UNIDIR

Deferred Verification

Verifiable Declarations of Fissile Material Stocks

UNIDIR RESOURCES

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Acronyms and abbreviations

ACRR	Annular Core Research Reactor (United States)
ALCM	Air-launched Cruise Missile
AWE	Atomic Weapons Establishment (United Kingdom)
BARC	Bhabha Atomic Research Center (India)
CAEP	Chinese Academy of Engineering Physics
CEA	Commissariat à l'Energie Atomique (France)
CESTA	Centre d'Etudes Scientifiques et Techniques d'Aquitaine (France)
DAM	Direction des Applications Militaires (France)
DPRK	Democratic People's Republic of Korea
FMCT	Fissile Material Cut-off Treaty
FMSF	Fissile Material Storage Facility (Russian Federation)
HEU	Highly Enriched Uranium
IAEA	International Atomic Energy Agency
ICBM	Intercontinental Ballistic Missile
INFCIRC	Information Circular
KAMS	K-Area Material Storage (United States)
KUMMSC	Kirtland Underground Munitions Maintenance and Storage Complex (United States)
LANL	Los Alamos National Laboratory (United States)
LEU	Low-enriched Uranium
LLNL	Lawrence Livermore National Laboratory (United States)
MOX	Mixed Oxide
MUF	Material Unaccounted For
NNSA	National Nuclear Security Administration (United States)
NPT	Non-Proliferation Treaty
PLA	People's Liberation Army (China)
PMDA	Plutonium Management and Disposition Agreement
SLBM	Submarine-launched Ballistic Missile
THORP	Thermal Oxide Reprocessing Plant (United Kingdom)
VNIIEF	Scientific Research Institute of Experimental Physics (Russian Federation)
VNIITF	Scientific Research Institute of Technical Physics (Russian Federation)
WIPP	Waste Isolation Pilot Plant (United States)

Introduction

The amount of separated plutonium and highly enriched uranium, the key weapon-usable fissile materials, produced since the beginning of the nuclear age is estimated to be almost 3,000 metric tons.[1] Most of that material was produced by the Soviet Union and the United States as part of their military programmes, which used a substantial amount of this material as it was produced. After the end of the Cold War, the Russian Federation and the United States eliminated about 670 tons of these materials from their weapon programmes. As a result, today, the global inventory of fissile materials is estimated to be about 1,800 tons of highly-enriched uranium and separated plutonium. Most of that material is in the custody of military programmes of nuclear-armed States, with the Russian Federation and the United States holding about 86% of the global stock.[2]

Beginning in the 1980s, most nuclear-armed States discontinued production of fissile materials for weapons and eliminated or converted to civilian uses their fissile material production facilities, although some continue to produce fissile materials for their weapon programmes or non-weapon military applications. Production of weapon-usable fissile materials for civilian purposes continues as well.

It has been widely acknowledged that a ban on production of fissile materials for weapons would be an important and indeed essential step toward nuclear disarmament. The beginning of negotiations in the Conference on Disarmament on a non-discriminatory, multilateral and internationally and effectively verifiable treaty banning the production of fissile material for nuclear weapons, usually referred to as the Fissile Material Cut-off Treaty or FMCT,[3] was identified as one of the thirteen practical disarmament steps in the final document of the 2000 Nuclear Non-Proliferation Treaty Review Conference. It was also included in the action plan agreed on at the NPT Review Conference in 2010.[4] Despite repeated calls, the Conference on Disarmament has yet to begin negotiations, but a number of steps toward developing key elements of the treaty have already been taken. In December 2012, the United Nations General Assembly adopted a resolution that asked the Secretary-General to establish a Group of Governmental Experts to make recommendations on possible aspects of the future treaty and seek the views of the Member States on the matter.[5] The group, which worked in Geneva during 2014–2015, became the first multinational body to discuss various issues related to the future FMCT.[6]

This report is based in part on the paper prepared for the FMCT Meeting Series held by UNIDIR in 2016. See Pavel Podvig, "Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions", UNIDIR, June 2016. Available from http://www.unidir.org/files/publications/pdfs/verifiable-declarations-of-fissile-material-stocks-challenges-and-solutions-en-652.pdf.

[1] This number is known with significant uncertainty, which means that while it is possible to estimate the amount of material produced, the accuracy of these estimates could be rather low. It includes only plutonium separated from irradiated fuel. For highly enriched uranium, it includes the amount of 90% HEU equivalents. For details, see International Panel on Fissile Materials, "Global Fissile Material Report 2010: Balancing the Books: Production and Stocks", 2010. Available from http://ipfmlibrary.org/gfmr10.pdf. Throughout this report, tons refer to metric tons.

[2] International Panel on Fissile Materials, "Fissile material stocks". Available from http://fissilematerials.org/ (accessed November 2017).

[3] FMCT is often written with parentheses around Cut-off, to indicate that the proposed treaty may not necessarily be limited to cutting future production. For simplicity and ease of reference, we use FMCT without parentheses in this report. We do this without prejudice to any views on the scope of a future treaty dealing with fissile materials.

[4] *2000 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, Final Document*, vol. I (NPT/CONF.2000/28 (Parts I–II)), p. 14; *2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, Final Document,* vol. I (NPT/CONF.2010/50 (Parts I-II)", p. 23.

[5] General Assembly resolution 67/53. Available from http://undocs.org/A/RES/67/53.

[6] Report of "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", in United Nations Official Document A/70/81. Available from http://undocs.org/A/70/81.

The discussions that have been held so far demonstrated that although the primary objective of a ban on the production of fissile materials for weapons is supported by most States, there are significant differences among them about the role of the treaty in the larger nuclear disarmament process and the obligations regarding the existing stocks of fissile materials that the treaty should include. The negotiation mandate agreed on in 1995 makes provisions for addressing existing stocks during negotiations and there is considerable support for including these stocks in the future treaty.[7] This support, however, is not universal as some nuclear-armed States object to including existing stocks in the FMCT scope.[8]

Supporters of the idea of including past production in the treaty suggested several ways of doing so. Some proposals would require States parties to declare and account for all existing fissile materials, others would only apply that requirement to fissile materials that are not in weapons or that are voluntarily declared excess to weapon purposes. Declarations of the amounts of existing materials are also seen as an important element of the fissile material cut-off regime, since they would provide "a baseline to assess non-diversion and for future disarmament efforts."[9]

One of the arguments against including existing stocks in the treaty is the difficulty of creating the provisions that would deal with the material produced in the past in a verifiable way. Regardless of whether the treaty includes specific obligations regarding the elimination of fissile materials or simply asks States to submit initial declarations that would serve as a baseline for future reductions, the FMCT would have to provide a mechanism that would support verification of declarations of stocks.

Verifying a declaration of the amount of fissile materials in any nuclear-armed State would be a challenging task in any circumstances because of the size and long history of most programmes. But the most serious problem with verification of declarations is the difficulty of covering military material in active use—that in operationally deployed and reserve warheads as well as warhead components or the material that may be reserved to maintain the arsenal. It is extremely unlikely that weapons in current nuclear arsenals or fissile material that is reserved for use in weapons would be available for inspection or other verification activities.

It is, however, possible to design a verification arrangement that would allow the future FMCT to include provisions covering all existing fissile materials, including material in active use, and to do so in a legally-binding and verifiable way. This arrangement, referred to as "deferred verification", relies on the fact that materials in weapons and weapon-related activities can be confined in a separate "closed" segment of a nuclear complex. Verification of the material in this segment would be deferred to the time when it enters the elimination or disposition process. Combined with a ban on the production of new materials that would be established by the FMCT this arrangement could support verification of initial declarations of fissile material stocks and the gradual elimination of all weapon-related fissile materials.

One significant feature of the deferred verification approach is that it provides a disarmament mechanism that avoids having to deal with accounting for nuclear warheads, authentication of nuclear weapons, or monitoring of the warhead dismantlement process. Neither does it rely on access to fissile materials in classified forms and therefore does not require implementation of information barriers or similar measures designed to protect sensitive weapon-related information.

[7] "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", United Nations Official Document CD/1299, Conference on Disarmament, 24 March 1995. Available from http://undocs.org/CD/1299.

[8] See views of States presented in "Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices. Report of the Secretary-General", United Nations Official Document A/68/154, 16 July 2013. Available from http://undocs.org/A/68/154.

[9] A/70/81, para 23.

This could help simplify the nuclear disarmament process by addressing (or, rather, avoiding) the most challenging verification issues. It is also significant that the deferred verification arrangement could be implemented as an internationally verifiable agreement with participation of non-nuclear-weapon States.

This report describes key elements of the deferred verification arrangement and discusses its potential use in the future FMCT. The first section of the report outlines a general approach to verification of fissile material stocks and considers the challenges that would be encountered in the process—the accuracy of closing the material balance and the lack of access to weapons and materials in classified forms. The next section introduces the deferred verification proposal in the context of an FMCT and describes key elements of the arrangement as well as potential challenges to its implementation. The final section outlines some practical measures that could be implemented as part of existing fissile material disposition programmes. The appendix provides information about existing fissile material stocks of nuclear-armed States and key facilities involved in maintenance of nuclear weapon arsenals.

Challenges of verifying declarations of fissile material stocks

Closing the material balance

To understand how the deferred verification approach would work in practice it is instructive to consider an idealized scenario in which a nuclear-armed State submits a declaration of its fissile material stocks and provides unrestricted access to all its nuclear materials so that the declaration can be verified. For the purposes of the discussion in this section, we set aside the question of the conditions that would make such a decision possible. Should that decision be made, however, the verification arrangements would most likely be similar to those that were used by the International Atomic Energy Agency (IAEA) when it implemented comprehensive safeguards in States that had substantial pre-existing stocks of fissile materials, such as the States that became independent after the breakup of the Soviet Union, or in South Africa, which had a history of fissile material production.[10]

At the beginning of the verification process, a State would submit an initial nuclear material inventory report, which would contain a detailed physical inventory listing for each material balance area within its facilities that handle fissile materials.[11] This report serves as a starting point for a cooperative verification programme that establishes the correctness and completeness of the report. This programme would begin with identifying the material balance areas to be included in the report and then proceed to take an independent physical inventory in these areas.

In the material accounting practice, a physical inventory would have to be accompanied by an analysis of accounting records that document production, acquisitions and removals of material from a "material balance area" and reconciling the result with the measured inventory.[12] This process, known as closing the material balance, is likely to identify so-called material unaccounted for (MUF or inventory difference), which is the difference between the measured inventory and the book inventory (i.e. the amount of material held in the area according to material accounting records). In most cases, there is a limit on the accuracy that closing the material balance can achieve.

The fissile material inventories published by the United States and the United Kingdom provide an illustration of the magnitude of the challenge. These accounts indicate that closing the material balance on a State-wide scale in a State with a long history of fissile material production cannot be done with perfect accuracy. For example, 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. The United Kingdom reported an audited stock of highly enriched uranium (HEU) of 21.86 tons, while the material balance records indicated that the amount should be 21.64 tons—an apparent gain of 0.22 tons of the material.[13]

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[10] For a more detailed discussion of the verification process, see Pavel Podvig, "Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions" (2016).

[11] According to the IAEA: "Nuclear material is accounted for within a structure of material balance areas (MBAs), similar to how banks account for money deposited by account holders. The accounting system records the quantity of nuclear material at the beginning of a period, keeps track of additions to the inventory and subtractions from the inventory, and provides a balance at the end of the period." See IAEA, *Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols* (Vienna, 2014), p. 21. Available from http://www-pub.iaea.org/MTCD/Publications/PDF/SVS-21_web.pdf.

