.

Next steps

More research and development is required to advance nuclear archaeology concepts and techniques, as most of them have only been explored to a limited extent and are far from being ready for implementation. While research would ideally be carried out at original military production sites, facilities in non-nuclear-weapon States can be equally suited for a multilateral research and development programme. Although these facilities have been used for peaceful purposes, they are often very similar (or even identical) to those used by nuclear-weapon States to produce weapons. Conducting the first multilateral nuclear archaeology exercises in nuclear-weapon States may be more difficult because access to facilities and documentation is generally more limited. In non-nuclear-weapon States, however, a larger set of documents could more readily be made available as no

25 Matthew Sharp, "Applications and Limitations of Nuclear Archaeology in Uranium Enrichment Plants", *Science & Global Security,* vol. 21, no. 1, 2013, pp. 70-92; Sébastien Philippe and Alexander Glaser, "Nuclear Archaeology for Gaseous Diffusion Enrichment Plants", *Science & Global Security*, vol. 22, no. 1, 2014, pp. 27-49.

26 Steve Fetter, "Nuclear Archaeology: Verifying Declarations of Fissile-Material Production", *Science & Global Security,* vol. 3, nos 3-4, 1993, pp. 237-59; Christopher Gesh, *A Graphite Isotope Ratio Method Primer: A Method for Estimating Plutonium Production in Graphite Moderated Reactors,* PNNL-14568, Richland, WA, 2004; Bruce Reid et al., *Trawsfynydd Plutonium Estimate,* PNNL-13528, Richland, WA, 2009.

27 Alex Gasner and Alex Glaser, "Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors", *Science & Global Security*, vol. 19, no. 3, 2011, pp. 223-33.

28 For GIRM, the uncertainty of plutonium produced at one reactor is about 3%. In the Russian case, this results in an uncertainty of 1% for the overall plutonium production. Due to a larger use of heavy water reactors in the United States, for which uncertainties are larger, the total uncertainty will be larger. See Thomas W. Wood et al., "The Future of Nuclear Archaeology: Reducing Legacy Risks of Weapons Fissile Material", *Science & Global Security,* vol. 22, no. 1, 2014, pp. 4–26.

conclusions would be drawn about past operations or existing fissile material stocks. Building on this experience, similar exercises could be carried out in nuclear-weapon States at a later point in time. These exercises would not be purely technical in nature, but would also contribute directly to confidence-building and transparency.

To initiate such a process, an international expert group could be created to propose, develop, and conduct practical nuclear archaeology exercises, aiming both at building confidence and at advancing the state of the art of research and development. A well-suited framework could be the International Partnership for Nuclear Disarmament Verification (IPNDV). Alternatively, such an expert group could be initiated by the Non-Proliferation and Disarmament Initiative (NPDI).

The IPNDV "brings together states possessing nuclear weapons and states that do not under a cooperative framework to further understanding of the complex challenges involved in the verification of nuclear disarmament, and to work to overcome those challenges."[29] In its current first phase, the IPNDV focuses on verifying the dismantlement of nuclear weapons. To that end, the IPNDV has formed three working groups, dealing with (1) monitoring and verification objectives, (2) on-site inspections and (3) technical challenges and solutions. Including cooperative nuclear archaeology as a focus of a next phase would fit very well with the overall aim and composition of the IPNDV. Cooperative nuclear archaeology is a field in which nuclear and non-nuclear-weapon States can work together constructively. Non-nuclear-weapon States—especially those with civilian nuclear programmes—can also contribute with important expertise. Furthermore, it would be an opportunity for IPNDV to contribute to the challenge of verifying the completeness of declarations, which is currently not in its focus.

The NPDI is equally well suited to initiate a cooperative nuclear-archaeology project, either among its members or jointly with nuclear-weapon States. The NPDI emphasizes the principles of irreversibility, verifiability, and transparency,[30] and has proposed a standard reporting form for declarations.[31] A cooperative nuclear-archaeology project would advance these principles. In particular, it would further develop the standard reporting form proposal by developing techniques that will help verify the information contained therein.