[12] Peter Dessaules, "The U.S. Plutonium and HEU Declarations", in *Global Fissile Material Report 2009: A Path to Nuclear Disarmament* (International Panel on Fissile Materials, 2009), pp. 42–47. Available from http://ipfmlibrary.org/gfmr09.pdf.

[13] This means that the measured inventory was 2.4 tons less than the amount reflected in the records. See United States, 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, p. 4. Available from http://fissilematerials.org/library/doe12.pdf; and 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. Available from http://fissilematerials.org/library/mod06.pdf.

It is likely that inventory differences in other States will be comparable to and probably larger than those demonstrated in the accounts published by the United States and the United Kingdom.[14] There are several reasons why the material balance process cannot reduce the inventory difference below a certain limit. In those States that have produced significant amounts of fissile materials over the years, the key challenge of closing the material balance on a State-wide scale is the availability and accuracy of production and material accounting records. It is almost certain that accounting and record-keeping practices that were implemented at the early stages of nuclear weapon programmes did not fully correspond to the requirements of an accurate material balance that exist today. For example, the United States reported that in its plutonium account "68% of the inventory difference occurred during the period prior to the late 1960s."[15]

Taking an accurate physical inventory would also be a challenging task. There is a limit to the accuracy of measuring the amount of fissile material submitted to verification, especially at facilities that handle materials in bulk form (for example, in solutions). Accurate accounting for the amount of material in waste would be especially challenging, if possible at all. In most cases the fissile material in waste is mixed with other substances and can be stored or disposed of in a way that makes it difficult to reach or measure.[16]

The ultimate goal of these verification activities would be to certify the correctness and completeness of the initial declaration of fissile material stock, submitted by a State. This procedure would be similar to the IAEA practice of reaching a broader conclusion drawn by the Agency for those States that have concluded a comprehensive safeguards agreement and an additional protocol. This conclusion, drawn annually, certifies "that all of the nuclear material in the State had been placed under safeguards and remained in peaceful activities or was otherwise adequately accounted for." Importantly, to be able to draw a broader conclusion, "the IAEA must draw the conclusions of both the non-diversion of the nuclear material placed under safeguards and the absence of undeclared nuclear material and activities for the State as a whole."[17] As of the end of 2016, the Agency was able to draw a broader conclusion for 69 States that have an additional protocol in force.[18] Some of these States have a substantial civilian nuclear industry that handles large amounts of fissile materials. All of them, however, are non-nuclear-weapon States parties to the NPT. There is no doubt that reaching a similar conclusion for a nuclear-armed States with a history of producing fissile materials for weapons would be significantly more difficult.[19]

Access to nuclear weapons and material in active military use

Closing the material balance would be a very challenging undertaking in any event, but it would be particularly difficult if a State maintains an active nuclear arsenal. Taking a full physical inventory of fissile material holdings would normally require access to all fissile materials in the State's

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[14] Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities* (Washington, D.C.: National Academies Press, 2005), pp. 194–98. Available from https://www.nap.edu/catalog/11265/monitoring-nuclear-weapons-and-nuclear-explosive-materials-an-assessment-of.

[15] United States, Department of Energy, "Plutonium: The First 50 Years. United States Plutonium Production, Acquisition, and Utilization from 1944 through 1994", February 1996, p. 53. Available from http://fissilematerials.org/library/doe96.pdf.

[16] For a discussion of these challenges in the context of IAEA and Euratom safeguards, see Alan J. Kuperman, David Sokolow and Edwin S. Lyman, "Can the IAEA Safeguard Fuel-Cycle Facilities? The Historical Record", in *Nuclear Weapons Materials Gone Missing: What Does History Teach?*, Henry D. Sokolski, ed. (Carlisle, PA: Strategic Studies Institute and U.S. Army War College Press, 2014). Available from http://npolicy.org/books/2014muf/Kuperman%20Chapter%205.pdf.

[17] International Atomic Energy Agency, "IAEA Safeguards Glossary", International Nuclear Verification Series, No. 3 (Vienna, 2002), para. 12.25. Available from http://www-pub.iaea.org/MTCD/Publications/PDF/NVS3_scr.pdf.

[18] International Atomic Energy Agency, "Safeguards Statement for 2016", presented to the IAEA Board of Governors on 14 June 2017. Available from https://www.iaea.org/sites/default/files/statement_sir_2016.pdf.

[19] Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials* (2005), p. 193.

possession. For nuclear-armed States, these would have to include materials that are in active military use—in deployed and reserve weapons, weapon components, or the material from dismantled warheads awaiting disposition. This presents a seemingly insurmountable problem for the effort to close the material balance if it is carried out by an international verification body. It is well recognized that no nuclear-armed State would be willing to grant this kind of access to international inspectors.

The immediate objection to granting such access is national security. Accounting for material in active use would require revealing information about the number and locations of all weapons in the arsenal as well as details of weapon design, such as the fissile material content of various types of weapons. Verification of this information would require physical access to weapons and their components. This would be an extremely high bar for a State that keeps an operational nuclear arsenal. The need to protect proliferation-sensitive information would also play an important role. Nuclear-weapon State parties to the NPT have an obligation to prevent the transfer of information about nuclear weapons to non-nuclear-weapon States.

A substantial amount of work has been dedicated to developing tools that would establish a degree of control over weapons in active arsenals or monitor the weapon dismantlement process.[20] Practical implementation of some of the monitoring measures was explored by the United States, the Russian Federation, and the IAEA in the Trilateral Initiative, and through the United Kingdom–Norway Initiative, the joint US–UK project on technical aspects of arms control, as well as other projects.[21] These projects, however, demonstrated the limits of existing approaches when it comes to measuring the amount of material in a nuclear weapon with the accuracy that is required for the purposes of the material balance.

The problem is that all the approaches considered so far are designed to protect sensitive information about inspected weapons, material, or facilities. This means that they are built to conceal such important attributes of an inspected object as the mass of fissile material or its isotopic composition. The concealment could be done by either introducing an information barrier that masks the results of attribute measurements or by using the template method that relies on comparing the inspected object with a reference object that is known to be a weapon.[22] In practical applications of the attribute method, such as the Trilateral Initiative, an inspector would be allowed to see if the mass of the material in a container is above a certain agreed threshold. This approach can work in a number of applications, but it is clearly unsuitable for the purposes of accurate accounting for the amount of material.

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[20] See, for example, a detailed discussion in *Transparency in Nuclear Warheads and Materials: The Political and Technical Dimensions*, Nicholas Zarimpas, ed. (Oxford; New York: Oxford University Press, 2003); Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials (2005)*; 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. Available from http://www.nti.org/media/pdfs/WG1_Verifying_Baseline_Declarations_FINAL.pdf.

[21] On the Trilateral Initiative and its potential role in nuclear disarmament verification, see Thomas E. Shea, "Weapon-Origin Fissile Material: The Trilateral Initiative", in *Global Fissile Material Report 2008: Scope and Verification of a Fissile Material (Cutoff) Treaty* (International Panel on Fissile Materials, 2008). Available from http://ipfmlibrary.org/gfmr08.pdf; Thomas E. Shea and Laura Rockwood, "IAEA Verification of Fissile Material in Support of Nuclear Disarmament", Paper No. 2015-01 (May 2015), Belfer Center, Harvard University. Available from http://belfercenter.ksg.harvard.edu/files/iaeaverification.pdf. Results of the UK–Norway Initiative are presented on the project web site "United Kingdom - Norway Initiative". Available from http://ukni.info/ (accessed 22 September 2017). For the joint US-UK verification project, see NNSA, Ministry of Defence and AWE, "Joint U.S.-U.K. Report on Technical Cooperation for Arms Control", May 2015. Available from https://nnsa.energy.gov/sites/default/files/Joint_USUK_Report_FINAL.PDF. Other projects are briefly described in "Norwegian Report on General Assembly Resolution 71/67 on Nuclear Disarmament Verification", 1 August 2017. Available from https://www.unog.ch/80256EDD006B8954/(httpAssets)/187E579426350611C125816E003F22D3/$file/2017+NDV+Norway.pdf.

[22] Oleg Bukharin, "Russian and US Technology Development in Support of Nuclear Warhead and Material Transparency Initiatives", in *Transparency in Nuclear Warheads and Materials: The Political and Technical Dimensions*, Nicholas Zarimpas, ed. (Oxford: Oxford University Press, 2003).

The template method would be able to confirm that, for example, the inspected object contains a warhead of the same type that was used as a reference. But to measure the amount of fissile material, inspectors would have to know the fissile material content of the reference warhead. There is no reason to expect that inspectors would have access to this information. Even if they did, the template method would be of limited use for purposes of material accounting, since it would require a comprehensive database of all possible reference objects.

Conducting measurements on nuclear weapons or other classified objects that contain fissile materials would also require the establishment of an object management system that would provide a chain of custody for inspected objects. Research in this area suggests that while there is an array of measures that could be used to create such a system, those measures that would provide a higher degree of confidence are rather intrusive and would almost certainly impact normal operations.[23] Even though it has been established that it should be possible to reliably track weapons and components in the dismantlement queue, it is far from clear that nuclear-armed States would be ready to provide access to weapons in their operational force. Experience with the US–Russian arms control agreements suggests that this will be a major issue.

Overall, the problems associated with gaining access to nuclear weapons and the resulting complexity of warhead and material monitoring schemes are widely recognized as the most serious challenge to verified nuclear disarmament.[24]

[23] Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials* (2005), p. 73.

[24] See, for example, the discussion of challenges of verifying nuclear warheads in George Perkovich and James M. Acton, "Verifying the Transition to Zero", in *Abolishing Nuclear Weapons: A Debate* (Carnegie Endowment for International Peace, 2009). Available from http://carnegieendowment.org/files/abolishing_nuclear_weapons_debate.pdf; Nathan E. Busch and Joseph F. Pilat, "Verifying Global Disarmament", in *The Politics of Weapons Inspections: Assessing WMD Monitoring and Verification Regimes* (Stanford University Press, 2017).

Deferred verification

Outline of the arrangement

One way of dealing with the issue of lack of access to weapons and fissile materials in active military use is to design an arrangement that would not require access. This arrangement, "deferred verification", would take advantage of the fact that the amount of fissile materials in weapons is in fact very accurately known. The State that owns nuclear weapons is likely to know the amount of plutonium and HEU in each of its weapons with a very high degree of accuracy, probably down to a gram. This would apply to weapons in active arsenals as well as to those in the dismantlement queue and to weapon components that are in storage. And since these weapons and components are countable items, which are presumably properly accounted for, the total amount of fissile material contained in nuclear weapons should be known with a similarly high accuracy.

This means that lack of access to material in active use would not affect the uncertainty that appears in the material balance. If a State declares the precise amount of fissile material contained in its nuclear weapons, that declaration will have no "material unaccounted for" or inventory difference associated with it. This declaration, of course, would not be immediately verifiable, but this should not affect the effort to close the material balance.

From a practical point of view, all materials and facilities that cannot be made available for verification would constitute a distinct "closed" segment of the nuclear complex. The rest of the nuclear complex would be considered an "open" segment, which should be open to verification and inspection activities associated with closing the material balance. **Table 1** summarizes key characteristics of the open and closed segments from the point of view of the material assigned to them and corresponding verification activities. A schematic representation of the open and closed segments is shown in **Figure 1**.

Table 1. Open and closed segments of a nuclear complex

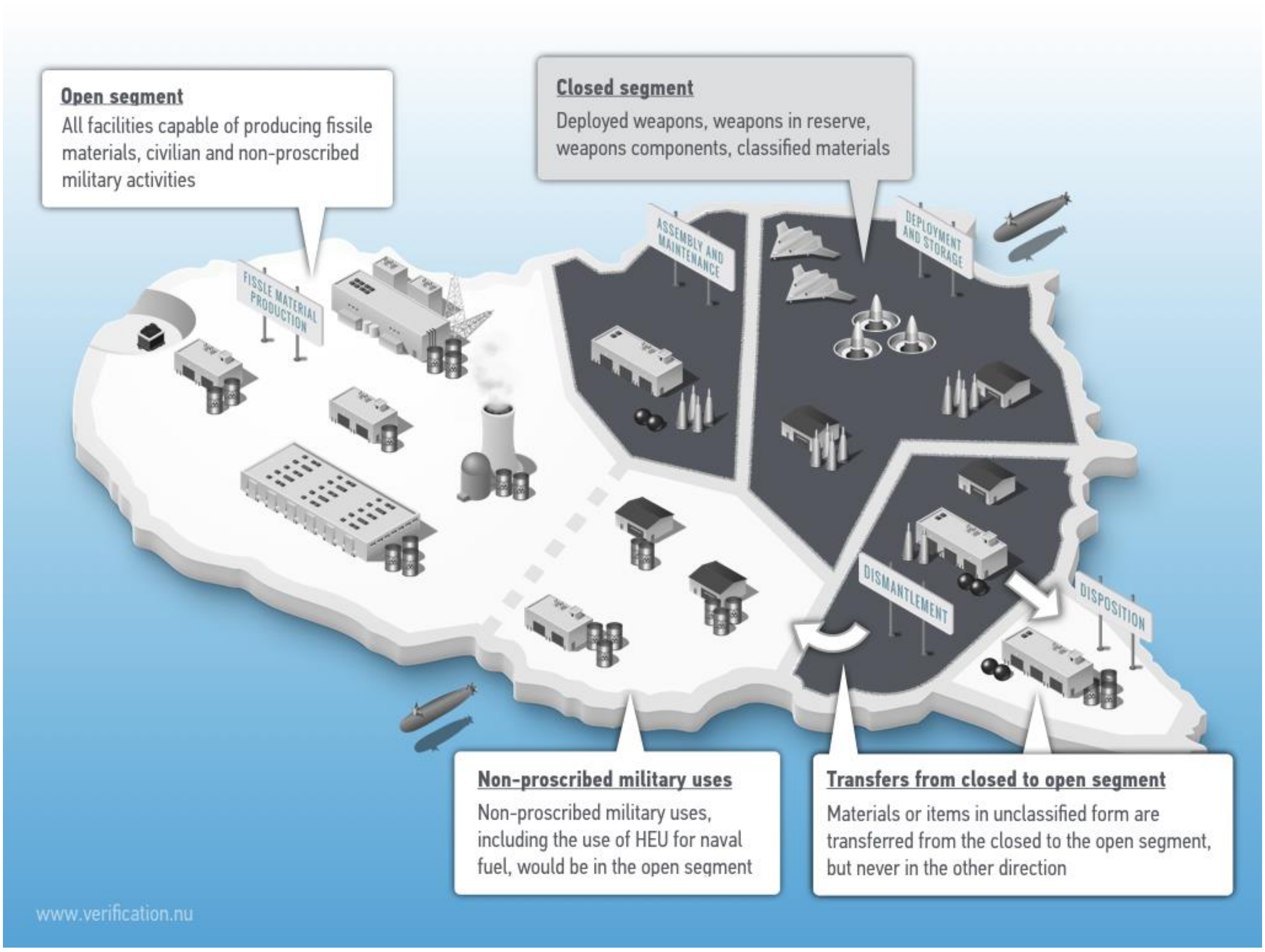
	Closed segment	Open segment
Material	Operational warheads, warheads in reserve, weapon components, classified material (including that declared excess), additional material	Civilian material, material in non-weapon military use, excess material submitted to verification, material in mixtures and waste
Declaration	Amount of material is known and declared with high accuracy	Amount of material may not be accurately known, is declared with uncertainty
Verification	No verification activity inside the segment	Verification to establish absence of undeclared material or undeclared production in the segment
Production	No production facilities	All production facilities and facilities capable of production are inside this segment
Additions	No new material can be added to the segment	All new production (including for non-weapon military purposes) is placed under verification
Removals	All removals are verified and accounted for. No irradiation in the closed segment	All material used and disposed of is verified and accounted for

The amount of material in the closed segment would be known and declared with a high degree of accuracy so this material can be properly accounted for in the material balance. From the material balance point of view, the material in the closed segment would be considered as part of the measured inventory, even though it would not be available for verification through actual measurements.

It should be noted that at the time of the declaration the closed segment does not have to have a defined physical boundary. Some facilities, such as nuclear warhead storage sites, would be known to belong to the closed segment, but as a general principle the list of these facilities does not have to be revealed. The boundary of the closed segment, of course, will be discovered in the process of gradual expansion of verification activities in the open segment.[25]

The lack of access to the closed segment does not mean that the declaration of the amount of material there would not be verified. Verification, however, would be *deferred* to the time the material is sent to disposition or elimination.

Figure 1. Schematic representation of the open and closed segments



Source: Nuclear Futures Laboratories, Princeton University, http://verification.nu/. Reproduced with permission.

[25] This is similar to the approach that was taken by the United States when it concluded an additional protocol with the IAEA. The additional protocol allows the IAEA to inspect any US facility, but the United States reserves the right to invoke the national security exclusion if a facility is not available for verification. "INFCIRC/288/Add.1. Protocol Additional to the Agreement between the United States of America and the International Atomic Energy Agency for the Application of Safeguards in the United States of America", IAEA, 9 March 2009, Article 1.b.

At this point, the material would be stripped of all sensitive attributes, so all its characteristics can be accurately measured.[26] At the end of the elimination process, the sum of all removals should correspond to the amount of material in the closed segment that was declared at the start of the process. Since at this point the closed segment would no longer contain any material, it would be open for verification to confirm the correctness of the declaration.

The key feature of the deferred verification arrangement is that it would not rely on access to nuclear weapons and materials in classified form. Importantly, it would not require an exchange of data about locations of nuclear weapons or their numbers and attributes, which are often considered an essential starting point of most baseline nuclear disarmament scenarios.[27] Neither would it require monitoring of the weapon dismantlement process and implementing elaborate information barriers and managed access measures associated with it. Indeed, this arrangement could be compatible with nuclear-armed States maintaining active nuclear arsenals for a certain period of time, although it would require a commitment to nuclear disarmament as a long-term goal.

Important elements of the arrangement could be introduced unilaterally or by a group of States. Indeed, the United States and the United Kingdom have already made a major step in that direction by providing public accounts of their fissile material holdings. At the same time, the deferred verification arrangement would be the most effective if it is implemented as part of a treaty banning the production of fissile materials for nuclear weapons. In addition to capping the amount of material that can be used in nuclear weapons, the treaty would provide a legal basis for carrying out the required verification activities.

Verification provisions of the Fissile Material Cut-off Treaty

The central objective of the Fissile Material Cut-off Treaty is to ban production of fissile materials for weapons and other explosive devices. In order to do so, the treaty will have to develop a legal framework that will translate the ban on production into concrete obligations and create a verification system that would ensure compliance with these obligations. Details of the treaty are yet to be negotiated, but if it is to serve its purpose the treaty would have to include a number of known provisions and elements. Indeed, the results of the discussion in the Group of Governmental Experts as well as the treaty drafts submitted to the Conference on Disarmament indicate that there is a general agreement on key aspects of the FMCT even though some fundamental issues, such as the treaty scope or the very definition of fissile material, are still open to discussion.[28] The provisions that are relevant to verification of existing stocks are discussed in this section.

A ban on production of fissile materials for weapons would require creating a verification system that would ensure that all facilities that are producing fissile materials, such as uranium enrichment plants or reprocessing plants, are subject to monitoring. This system would have to ensure that any fissile material produced after the FMCT enters into force is properly declared and submitted to

[26] Since all removals from the closed segment would have to be accurately accounted for, the segment cannot include any irradiation activity.

[27] For a discussion of nuclear disarmament scenarios see Sidney Drell, "Verification of Dismantlement of Nuclear Warheads and Controls on Nuclear Materials" (JASON, January 1993). Available from https://fas.org/irp/agency/dod/jason/dismantle.pdf; Zarimpas, *Transparency in Nuclear Warheads and Materials* (2003); Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials* (2005); George Perkovich and James M. Acton, *Abolishing Nuclear Weapons: A Debate* (Carnegie Endowment for International Peace, 2009).
Available from http://carnegieendowment.org/files/abolishing_nuclear_weapons_debate.pdf; Busch and Pilat, "Verifying Global Disarmament" (2017).

[28] The discussion of the elements of the FMCT follows Pavel Podvig, ed., *FM(C)T: Elements of the Emerging Consensus,* FM(C)T Meeting Series (UNIDIR, 2016). Available from http://unidir.org/files/publications/pdfs/fmct-series-final-report-meeting-1-en-667.pdf.

verification. The material will also be followed through its life cycle to rule out its use in nuclear weapons. Facilities that are capable of but not currently producing fissile materials would be subject to monitoring as well—to ensure that no production is taking place there.

Categories of facilities that are covered by specific monitoring measures would depend on the definition of fissile material that the treaty will adopt.[29] For example, if the treaty defines fissile material as unirradiated direct-use material, such as separated plutonium or highly-enriched uranium, then a uranium enrichment plant that produces HEU would be classified as a production facility, while those enrichment plants that produce only low-enriched uranium would be considered facilities capable of fissile material production. The important point here is that all facilities that have the capability to produce fissile materials would be subject to verification. For the purposes of the deferred verification arrangement, all these facilities will be placed in the open segment.

Another important component of the treaty verification system would provide assurances of the absence of undeclared production at declared facilities as well as of the absence of clandestine production. Credible assurances of this kind would most likely require implementing a range of measures that would be "similar, but not necessarily identical, to those contained in the additional protocol."[30] Specific measures would depend on other choices made in the treaty, but they would have to include a degree of accountability regarding all nuclear fuel cycle activities that take place in the open segment.

The FMCT is unlikely to prohibit production of fissile materials for non-weapon military purposes, for example for the use in fuel of military naval or research reactors. There is a general understanding, however, that these uses of fissile materials would be subject to verification, even though specific verification measures might be different from those applied to civilian activities and materials. The material reserved for the use in these military non-weapon applications could be placed in the closed segment, but the FMCT will include provisions that would allow this material to be transferred to the open segment before it is irradiated. This would ensure that all removals from the closed segment can be accurately accounted for.

It is important to emphasize that the FMCT would not have to impose specific obligations regarding elimination of fissile material stocks. These obligations would be part of the broader nuclear disarmament process. The role of the FMCT and the deferred verification arrangement would be to create a path to nuclear disarmament that does not rely on access to active nuclear weapons or fissile materials.

Baseline scenario for material elimination and disarmament

Once the FMCT is in force, it will establish a ban on production of fissile materials for weapons and institute the necessary verification arrangements. The baseline disarmament scenario considered here also assumes that the treaty will include a commitment to declare (but not necessarily eliminate) existing fissile material stocks in line with the deferred verification arrangement.

When the treaty enters into force, States parties would be required to submit declarations of their fissile material holdings, which would include information about the total amount of fissile material in each State as well as the amount of material that remains in military use and therefore would not be available for verification. The latter number would be declared with high accuracy to demonstrate that the closed segment does not contain materials that would be difficult to

[29] For a discussion of possible definitions of fissile materials see Pavel Podvig, "Fissile Material (Cut-off) Treaty: Definitions, Verification, and Scope" (UNIDIR, 2016). Available from http://unidir.org/files/publications/pdfs/fmct-definitions-verification-and-scope-en-655.pdf.