Several non-nuclear-weapon States involved in the IPNDV and NPDI have extensive nuclear infrastructures including facilities of great relevance for nuclear archaeology. Particularly relevant facilities include gaseous diffusion and gas centrifuge enrichment facilities, graphite-moderated and heavy water reactors and reprocessing plants. Relevant facilities can be found, for example, in Germany, Japan, South Korea, Canada and Sweden. An exercise conducted in one or several of these countries could focus

29 United States, Department of State, *An International Partnership for Nuclear Disarmament Verification,* Fact Sheet, 2 August 2016, www.state.gov/t/avc/rls/2016/260759.htm.

30 *Recommendations for consideration by the 2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons*, *op. cit.*

31 *Recommendations for consideration by the 2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons*, *op. cit.*

on advancing methods to analyse fissile material production data (by providing such), nuclear archaeology measurement techniques (by granting access to relevant fuel cycle facilities or material samples from them) or both. The scope of such exercises is flexible, ranging from a single measurement in a facility to a comprehensive case study of the total amount of uranium and plutonium produced for civilian purposes. This range allows for broadening the scope of such exercises over time.

Advancing research on nuclear archaeology is urgent. Further deferral of work in this area means that important information will be irreversibly lost. After all, as time goes on, shut-down nuclear facilities will continue to be dismantled, original records of nuclear fuel-cycle histories will be destroyed or lost, and the people who operated the facilities decades ago will no longer be around. Increasing research activities now and demonstrating the feasibility of nuclear archaeology would also raise awareness of the need to preserve records, samples and knowledge documenting the past production more broadly.

Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions

Summary of the discussion

Pavel Podvig

This part of the report presents a brief summary of the discussion that followed the presentation of the papers included in this volume at the second meeting of the UNIDIR FM(C)T Meeting Series, which took place in the Palais des Nations, Geneva on 1 June 2016. The discussion focused primarily on the practical issues related to the deferred verification concept and the role of confidence building measures in the verifying declarations of existing stocks.

Deferred verification

There were a number of questions about the concept of deferred verification. The concept of deferred verification assumes that nuclear-armed States will separate their existing fissile material stocks into two segments. While one of these segments would cover military material and be “closed” for verification, another “open” segment would cover production facilities as well as any material that is not used for weapons or other military purposes.

Regarding the allocation of existing fissile material between the open and closed segments, it was noted that the civilian nuclear cycle in nuclear-armed States will effectively become part of the open segment since the material in civilian use will eventually be covered by the treaty verification system. The approach to the material that is declared excess for weapons or other military purposes might be different. One of the reasons these categories of fissile material may not be immediately available for verification is that most of this material is weapon-origin and therefore may still be in classified form.

For example, some plutonium and highly-enriched uranium (HEU) that was declared excess to weapon needs is still contained in weapon components. The experience of a number of US-Russian fissile material elimination programmes, such as the HEU-LEU deal or the Plutonium Management and Disposition Agreement, showed that verification would normally be possible only as part of the elimination or disposition process in which the material loses its classified characteristics. Also, some of the weapon-origin material, namely the HEU that is assigned to be used in naval fuel, may remain unavailable for verification despite the commitment not to use this material in weapons.

In this context, the participants discussed the potential role of the US-Russian-IAEA Trilateral Initiative, which explored ways to apply IAEA safeguards to the material with classified characteristics. It was noted that the procedures developed as part of the initiative cannot be directly applied to the verification of stock declarations, since they were deliberately designed to mask information about the amount of fissile material that is placed under safeguards.

Some participants noted that the concept of deferred verification is compatible with the proposals that assume that an FM(C)T would allow States to exclude the material in weapons from the treaty scope even if the treaty requires them to submit all other material for verification. The discussion showed that while these approached have some similarities, there are significant differences as well. The deferred verification concept assumes that States would declare the exact amount of material used in weapons and then implement measures that would allow verification of this declaration in the future. Also, States would be required to open the non-weapon segment of their nuclear fuel cycle to verification and provide information about the history of fissile material production. This would be necessary to verify the declaration.

One concern about deferred verification that was raised during that discussion was the possibility that a State would over- or under-declare the amount of material in the closed segment. This might give the State an option to hide some material from verification. This concern was countered by an observation that an intentional misreporting of the amount of material in the closed segment does not give the State any military or political advantage. More importantly, the deferred verification arrangement assumes that the closed segment will become open to verification as the military fissile material is eliminated, making it impossible to retain material at the end of the elimination process.