[30] A/70/81, para 46.

accurately account for, such as waste. The former number—the total amount of material—would be a result of the best effort of the reporting State to close its material balance, but it should be understood that this number may be known with a large uncertainty.

Once the declaration is made, a State would begin implementation of a cooperative verification programme that would aim to verify the correctness and completeness of the declared data and to establish the absence of undeclared materials and activities in the open segment. This programme would follow the template for closing the material balance outlined earlier, such as taking a physical inventory and analysing production and removal records, with the key difference being that all these activities will be confined to the open segment of the State.

As for the closed segment, a State would be free to use the material contained there for weapons, but it would not be allowed to add any new material to that segment. It is expected that with time States would begin removing material from the closed segment. For example, material can be transferred to the open segment for safeguarded storage, civilian or non-weapon military uses, or for disposition. The primary goal of the verification activity in the closed segment will be maintaining an accurate knowledge of the amount of material in the closed segment at each point of that process.

Figure 2. B53 nuclear bomb during dismantlement process

The deferred verification arrangement makes monitoring the dismantlement of nuclear weapons unnecessary.
Source: National Nuclear Security Administration, https://www.flickr.com/photos/nnsanews/6263759050/in/album-72157627937731182/.

In that sense, all material in the closed segment will still be verified, although the actual verification would be deferred to the moment when the material is eliminated or transferred to non-weapon uses.

The long-term goal of this process is the complete removal of all material from the closed segment (which would require the elimination of all nuclear weapons). At that point the closed segment would be open to verification, so the conclusion about the absence of undeclared materials and activities that applied to the open segment would be extended to the State as a whole.

Practical implementation of the disarmament scenario outlined above would have to address a number of issues, some of which are considered in the following sections.

Confidence in the absence of undeclared material

The key question for the viability of the deferred verification arrangement is whether a verification body would be able to draw a conclusion about the absence of undeclared materials or facilities in a State that had a substantial history of fissile material production, including the production of materials for weapons. Historical precedents suggest that the answer to this question may be positive, although with some significant qualifications.

The key precedent in this area is the case of South Africa. It produced about 990kg of HEU, about 480kg of which was in the nuclear weapons programme.[31] The weapons had been dismantled by the time South Africa joined the NPT and concluded a comprehensive safeguards agreement with the IAEA in 1991. All materials, facilities, and production records were made available to the IAEA, which concluded in 1993 that the declared amount of material was consistent with the production records. Further verification efforts by the IAEA, which included a detailed analysis of South Africa's past production programmes, allowed the Agency to reach a conclusion about the completeness of the State's declarations.[32] These activities were expanded after 2005, when the additional protocol for South Africa entered into force, and in 2010 the IAEA was able to draw a broader conclusion for the country.

A less known example of successful implementation of an analysis of the past production activities is the verification process that the IAEA conducted in Canada after it concluded an additional protocol in 2000. Since Canada separated about 17kg of plutonium in 1949–1954 and then produced about 250kg of weapon-grade plutonium in spent fuel for the United States in 1959–1964,[33] it had to provide an account of this activity. Analysis of the extensive documentation about these programmes that Canada submitted to the IAEA allowed the Agency to reach a broader conclusion about Canada in 2005.

These examples show that a conclusion about the absence of undeclared materials and facilities is possible in principle. At the same time, these cases also demonstrate that taken in isolation technical tools and examination of records may not be able to produce a definitive conclusion about

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[31] David Albright and Andrea Stricker, *Revisiting South Africa's Nuclear Weapons Program: Its History, Dismantlement, and Lessons for Today* (Institute for Science and International Security, 2016), p. 66. Available from http://isis-online.org/uploads/isis-reports/documents/RevisitingSouthAfricasNuclearWeaponsProgram.pdf.

[32] International Atomic Energy Agency, "The Denuclearization of Africa. Report by the Director General", September 9, 1993. Available from https://www.iaea.org/About/Policy/GC/GC37/GC37Documents/English/gc37-1075_en.pdf; 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?*, Henry Sokolski, ed. (The Nonproliferation Policy Education Center, 2014), pp. 89–95. Available from http://belfercenter.hks.harvard.edu/files/Verifying%20the%20Dismantlement%20-%20Heinonen%20Chapter%208.pdf.

[33] "Nuclear Weapon Programs: Canada", Institute for Science and International Security (n.d.). Available from http://isis-online.org/country-pages/canada. The records submitted by Canada included more than 300,000 pages of documents; interview with a former IAEA official on IAEA safeguard practices, 24 August 2014.

correctness and completeness of a fissile material declaration. In the case of the South African weapon programme, which was fairly small, there are a number of questions that may not have been fully resolved.[34]

The verification process, however, does not have to rely on technical tools alone. The record of transparency of the inspected State plays an essential role as well as does the degree of cooperation with the inspection activities. For example, IAEA verification activity in South Africa was described as "a dynamic process of dialogue with South African authorities that defined what assurances were further required along the way."[35] In the case of Canada, the good-faith effort on the part of the Government helped complete the analysis of the records in reasonable time.[36]

Overall, it is rarely disputed that cooperation of the inspected State and a high degree of transparency of its actions will be an essential element of the disarmament process.[37] It is also important to emphasize that the degree to which individual States would be willing to accept conclusions obtained by a verification body would depend on their assessment of the political security environment and their trust in the strength of the verification arrangements.

It is safe to assume that in today's circumstances it would be impossible to achieve the high degree of confidence regarding fissile materials stocks in nuclear-armed States that would be required for these States to consider elimination or deep reductions of their nuclear arsenals. Circumstances, however, can change and steps toward greater transparency of fissile material stocks would be an important and indeed a necessary condition for that change. The deferred verification arrangement could become an element of this process, since it does provide a way to increase transparency and build confidence, but would not require States to commit to disarmament unless they are comfortable doing so.

Even under quite generous assumptions about the degree of cooperation and access to materials and facilities, verification of declarations would take considerable time, maybe decades in the case of the larger nuclear programmes.[38] Achieving a meaningful change in the international security environment, however, would probably take even longer. These processes, of course, can and will occur in tandem.

In the end, there is every reason to believe that, given sufficient time, a competent verification agency that operates with the full cooperation of the host State will be able to establish with some confidence that the State does not have unaccounted fissile materials or facilities on its territory. It is also reasonable to assume that at some point the international community would be able to accept that conclusion as proof of the absence of undeclared materials or activities. Getting to that point is likely to take a long time, but in the end this is the only approach that could work in practice. If elimination of nuclear weapons is the goal, the international community will have to assume that this process works and can be relied on, despite its known limitations.

Closed segment

There are several categories of fissile materials and material handling facilities that would be placed in the closed segment. Most importantly, this segment would contain all material in nuclear weapons, including those that are operationally deployed, placed in reserve, or awaiting

[34] Nathan E. Busch and Joseph F. Pilat, "South African Rollback: Revisiting Monitoring and Verification Lessons after 20 Years", *Comparative Strategy* 33, no. 3 (27 May 2014): pp. 236–61. Available from https://doi.org/10.1080/01495933.2014.897132.
[35] Heinonen, "Verifying the Dismantlement of South Africa's Nuclear Weapons Program" (2014), p. 172.
[36] "IAEA safeguard practices", Interview (2014).
[37] See, for example, the discussion in Perkovich and Acton, *Abolishing Nuclear Weapons* (2009), pp. 70–71.
[38] The experience of the United States and the United Kingdom suggests that it would take a State several years to complete this process internally. However, the process would be longer if an external verification body is involved.

elimination. Warhead components, such as plutonium pits or canned subassemblies that contain HEU, would also be placed in the closed segment since they retain classified attributes, such as mass, shape, or chemical and isotopic composition of the material.

A declaration of the total amount of fissile materials assigned to weapons would, of course, be a very significant step toward transparency of nuclear arsenals. It should be expected that nuclear-armed States would be reluctant to make a declaration of this kind, citing national security or proliferation sensitivity of such information. However, the declarations made by the United States and the United Kingdom suggest that this information can be released without exposing sensitive data, such as the amount of materials in operational weapons or average fissile material content of weapons in active arsenal.

For example, the plutonium balance released by the United States in 2009, gives a number—67.7 tons—for the combined inventory of plutonium in weapons that are in the custody of the US Department of Defense, i.e. in the active arsenal, and in weapons and components stored at the Pantex plant.[39] For highly-enriched uranium, the United States reported a combined inventory of active weapons, weapons in the dismantlement queue at Pantex, weapon components stored at the Y-12 plant, and the material at various sites that are involved in the naval fuel cycle.[40] Once a report combines data in this way, it is impossible to determine the amount of material that is actually used in active nuclear weapons, whether aggregate or average, even if the number of weapons is known.[41]

The material in the closed segment does not have to be weapon-related or weapon-grade. A State should be able to add to the closed segment any material that it believes could help protect sensitive information about its weapon arsenal. The only condition is that the addition should not degrade the accuracy of the closed segment declaration.

Once a State has made a declaration of the amount of material in its closed segment, it should not have an option of increasing that amount by adding new material or by transferring it from the open segment. This would ensure that no State can increase the amount of fissile materials available for weapons, which is one of the key objectives of a ban on the production of fissile materials for weapons.[42] The downside of this requirement is that it would certainly provide an incentive to include as much material as possible in the closed segment before the amount is declared. However, this would hardly be substantively different than the current situation in which virtually all material in nuclear-armed States is unavailable for monitoring.

Another important condition is that the closed segment should not contain fissile material production facilities. This ban would also stem from one of the key requirements of the FMCT, which would be to place all facilities capable of production under verification to ensure that no material produced after the treaty enters into force can be used for weapon purposes. Verification of the absence of production facilities might require a certain degree of access to the closed segment.

[39] "The United States Plutonium Balance, 1944 - 2009" (2012), p. 9.

[40] 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, p. 38. Available from http://fissilematerials.org/library/doe01.pdf; United States, Department of Energy, "Highly Enriched Uranium Inventory: Amounts of Highly Enriched Uranium in the United States", Office of Security and Safety Performance Assurance, January 2006, p. 4. Available from http://ipfmlibrary.org/doe06f.pdf.

[41] United States has released information about its active nuclear weapon stockpile, which in September 2016 included 4,018 weapons. "Remarks by the Vice President on Nuclear Security" (Carnegie Endowment for International Peace, Washington, DC, 12 January 2017), Available from https://obamawhitehouse.archives.gov/the-press-office/2017/01/12/remarks-vice-president-nuclear-security. Retired weapons that are awaiting dismantlement are not included in that number. United States, Department of State, "Transparency in the U.S. Nuclear Weapons Stockpile", 27 April 2015. Available from https://2009-2017.state.gov/documents/organization/241377.pdf.

[42] A/70/81, para 6.

However, this can be done in a fairly non-intrusive manner, since the goal would be to ensure the absence of essential equipment, rather than the absence of materials.

Accuracy

It should be expected that the amount of fissile material in the closed segment would indeed be known with very high accuracy. Nuclear weapon components (as well as assembled weapons) is probably the most convenient form of storage from the point of view of material accounting, as these are countable items each containing a documented amount of material. The United States is known to store most of its military-origin fissile material this way; other nuclear-armed States also seem to keep their material in weapons or components (see Appendix for details).

There is also weapons-related material outside components or similar countable items. It is likely that all nuclear-armed States routinely produce new weapons to replace those that have reached the end of their service life or have been dismantled to assess reliability and safety of operationally deployed weapons. Some States may produce new weapons as well. This means that some fissile materials are tied up in the dismantlement and production process. These materials are most likely in metal form, but they may be converted to other forms as well. For example, the United States maintains the capability to remove americium from aged weapon plutonium in a chemical process.[43] Whether or not other nuclear-armed States follow this practice, it is necessary to assume that some material in the weapon maintenance and production complex can be present in the form of solutions, mixtures, or alloys. This may complicate accurate accounting of the material, but should not present an insurmountable problem, especially if special care is taken to reduce inventory differences at all stages of material processing.