Finally, the discussion touched on the issue of protecting information that may be sensitive from a national security or nuclear proliferation point of view. It was noted that any potentially sensitive national security information would most likely be contained predominantly in the closed segment, and thus not immediately available for verification. As for the open segment, it appears to be possible to design verification procedures in a way that would limit access to sensitive information. In order to do so, States could adopt managed access procedures that have been used in the current IAEA safeguard practice.

The questions raised during the discussion suggest that there is significant interest in developing new approaches to verified declarations of existing fissile material stocks, including the concept of deferred verification. At the same time, it was clear that the concept needs to be developed further if it is to become an element of the future fissile material control regime.

Importance of confidence building

Since verification is an inherently cooperative enterprise, the effectiveness of a verification system depends crucially on the confidence that States gain over the course of applying verification procedures. This point was repeatedly emphasized by panellists when they discussed various aspects of verification arrangements.

As was pointed out during the discussion, verification of declarations of fissile material stocks would face a number of challenges. The declarations made by the United States and the United Kingdom demonstrated that it is extremely difficult to determine the exact amount of fissile material in a large inventory, especially if it contains material in wastes and in bulk form. Reconstruction of the history of fissile material production is often made difficult by the lack of adequate accounting records from the early days of most nuclear weapon programmes. The nuclear archaeology techniques that rely on physical evidence of material production may not have the accuracy that would be required to determine the exact amount of material that was produced. For example, one estimate suggests that the uncertainty in determining the amount of plutonium produced by a State that can be achieved by nuclear archaeology can be as high as five percent. In large plutonium production programmes, such as the ones run by the United States and the Soviet Union, this could amount to several tons of weapon-grade fissile material. In addition, unlike production, removal of fissile material from active inventory (for example, for nuclear tests or for permanent disposition) does not leave physical evidence that can be examined later.

In this situation, inspectors' confidence in full cooperation of the inspected State would become an extremely important element of the verification system. In fact, as was noted during the discussion, the verification procedures can in most cases be adjusted to reflect the experience of conducting inspections as well as the degree of cooperation of inspected States. In one example of such an adjustment, the verification procedures provided for in the most recent US-Russian strategic arms control agreement, the New START treaty, are much simpler than those of earlier US-Russian nuclear arms control treaties, such as the 1987 Intermediate Nuclear Forces Treaty and the START treaties of the early 1990s. It was suggested that similar evolution would be possible in the future FM(C)T, and that States would move toward more intrusive, but probably simpler, verification measures as they accumulate experience of monitoring treaty compliance.

The discussion emphasized that the confidence-building process is likely to take considerable time. At the same time, there is no reason to delay the implementation of some of the measures that will inevitably form an essential element of an agreement to ban the production of fissile material for weapons and, ultimately, for nuclear disarmament. For example, it was suggested that there is a broad range of projects on nuclear archaeology that can be implemented today and that would be crucial for verifying fissile material production records and, most importantly, for gaining confidence in the accuracy of these records. The declaration of fissile material stocks made by the United States and the United Kingdom provide a good starting point for these projects.

Conclusion

Overall, the discussion showed that there are a number of challenges associated with including declarations of existing fissile material stocks in the FM(C)T. One of the most difficult issues concerns the verifiability of declarations. Establishing effective verification measures would no doubt be necessary if a commitment to issue declarations is included in the treaty as a legally binding obligation. There are a number of approaches that address various aspects of verifiability, but most require further research before they can become elements of the treaty. Also, there has to be a political discussion of the role that declarations of fissile material stocks would play in the FM(C)T. At the same time, whether or not the future treaty requires declarations of existing stocks, it is important to use every opportunity to involve nuclear-armed States as well as non-nuclear-weapon States in cooperative work on various aspects of past fissile material production. This work will help develop technical expertise and establish the confidence between States that would be essential for the FM(C)T's success.

UNIDIR

FM(C)T Meeting Series

Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions

If the future treaty that bans the production of fissile material for weapons is to require declarations of the existing fissile material stocks, it would have to include provisions to allow effective verification of these declarations as well as measures that would deal with the materials in active nuclear arsenals. These requirements may present a significant challenge for the future fissile material control agreement. The papers presented in this volume examine some practical challenges of including declarations of fissile material stocks in the treaty as well as solutions that could help address these challenges.