Accurate removals

Maintaining accurate knowledge of the amount of material in the closed segment would require careful accounting of all removals from the segment. This means that characteristics of the material withdrawn from the closed segment would have to be accurately measured. Since some of these characteristics, such as mass and isotopic composition, could be considered sensitive, special measures would be needed to avoid revealing classified information about the material.

The problem of the classified nature of weapon-origin material, however, occurs only in those scenarios that consider withdrawal of material while it is still in classified form. This, for example, was the case in the Trilateral Initiative, which considered the possibility of placing weapon material declared excess under IAEA safeguards. Since that procedure had to protect classified attributes of the material, it had to use information barriers that were designed to hide the mass, shape, and other characteristics of the objects submitted to monitoring. Although the methods developed by the Trilateral Initiative allowed inspectors to confirm that the amount of material in an inspected container exceeded a certain agreed amount, they were unsuitable for accurately determining its mass.[44]

The scenario of withdrawal of material considered here implies that the material will be removed from the closed segment as part of a disposition process. This means that it could be submitted to measurement after it had been converted to unclassified form. This would be similar to the procedure that was agreed on in the US–Russian Plutonium Management and Disposition

[43] United States Government Accountability Office, "Nuclear Materials: Plutonium Processing in the Nuclear Weapons Complex", no. RCED-92-109FS, September 10, 1992. Available from http://www.gao.gov/products/RCED-92-109FS; Carol A. Clark, "LANL Internal Memo Addresses Ongoing Safety Improvements at TA-55 Plutonium Facility", *Los Alamos Daily Post*, 21 June 2017. Available from http://ladailypost.com/content/lanl-internal-memo-addresses-ongoing-safety-improvements-ta-55-plutonium-facility.

[44] Shea, "Weapon-Origin Fissile Material: The Trilateral Initiative" (2008).

Agreement (PMDA). This agreement explicitly specifies that the plutonium that is submitted to monitoring should not have classified properties.[45] Since it is no longer classified, the mass and isotopic composition of the plutonium would be measured directly, without an information barrier.[46] To protect some information about the weapon-grade plutonium, PMDA allows the parties to mix the disposition plutonium with so-called blend stock, which can be plutonium of a different grade. It should be noted that the United States chose not to exercise this option, probably because the disposition material already contains a variety of plutonium grades, allowing it to be its own blend stock. The approach taken by PMDA suggests that by deliberately adding some materials to the closed segment, a State should be able to protect sensitive information about removed material while accurately accounting for all removals.

The PMDA approach would be more difficult to implement in the case when material is withdrawn from the closed segment for use in non-weapon military applications, as would be the case of HEU that is used in the fuel of naval reactors. Since that material has to meet certain specifications, mixing it with some blend stock would not be an option. Also, States might be concerned about revealing the information about the amount of HEU that is used in their submarine programmes. This may also present a problem for accurate accounting of the withdrawals. This problem, however, should be considered in the context of the FMCT regime, which is an important prerequisite of the deferred verification arrangement. As previously mentioned, it is commonly accepted that the FMCT would allow States parties to produce fissile materials for non-weapon purposes, such as naval reactor fuel. However, it is also commonly accepted that this material would have to be submitted to the FMCT verification system to exclude the possibility of it being used in weapons. Specific verification procedures that would be applied in this case are still subject to discussion, but they would certainly require accurate knowledge of the mass and isotopic composition of the new material.[47] From this point of view, the transfer of HEU from the closed segment for use in the military naval fuel cycle would be no different from new production, so it could use similar monitoring procedures.

The isotopic composition of weapon-origin material may not, in fact, be a very sensitive characteristic. In the past, the Russian Federation and the United States directly or indirectly revealed that information to each other or to the IAEA. For example, in the monitoring arrangements of the US–Russian HEU-LEU deal, US inspectors had an opportunity to use gamma-ray equipment to confirm the weapon origin of the highly-enriched uranium that was then converted to LEU.[48] Another US–Russian agreement, on decommissioning of plutonium production reactors, allows inspectors from the United States to conduct measurements of the isotopic content (as well as mass) of weapon-grade plutonium produced after the agreement entered into force.[49] The United States on its part, placed approximately 10 tons of its surplus "high grade" HEU under IAEA safeguards in 1994.[50] The willingness of the United States to forgo the option of using blend

[45] "Agreement between the Government of the United States of America and the Government of the Russian Federation Concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation (as Amended by 2010 Protocol)", 13 April 2010, Article I. Available from http://ipfmlibrary.org/PMDA2010.pdf.

[46] "Plutonium Management and Disposition Agreement" (2010), Annex on Monitoring and Inspections, Section II.15.

[47] See, for example, Pavel Podvig, "Fissile Material (Cut-off) Treaty: Elements of the Emerging Consensus" (UNIDIR, 2016). Available from http://www.unidir.org/files/publications/pdfs/fissile-material-cut-off-treaty-elements-of-the-emerging-consensus-en-650.pdf.

[48] Oleg Bukharin, "Understanding Russia's Uranium Enrichment Complex", *Science & Global Security* 12, no. 3 (2004): p. 203.

[49] The United States and Russia agreed to develop an information barrier that would protect that information, but it is unclear if that in fact has been done. "Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning Cooperation Regarding Plutonium Production Reactors", September 23, 1997, Subsidiary Arrangement B to Annex III. Available from http://ipfmlibrary.org/gov97.pdf.

[50] "U.S. Highly Enriched Uranium (HEU) Disposition—Overview", 26 January 2005, p. 7. This material was later withdrawn from safeguards and transferred to the naval reserve.

stock in the PMDA arrangements also suggests that the isotopic composition of weapon-origin plutonium can be effectively protected during a normal disposition process.

Open segment

The open segment would include most of the nuclear complex. Most importantly, it should include all fissile material production facilities as well as sites that are involved in the civilian nuclear fuel cycle. The open segment should also include closed down and decommissioned production facilities as well as facilities that handle fissile material containing waste and sites that contain disposed of or abandoned material.

As discussed earlier, the quantity of the material in the open segment is likely to be known with limited accuracy; it will be included in the initial declaration with the understanding that this number will be updated and corrected in the course of verification activities. For example, in its first statement about the national HEU inventory, the United States declared having produced 994 tons of HEU. This number was later corrected to 1,045 tons, with the discrepancy explained by the fact that the initial announcement relied on management reports rather than results of an analysis of material balance records.[51] Since these kinds of corrections in the open segment are to be expected, States should not be penalized for updating this part of their declarations.

Figure 3. Shutdown of the ADE-2 plutonium reactor at Zheleznogorsk in April 2010

The reactor was the last operational plutonium production reactor in the Russian Federation. Under the deferred verification arrangement, the production records of all production facilities would be subject to verification.
Source: National Nuclear Security Administration, https://www.flickr.com/photos/nnsanews/4685405644/in/album-72157624113651363/.

[51] Peter Dessaules, "The U.S. Plutonium and HEU Declarations" (2009).

The long-term goal of verification activities in the open segment would be to certify that the segment does not contain undeclared fissile materials or production facilities. In practice, the verification arrangements are likely to be introduced gradually as the organization entrusted with verification, working together with States parties, develops a comprehensive cooperative verification programme for each State.

The first verification measures would be focused on monitoring facilities capable of producing fissile materials to make sure that all material produced after the treaty enters into force is placed under verification and cannot be transferred to the closed segment, where it can be used in nuclear weapons. A general outline of this arrangement has been discussed in the context of the FMCT and there is a common agreement on its key elements.[52] There is a broad agreement that these materials should remain in the open segment, even if specific verification measures applied to this material would be less intrusive than those applied to non-military material.

Existing fissile materials that were not included in the closed segment, such as civilian materials or weapon-related materials in unclassified forms, would have to be placed under verification to prevent diversion of these materials to the closed segment. This process will include taking initial physical inventory of the materials that would later be used to close the material balance in each material balance area identified by the verification body and the inspected State.

As discussed earlier, closing the material balance will be the most challenging part of the verification activity. In order to close the balance, inspectors would have to examine historical records or material production, transfer, and disposal going back several decades and, when necessary, perform additional measurements. In a State with a substantial history of production of fissile materials for weapons this process would take considerable time and may never be fully completed.

Opening of the historical records may require a gradual approach as some transactions could potentially reveal classified details about weapon-related activities. It should be possible, however, to aggregate data in a way that protects these details, at least at the early stages of the implementation of the verification programme.

To provide higher confidence in the correctness of a declaration, the analysis of production records would have to be complemented by a programme of measurements at the production facilities that would allow checking the records for consistency and increase confidence in the correctness of the closed segment declaration. This approach, developed in the early 1990s, is known as nuclear archaeology.[53] It was demonstrated that it can be applied successfully to verification of plutonium production in graphite moderated reactors; research has been done to demonstrate the applicability of this approach to other production facilities, such as heavy water reactors and gaseous diffusion enrichment plants.[54] Even though nuclear archaeology is unlikely to provide a

[52] A/70/81; International Panel on Fissile Materials, "Global Fissile Material Report 2008: Scope and Verification of a Fissile Material (Cutoff) Treaty", October 2008. Available from http://ipfmlibrary.org/gfmr08.pdf; "Draft Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices Submitted by France", 9 April 2015. Available from http://www.delegfrance-cd-geneve.org/IMG/pdf/2015-04-09_projet_traite_fmct_version_finale_eng.pdf; Pavel Podvig, "Fissile Material (Cut-off) Treaty: Elements of the Emerging Consensus" (2016).

[53] Alexander Glaser and Malte Göttsche, "Fissile Material Stockpile Declarations and Cooperative Nuclear Archaeology", in *Verifiable Declarations of Fissile Material Stocks: Challenges and Solutions,* FM(C)T Meeting Series (UNIDIR, 2017). Available from http://unidir.org/files/publications/pdfs/fm-c-t-meeting-series-verifiable-declarations-of-fissile-material-stocks-challenges-and-solutions-en-671.pdf.

[54] Steve Fetter, "Nuclear Archaeology: Verifying Declarations of Fissile-Material Production", *Science & Global Security* 3, no. 3–4 (1993): pp. 237–59; Bruce D. Reid and others, "Trawsfynydd Plutonium Estimate", Pacific Northwest National Laboratory (PNNL), Richland, WA (US), September 1997. Available from https://doi.org/10.2172/992380; Alex Gasner and Alexander Glaser, "Nuclear Archaeology for Heavy-Water-Moderated Plutonium Production Reactors", *Science & Global Security* 19, no. 3 (2011): pp. 223–33; Sébastien Philippe and Alexander Glaser, "Nuclear Archaeology for Gaseous Diffusion Enrichment Plants", *Science & Global Security* 22, no. 1 (2014): pp. 27–49.

definitive confirmation of the correctness of production records, it is an extremely valuable tool that would help estimate their consistency and support the broader verification effort.

In assessing the limits of various methods in confirming the historical records, it should be understood that verifying removals would be difficult and probably impossible. For example, even though the United States keeps a record of the amount of plutonium disposed in the Waste Isolation Pilot Plant (WIPP) with an accuracy of one gram, it is impossible to verify the accuracy of this record once containers with plutonium are buried underground.[55] This would also be the case with plutonium and HEU consumed in nuclear tests, as the record of removal would not be verifiable.

In the end, the degree of confidence in the analysis of past production or removals, will depend on many factors, including the degree of cooperation of the inspected State. It is also important to note that the verification activities would have to include measures that would allow inspectors to search the open sector for undeclared materials and facilities. Specific verification procedures would be subject to negotiations, but they should be largely similar to those conducted by the IAEA under additional protocols.[56] As discussed earlier, taken in combination, all these measures should allow the verification body to confirm the absence of undeclared material or production facilities in the open segment.

Potential challenges

Since the accuracy of a declaration of the amount of material in the closed segment would not be verified at the time the declaration is made, it opens a possibility that a State can submit an incorrect declaration. While overstating the quantity of material in the closed segment does not seem to offer a State any benefits, the possibility of understating the amount of material available for weapons should be taken seriously as it could undermine trust in the arrangement.

The first safeguard against such misreporting would be provided by the process of closing the material balance in the open sector. Even though, as discussed earlier, there are limits on the accuracy that can be achieved in the process, if given sufficient time inspectors should be able to discover any significant discrepancies between the amount of produced material and the amount listed in the declaration.

The verification process should also take into account the possibility of deliberate concealment efforts on the part of the inspected State, such as falsification of production or removal records, or taking advantage of the gaps in the existing records. It is difficult to estimate how successful a coordinated concealment attempt might be, since we only know of those efforts that have failed.[57] The known examples, however, suggest that the threshold for success is fairly high. Even though the verification body would never be certain that it can uncover a deliberate deception, a State that undertakes an attempt to deceive would also never be certain that this attempt can withstand a sustained scrutiny of inspectors over a long period of time.

An assessment of the fissile material production programmes in the nuclear-armed States that has been done so far demonstrates that even when based on a rather limited set of publicly released data it can provide a good understanding of the key elements of fissile material production programmes.[58] It has been demonstrated that if a State releases more information about its

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[55] "Disposition of Plutonium in Waste Isolation Pilot Plant (WIPP)", *IPFM Blog* (blog), September 24, 2016. Available from http://fissilematerials.org/blog/2016/09/disposition_of_plutonium_.html.

[56] A/70/81, para 47.

[57] For an analysis of the South Africa's efforts to conceal the weapon nature of its programme, see Frank V. Pabian, "The South African Denuclearization Exemplar: Insights for Nonproliferation Monitoring and Verification", *The Nonproliferation Review* 22, no. 1 (2 January 2015): pp. 27–52. Available from https://doi.org/10.1080/10736700.2015.1071969.

[58] "Global Fissile Material Report 2010" (2010).

programme, confidence in this assessment can be significantly improved.[59] Since the verification programme would have access to a much larger data set, it should be able at the very least to identify the areas of uncertainty and to request clarification. If verification is done in a cooperative manner, as it would have to be, it should be possible to resolve most of the issues.

Should a significant discrepancy be discovered in the material balance process, the State would be asked to provide an explanation and update its declaration accordingly. As is the case with many arms control and disarmament agreements, it is difficult to design an effective enforcement mechanism that would force the violator to comply, but all States would probably reassess their disarmament policies until the matter is resolved in a satisfactory manner. It is also possible to imagine an amnesty mechanism that would allow a State to come clean about deliberately inaccurate statements that it may have made in the past (for example, by a previous government). It is reasonable to expect that this mechanism would require a full explanation of the change.

One can also note that understating the amount of fissile material in the closed segment might not offer any particular benefits to a State. Once the declared material is eliminated, the State would have to eliminate its closed segment as well by opening it up to verification, so any extra material would inevitably be discovered.

[59] Frank N. von Hippel, "Consistency Tests for the Declarations of U.S. Fissile-Material Production", *Science & Global Security* 19, no. 1 (2011): pp. 1–14.

Practical steps toward implementation

Implementation of the deferred verification arrangement would most likely depend on an agreement in the FMCT that would include verified declarations of existing fissile material stocks. Even though the prospects for concluding the treaty are highly uncertain, there are a number of steps that could demonstrate feasibility of the verification arrangements outlined here. These steps could build on the transparency and disarmament initiatives undertaken by the United States, the Russian Federation, and the United Kingdom.

Accurate declarations of fissile material stocks

Publication of plutonium and HEU material balances by the United States and the United Kingdom was a very important step toward greater transparency of fissile material stocks. The accuracy of the information provided in these public accounts was adequate for the purpose of the reports. However, it would be important to explore an option of providing more accurate information about materials that are available for weapons.

The United States could lead the way by providing more accurate numbers for the amounts of plutonium and HEU in its weapon programme. This information is already included in the public accounts of the inventories. The 2009 plutonium balance provides a consolidated number of 67.7 tons of plutonium in the custody of the Department of Defense (weapons) and at the Pantex plant (retired weapons and weapon components). This number could be given with much higher accuracy without exposing any additional information about weapons or weapon components. Similarly, the United States could update the accuracy of the data on the amount of HEU associated with its military programmes. In the 2006 HEU account, the amount of HEU in the custody of the Department of Defense (weapons and naval fuel), at the Pantex plant (retired weapons), and Y-12 plant (weapon components) was reported to be 621.2 tons (uranium-235 content of the HEU was 546.6 tons).[60]

The United Kingdom could consider disclosing more accurate information about its stock of plutonium available for weapons. In 1998, the Government of the United Kingdom declared a defence stock of 7.6 tons of plutonium.[61] Of this amount, 0.3 tons of weapon-grade plutonium and 4.1 tons of non-weapon-grade plutonium were identified as excess for military purposes and placed under Euratom safeguards, leaving 3.2 tons of plutonium available for the weapon programme.[62] It should be possible for the United Kingdom to update that declaration and provide data on the amount of defence plutonium with higher accuracy.[63]

Should the United States and the United Kingdom provide accurate data about their defence stocks as described above, their reports would be a good approximation for the closed segment declarations that would be provided under the deferred verification arrangement. In the case of the UK plutonium, these declarations would probably be identical unless the audited stock of 3.2 tons includes plutonium in waste that would be excluded from the closed segment. For the United States,

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[60] "Highly Enriched Uranium Inventory" (2006), p. 3.

[61] United Kingdom, Ministry of Defence, "Strategic Defence Review", July 1998, para 72. Available from http://fissilematerials.org/library/mod98.pdf.

[62] United Kingdom, Ministry of Defence "The United Kingdom's Defence Nuclear Weapons Programme", The National Archives, Ministry of Defence, September 3, 2003. Available from http://webarchive.nationalarchives.gov.uk/20060130214247/http:/www.mod.uk/publications/nuclear_weapons/accounting.htm.

[63] The United Kingdom also declared its HEU stock, but that declaration did not provide the uranium-235 content of the material, apparently because it was considered sensitive. Unless the United Kingdom would be willing to disclose data on the enrichment of its HEU, this declaration would be of limited use for verification purposes. "Historical Accounting for UK Defence Highly Enriched Uranium" (2006).

the difference would be larger as the closed segment would probably include nuclear weapon laboratories and some other sites.

The Russian Federation can also make a contribution to increased transparency of nuclear holdings, even though it has never released information about its fissile material stocks. One option would be to provide an accurate account of the highly-enriched uranium that was eliminated by the US–Russian HEU-LEU deal. As part of this project, which was concluded in 2013, the Russian Federation eliminated about 500 tons of weapon-origin HEU by down-blending it to produce low-enriched uranium that was later used to manufacture fuel for US power reactors. The programme included a number of transparency measures at all stages of that process starting from the process of oxidation of metal HEU.[64] This means that it should be possible to release the accurate amounts of HEU and uranium-235 that entered the down-blending process. This number would not release any sensitive information or, for that matter, add much value to the public knowledge about the programme. It would, however, provide an important data point in our understanding of the process of removal of weapon-origin fissile material from weapon-related activities.

Figure 4. The Waste Isolation Pilot Plant (WIPP)

The WIPP is a geological repository that is licensed to permanently dispose of transuranic radioactive waste that is left from the research and production of nuclear weapons. Under the deferred verification arrangement, the emplacement of material within WIPP would be subject to verification. *Source: "Waste Isolation Pilot Plant", US Department of Energy,* http://www.wipp.energy.gov/WIPPCommunityRelations/photos.html.

[64] United States, Department of Energy, "Highly Enriched Uranium Transparency Program", NNSA, 13 November 2013. Available from https://nnsa.energy.gov/mediaroom/factsheets/heutransparency; Bukharin, "Understanding Russia's Uranium Enrichment Complex" (2004), p. 213.

Non-nuclear-weapon States could also make a contribution to this process by releasing information about their fissile material stocks that they currently share with the IAEA. One example of this is the annual reports on the status of plutonium management published by Japan. These documents provide information about the amounts of plutonium, the facilities where the material is located, and the isotopic composition of the material with a considerably higher accuracy than that included in the INFCIRC/549 reports that Japan submits to the IAEA.[65]

Non-nuclear-weapon States could also publish data on their past production activities. For example, it would be extremely valuable to have more information about the plutonium separation programme in Canada and the subsequent effort to dispose of the material that was produced.

None of the measures outlined in this section would involve additional verification or accounting activities, since all that information is already available in the internal records. They would, however, demonstrate commitment to accountability in elimination of weapon-related fissile materials and will help better understand the challenges that could be encountered in the process.

Material disposition in the United States

The United States is currently carrying out a material disposition programme that eliminates its excess plutonium and HEU (see Appendix for details). These programmes present an opportunity to explore some important elements of the deferred verification arrangement.

Within the plutonium disposition programme, the United States is prepared to begin elimination of up to 6 tons of non-pit surplus plutonium stored at the Savannah River Site.[66] The material is stored in containers in the K-Area Material Storage (KAMS) facility awaiting disposition. During this process, known as “dilute and dispose”, plutonium will be blended with a special adulterating substance and placed in containers that will be shipped to WIPP, where they will be placed underground. In the normal material accounting practice, the amount of plutonium that is emplaced underground at WIPP is recorded very accurately with a breakdown by plutonium isotopes.[67]

In 2016, the United States announced that it will invite the IAEA to monitor the dilution and packaging of this plutonium at the Savannah River Site.[68] This opportunity should be used to develop a procedure that would allow international inspectors to accurately account for the material that is withdrawn from KAMS, which would effectively play a role in the closed segment. Since the 6 tons of plutonium in question is a non-pit material, the process would not have to deal with the potential sensitivity of the disposed plutonium’s isotopic composition. At the same time, the US offer to submit the dilute and dispose process to the IAEA monitoring seems to extend to the 34 tons of PMDA plutonium, which is a weapon-origin material. Withdrawal of this plutonium could be accurately accounted for as well, with the procedures developed for the initial 6 tons appropriately modified.

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[65] Government of Japan, “The Status Report of Plutonium Management in Japan - 2016”, Office of Atomic Energy Policy, 1 August 2017. Available from http://www.aec.go.jp/jicst/NC/about/kettei/170801_e.pdf.

[66] This material is not included in the 34 tons of surplus plutonium covered by the US–Russian PMDA agreement. Some of the PMDA material (7.1 tons of pit plutonium) is also stored at the Savannah River Site. United States, Department of Energy, “Final Surplus Plutonium Disposition Supplemental Environmental Impact Statement. Summary”, April 2015, p. vii. Available from http://fissilematerials.org/library/doe15.pdf; Tom Clements, “United States to Dispose of 6 MT of Weapon-Grade Plutonium in the Waste Isolation Pilot Plant”, *IPFM Blog* (blog), 6 January 2016. Available from http://fissilematerials.org/blog/2016/01/united_states_to_dispose_.html.

[67] The records show that as of 2014, the United States placed a total of 5,713,974 grams of plutonium in WIPP, of which 5,307,349 grams was plutonium-239. “Disposition of Plutonium in Waste Isolation Pilot Plant (WIPP)” (2016).

[68] “United States Asks IAEA to Monitor Dilute and Dispose Steps for 6 Tons of Plutonium”, *IPFM Blog* (blog), 5 December 2016. Available from http://fissilematerials.org/blog/2016/12/united_states_commits_to_.html.

Another transparency measure that the United States could introduce in its fissile material disposition programme is a release of accurate data for the amount of HEU that enters the down-blending process. As of September 2016, the United States completed down-blending of 154.3 tons of HEU. The goal of the current programme is to down-blend 162 tons of the material by the end of 2019.[69] As is the case with the US–Russian HEU-LEU programme, this amount could be published with higher accuracy without revealing any additional information about the material being disposed. In a more ambitious step, the United States could provide a breakdown of this number by the source of material. Most of the HEU for down-blending comes from warhead dismantlement, but some material also comes from fresh and spent HEU fuel of research reactors.[70] A breakdown by source could help develop procedures for handling potentially sensitive information about the isotopic composition of weapon-origin HEU.

Material disposition in the Russian Federation

The structure of the Russian Federation's plutonium disposition programme makes it a good testing ground for key elements of the deferred verification arrangement. As part of the PMDA arrangement with the United States, the Russian Federation designated 34 tons of weapon-grade plutonium as excess to weapon needs and made a commitment to dispose of this material (see Appendix for details). A large fraction of this material, about 25 tons of weapon-origin plutonium in the form of metal, is stored at the Fissile Material Storage Facility (FMSF) located at the Mayak Plant. This facility, built with technical and financial assistance from the United States, does not appear to contain any other material and the Russian Federation does not seem to have plans to add any new material there. This means that the storage facility at Mayak could be a good pilot model of the closed segment.

The plutonium disposition method chosen by the Russian Federation in the PMDA involves using plutonium to manufacture mixed oxide (MOX) fuel for fast-neutron BN-600 and BN-800 reactors. The agreement specifies that the Russian Federation can use up to about four tons of blend stock that will be mixed with the disposition plutonium before it can be inspected at the disposition facility.[71]

Figure 5. A mock-up of a container that is used to store weapon-origin plutonium at the Mayak Plant Fissile Material Storage Facility

The amount of material in each container and therefore the total amount of material in the facility is known with high accuracy, making the Mayak Plant Fissile Material Storage Facility an ideal location for a deferred verification pilot project. *Source: "Выставка '70 лет атомной отрасли' [Exhibition '70 years of the atomic industry']", https://fotki.yandex.ru/users/pfc-joker/album/490878/. Reproduced with permission.*

[69] United States, Department of Energy, "Department of Energy FY 2018 Congressional Budget Request", May 2017, p. 502. Available from https://energy.gov/sites/prod/files/2017/05/f34/FY2018BudgetVolume1_0.pdf.

[70] "Department of Energy FY 2018 Congressional Budget Request" (2017), p. 502; "U.S. Reprocessing Plant at the Savannah River Site Resumed Operations", *IPFM Blog* (blog), 26 August 2016. Available from http://fissilematerials.org/blog/2016/08/us_reprocessing_plant_at_.html.

[71] "Plutonium Management and Disposition Agreement" (2010), Annex on Monitoring and Inspections, II.11.

To implement a pilot closed segment arrangement at the Mayak facility, the Russian Federation can declare the amount of plutonium stored in FMSF with high accuracy. If necessary, some blend stock plutonium can be moved to the facility, so it will be included in the declaration as well. This would ensure that the plutonium that enters the fuel manufacturing plant does not have any classified attributes and therefore can be measured and accounted for. These measurements would provide accurate knowledge of the amount of plutonium stored in FMSF throughout the disposition process. When all the plutonium declared in the beginning is disposed, the Russian Federation should be able to demonstrate that the Mayak storage facility is empty.

This pilot project would not require significant changes in the existing plutonium disposition plan. The PMDA would provide a natural framework for the project as it called for international monitoring of the disposition process. However, since the Russian Federation suspended PMDA implementation in 2016, this path no longer seems viable. At the same time, as the Russian Federation confirmed that the PMDA plutonium will not be used for weapons, it should have an interest in demonstrating its commitment to that obligation.[72] To do so, the Russian Federation could follow the example set by the United States and invite the IAEA to monitor the disposition process. Or it could implement the project unilaterally by providing an account of the amount of plutonium stored in FMSF as well as that entering the fuel fabrication process.

[72] "Russia Suspends Implementation of Plutonium Disposition Agreement", *IPFM Blog* (blog), 3 October 2016. Available from http://fissilematerials.org/blog/2016/10/russia_suspends_implement.html; Pavel Podvig, "Can the US–Russia Plutonium Disposition Agreement Be Saved?", *Bulletin of the Atomic Scientists*, 28 April 2016. Available from https://thebulletin.org/can-us-russia-plutonium-disposition-agreement-be-saved9389.

Conclusion

Verification is definitely one of the hardest aspects of nuclear disarmament. The progress toward reduction of nuclear arsenals and elimination of stocks of weapon-usable materials will be impossible unless it is supported by robust verification arrangements. The difficulty of verifying nuclear zero is one of the stronger arguments against complete nuclear disarmament. There are, of course, other arguments as well and it would be wrong to expect that a technical solution of the verification challenge would immediately open the way to elimination of nuclear weapons. But even though verification is hardly a sufficient element of nuclear disarmament process, it is certainly a necessary one.

The deferred verification arrangement described in this report could become a useful tool in building a comprehensive verification system that would ensure verified elimination of fissile material stocks. A distinct advantage of this arrangement is that it does not require access to nuclear warheads, the warhead dismantlement process, or fissile materials in classified forms. This greatly simplifies verification procedures and should make them more politically acceptable as well as easier to introduce and implement.

The lack of access to weapons and classified components and materials means that nuclear-armed States would retain their arsenals and weapon-usable fissile materials throughout the disarmament process. Although this can be considered a downside of the deferred verification arrangement, it is probably an advantage as it would allow nuclear-armed States to be confident that the disarmament steps they undertake do not negatively affect their security. At the same time, verification activities that are an integral part of the deferred verification would help create conditions for deeper nuclear disarmament.

From a practical point of view, deferred verification could be an integral element of the Fissile Material Cut-off Treaty that would ban production of fissile materials for weapons. The treaty will cap the amount of materials available for weapons and will provide the legal and institutional framework for verification activities that would be required for implementation of the deferred verification arrangement. It should be emphasized that FMCT would not have to include specific obligations regarding elimination of the existing stocks. Rather, it would provide a mechanism for verified declarations of fissile material holdings, which would then serve as a baseline in future reduction of the amount of weapon-usable fissile materials.

The deferred verification arrangement will, of course, require a certain degree of openness on the part of nuclear-armed States. Most of its verification measures—monitoring of fissile material production and safeguarding materials in civilian and non-weapon military use—would be a part of the FMCT regime. In addition to these, deferred verification would require a declaration of the total amount of fissile materials as well as the amount of material available for weapon. Also, closing the material balance will require access to historical production and removal records as well as to some additional facilities. Nuclear-armed States may consider some of this information sensitive and are likely to be reluctant to open it in full, but it should be possible to introduce transparency gradually. While this problem should not be underestimated, it is not as serious as that of obtaining access to nuclear warheads or classified forms of fissile materials.

Finally, even though it would be essential to have a robust legal framework in the form of an FMCT, some elements of the deferred verification arrangement can be implemented unilaterally or on a bilateral basis as part of the fissile material disposition projects that are currently underway. These pilot projects could help include verified declarations of stocks in the FMCT and develop verification procedures that would support verified elimination of weapon-usable fissile materials.

Appendix
Key facilities that handle nuclear weapons and weapon materials

United States

Facilities in the United States that handle nuclear weapons and weapons-related fissile materials. Operational-level bases that host nuclear weapons are not depicted.

Total amount of material and production facilities

According to the 30 September 2009 US plutonium balance report, the total US plutonium stock at that time was 95.4 tons.[73] Analysis of this report and the US INFCIRC/549 submissions indicates that by the end of 2016 the total amount of plutonium was 95.6 tons. This takes into account 0.1 tons disposed of in WIPP after 2009, a 0.1 tons adjustment of the loss to decay, and an addition of 0.4 tons of research reactor plutonium transferred from abroad. The 95.6 tons, however, includes 7.8 tons of irradiated plutonium.[74]

This suggests that the amount of separated unirradiated US plutonium is 87.8 tons. Most of that material, 67.7 tons, is in weapons and weapon components that are either in the custody of the Department of Defense or stored at the Pantex Plant.

Even though a significant fraction of US plutonium is in weapon components, not all plutonium can be used for weapons. The United States declared a total of 61.5 tons of plutonium excess for its military needs. Of this amount, 49 tons is separated unirradiated plutonium. An additional 0.4 tons is plutonium that has been declared as received from foreign countries and will not be used for weapons.[75] Almost half of the excess material, 23.4 tons, is stored in weapons and weapon

[73] "The United States Plutonium Balance, 1944 – 2009" (2012), p. 9.
[74] "INFCIRC/549/Add.6/20. Communication Received from the United States of America Concerning Its Policies Regarding the Management of Plutonium", 12 October 2017, p. 20. Available from https://www.iaea.org/sites/default/files/publications/documents/infcircs/1998/infcirc549a6-20.pdf. Some of this material is in used fuel of Zero-Power Physics Reactor and Fast Flux Test Facility, which may be only slightly irradiated.
[75] "INFCIRC/549/Add.6/20" (2017).

components at the Pantex Plant.[76] This material, together with 10.6 tons of other weapon-origin plutonium (in metal or oxide), constitute 34 tons of plutonium that the United States committed to eliminate under the US–Russian Plutonium Management and Disposition Agreement (PMDA). In addition, the excess stock includes 7.1 tons of non-PMDA pit plutonium currently stored at the Savannah River Site.[77] In total, the amount of weapon-origin excess plutonium that may have sensitive attributes is 41.1 tons. This material is located at several sites across the US nuclear complex.[78]

The remaining excess material includes 5.1 tons of non-pit plutonium metal, 4 tons of fuel from the Zero-Power Physics Reactor, irradiated plutonium, scraps and residues. [79] This material, although technically in the custody of the Department of Energy, does not seem to have sensitive attributes and can be treated accordingly. Indeed, the United States has made a commitment to allow the IAEA to monitor disposition of up to 6 tons of non-PMDA non-pit plutonium stored at the Savannah River Site.[80] Two tons of plutonium are already under IAEA safeguards there.[81]

In 2016, the United States declared that as of September 30, 2013 the total US HEU inventory was 585.5 tons. Of this amount, 499.4 tons was used or reserved for use in different military and civilian programmes. At the time, 44.6 tons of HEU was in spent reactor fuel and 41.6 tons was available for down-blending.[82] By the end of September 2016, the United States down-blended additional 10.5 tons of HEU. At the same time, the amount of HEU designated for down-blending was reduced by 24 tons.[83]

This suggests that at the end of 2016, the total US inventory of unirradiated HEU was 540.9 tons, of which about 17.6 tons was designated for down-blending and 523.3 tons was available for weapons and reserved for other applications, including naval reactors and civilian applications.

Some of the material in the current stock of 540.9 tons is allocated to specific applications. For example, 20 tons of HEU is designated for use in HEU research reactor fuel, approximately 162 tons of HEU constitutes a naval fuel reserve.[84] Some HEU is reserved for transfer to the United Kingdom under a bilateral Mutual Defense Agreement, most likely for use in naval reactor fuel.[85] Most of the material covered by these obligations appears to be in weapons and weapon components. In the 2004 material balance, the Department of Energy showed that 90% of all HEU was at the Y-12 Plant, Pantex Plant, and in the custody of the Department of Defense.[86] It is reasonable to assume

[76] "The United States Plutonium Balance, 1944 - 2009" (2012), p. 14.

[77] "Final Surplus Plutonium Disposition Supplemental Environmental Impact Statement. Summary" (2015), S-9.

[78] The sites are the Pantex Plant, the Savannah River Site, the Los Alamos National Laboratory, and the Hanford Site. "Plutonium Management and Disposition Agreement" (2010), Annex on Quantities, Forms, Locations, and Methods of Disposition, Section III-Locations.

[79] "Final Surplus Plutonium Disposition Supplemental Environmental Impact Statement. Summary" (2015), S-9.

[80] "United States Asks IAEA to Monitor Dilute and Dispose Steps for 6 Tons of Plutonium" (2016).

[81] "Global Fissile Material Report 2007: Developing the Technical Basis for Policy Initiatives to Secure and Irreversibly Reduce Stocks of Nuclear Weapons and Fissile Materials" (International Panel on Fissile Materials, 2007), p. 72. Available from http://ipfmlibrary.org/gfmr07.pdf.

[82] United States, White House, "Transparency in the U.S. Highly Enriched Uranium Inventory", 31 March 2016. Available from https://www.whitehouse.gov/the-press-office/2016/03/31/fact-sheet-transparency-us-highly-enriched-uranium-inventory.

[83] United States, Department of Energy, "Department of Energy FY 2015 Congressional Budget Request", March 2014, p. 539. Available from http://www.energy.gov/sites/prod/files/2014/03/f12/Volume_1_NNSA.pdf; "Department of Energy FY 2018 Congressional Budget Request" (2017), p. 502.

[84] This includes and 10 tons of HEU from the 1994 excess declaration and 152 tons of material transferred to naval reserve in 2005. "U.S. Highly Enriched Uranium (HEU) Disposition—Overview" (2005); United States, Department of Energy, "Tritium and Enriched Uranium Management Plan Through 2060. Report to Congress", October 2015, p. 6. Available from fissilematerials.org/library/doe15b.pdf.

[85] "Tritium and Enriched Uranium Management Plan" (2015), p. 27; "Ongoing Transfers of Weapon Materials between the United States and the United Kingdom", *IPFM Blog* (blog), 1 March 2016. Available from fissilematerials.org/blog/2016/03/ongoing_transfers_of_weap.html.

[86] Of the total reported stock of 686.6 tons of HEU, 621.2 tons was at these three locations. "Highly Enriched Uranium Inventory" (2016), p. 3.

that as much as 530 tons of the current stock of 540.9 tons of unirradiated HEU is at these three locations.[87]

The United States had produced its weapon materials at four dedicated sites. Almost all plutonium was produced at the reactors at the Hanford Site in Washington and at the Savannah River Site in South Carolina. All production reactors were shut down by the late 1980s.[88] Plutonium was separated at several reprocessing facilities located at these sites. Only one of these facilities, H-Canyon at the Savannah River Site, is still in operation, reprocessing legacy and research reactor fuel.[89]

The two key uranium enrichment plants, in Oak Ridge, Tennessee and Portsmouth, Ohio, produced most of the US HEU. All production of HEU ended in 1992.[90] The gaseous diffusion plants in Oak Ridge and Portsmouth were eventually shut down. Today, the United States does not have an operational facility that can produce HEU.[91]

Deployed and non-deployed weapons

According to an official declaration, the United States had 4,018 nuclear warheads in its arsenal in September 2016.[92] This number includes active warheads, which have their limited life components (such as tritium bottles) installed as well as inactive warheads that are stored without limited life components.[93] The number of operationally deployed weapons is smaller and estimated to be about 1,590 strategic warheads and 150 non-strategic warheads in Europe.[94] The roughly 2,800 remaining warheads constitute a hedge that includes active as well as inactive warheads.[95]

In addition to the warheads that are included in the arsenal, the United States declared about 2,500 warheads that were retired and awaiting dismantlement in September 2014.[96] By September 2016 that number increased to 2,800 as more warheads were moved from the active arsenal to the dismantlement queue.[97]

Assuming that the United States had about 6,800 assembled nuclear warheads at the end of 2016, and that on average a warhead contains 4kg of plutonium and 20kg of HEU, we can estimate that assembled nuclear warheads contain 27.2 tons of plutonium and 136 tons of HEU.[98]

United States maintains a nuclear force that includes ICBMs, SLBMs on submarines, strategic bombers, and non-strategic weapons. Nuclear warheads that are assigned to deployed ICBMs and SLBMs are normally installed on their respective launchers. The three US Air Force bases that

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[87] Between 2004 and 2016, the United States down-blended about 90 tons of HEU. Most of that material probably came from the 621.2 tons that was at Y-12 Plant, Pantex and Department of Defense. The cumulative amount of down-blended HEU was reported as 65 tons in 2004 and 154.3 tons in 2016. "Department of Energy FY 2008 Congressional Budget Request" (National Nuclear Security Administration, February 2007), p. 488; "Department of Energy FY 2018 Congressional Budget Request" (2017), p. 502.

[88] "Global Fissile Material Report 2010" (2010), p. 34.

[89] Tom Clements, "U.S. Department of Energy Set to Restart Last Remaining U.S. Reprocessing Plant", *IPFM Blog* (blog), 30 April2015. Available from fissilematerials.org/blog/2015/04/us_department_of_energy_s_1.html.

[90] "Global Fissile Material Report 2010" (2010), p. 29.

[91] "Tritium and Enriched Uranium Management Plan" (2015), p. 31.

[92] "Remarks by the Vice President on Nuclear Security" (2017).

[93] "Transparency in the U.S. Nuclear Weapons Stockpile" (2015).

[94] Hans M. Kristensen and Robert S. Norris, "United States Nuclear Forces, 2017", *Bulletin of the Atomic Scientists* 73, no. 1 (2 January 2017): pp. 48–57. Available from https://doi.org/10.1080/00963402.2016.1264213.

[95] For a discussion of hedge, see *The Nuclear Matters Handbook. Expanded Edition* (Washington, D.C.: Office of the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, 2011), pp. 37–38. Available from http://www.acq.osd.mil/ncbdp/nm/nm_book_5_11/docs/NMHB2011.pdf.

[96] "Transparency in the U.S. Nuclear Weapons Stockpile" (2015).

[97] "Remarks by the Vice President on Nuclear Security" (2017).

[98] This is in line with the Department of Energy's own estimate, which assumes that a nuclear weapon contains about 25kg of fissile material (HEU and plutonium). "Department of Energy FY 2016 Congressional Budget Request", February 2015, p. 565. Available from http://www.energy.gov/sites/prod/files/2015/02/f19/FY2016BudgetVolume1%20_1.pdf.

operate ICBMs—Malmstrom, Minot, and Warren—have the necessary infrastructure to support warhead storage and maintenance. SLBM warheads are supported by Strategic Weapon Facilities Pacific and Atlantic at the Bangor and Kings Bay naval submarine bases respectively. Weapons assigned to strategic bombers are stored at Whiteman and Minot Air Force Bases. The Kirtland Underground Munitions Maintenance and Storage Complex (KUMMSC) at Kirtland Air Force Base is a central storage facility for various types of weapons, including those non-strategic weapons that are not deployed in Europe. The United States also maintains deployed nuclear weapons at five sites in Europe—in Belgium, Germany, Italy, the Netherlands, and Turkey.[99]

Non-active weapons in the United States are stored at the Pantex facility. Pantex assembles and disassembles nuclear warheads. Once a warhead is retired, Pantex removes the high explosives from the special nuclear material. Other HEU and non-nuclear weapons components are disassembled or shipped to other facilities for disassembly. Plutonium pits from disassembled weapons are stored at Pantex.

HEU components of disassembled nuclear weapons as well as most other HEU material are stored at the Y-12 National Security Complex in Oak Ridge, Tennessee. The Y-12 Complex supplies HEU for the naval reactors programme.[100]

Research and development facilities

The United States National Nuclear Security Administration (NNSA), which is a part of the Department of Energy, operates four main research and development laboratories, Los Alamos, Lawrence Livermore, Sandia National Laboratories and the Nevada National Security Site.

The Los Alamos facility is one of the two main weapons design laboratories in the United States. The Plutonium Processing 4 (PF-4) facility at Los Alamos is currently the only facility in the country that can disassemble and produce plutonium pits.[101]

Lawrence Livermore National Laboratory (LLNL), the other weapon design lab, does not currently store special nuclear material. In 2012, the NNSA announced that all special nuclear material has been removed from LLNL.[102] The laboratory continues to receive small quantities of special nuclear material that is used in various experiments at the National Ignition Facility.[103]

Sandia National Laboratories is another weapon laboratory that consists of nine federally funded military research facilities at various locations across the United States. It conducts experiments with plutonium and operates an HEU-fuelled pulsed reactor, the Annular Core Research Reactor (ACRR).[104]

The Nevada National Security Site, previously known as the Nevada Test Site, conducts research and maintenance activities on the United States nuclear weapons stockpile. As part of this work, it

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[99] Hans M. Kristensen and Robert S. Norris, "Worldwide Deployments of Nuclear Weapons, 2017", *Bulletin of the Atomic Scientists* 73, no. 5 (3 September 2017): pp. 289–97. Available from https://doi.org/10.1080/00963402.2017.1363995.
[100] "Naval Reactors", Y-12 National Security Complex. Available from http://www.y12.doe.gov/naval-reactors (accessed 24 October 2017).
[101] "TA-55 PF-4. LANL Plutonium-Processing Facilities", Los Alamos National Laboratory. Available from http://www.lanl.gov/about/_assets/docs/fact-sheets/ta-55-factsheet.pdf (accessed 23 October 2017).
[102] "NNSA Completes Removal of All High Security Special Nuclear Material from LLNL", National Nuclear Security Administration, 21 September 2012. Available from https://nnsa.energy.gov/mediaroom/pressreleases/snmremoval092112.
[103] "Experimental Innovation at NIF Allows New Look at Plutonium Behavior at Extreme Conditions", National Nuclear Security Administration, 7 April 2017. Available from https://nnsa.energy.gov/blog/experimental-innovation-nif-allows-new-look-plutonium-behavior-extreme-conditions.
[104] "Weapons Science", Sandia National Laboratories. Available from http://www.sandia.gov/missions/nuclear_weapons/science_technology.html (accessed 23 October 2017); "Research Reactors: United States", International Panel on Fissile Materials. Available from http://fissilematerials.org/facilities/research_reactors/united_states.html (accessed 24 October 2017).

conducts subcritical testing and plutonium shock physics experiments.[105] The Nevada National Security Site also conducts non-plutonium experiments, such as hydrodynamic testing, to support stockpile stewardship. The site also operates several HEU critical and subcritical assemblies that are used in weapon-related research.[106]

Non-proscribed military use

The United States uses substantial amounts of HEU in fuel of naval reactors. Reactors on submarines and surface ships are expected to consume 128.3 tons of HEU with enrichment of more than 92% of uranium-235 through 2060.[107] Most of this HEU is probably still in warheads and warhead components and will be released to the naval fuel programme as necessary.

Some HEU is used in research facilities that are used for military research. These facilities include three pulsed reactors, six critical and subcritical assemblies, and four naval prototype and training reactors.[108] This HEU would normally be considered military material.

Civilian material

Virtually all HEU in US inventory is of military origin. A number of civilian applications, such are research reactors, use HEU fuel, but the amount of HEU in civilian use is fairly small. The United States operates six steady-state research reactors that use HEU fuel.[109] These reactors are estimated to consume about 250kg of HEU annually.[110] This material, as well as other HEU used in civilian applications, for example HEU for export, is provided by the Y-12 Plant as necessary, probably from the common stock that includes weapon-origin material. However, it would be considered civilian material once it is used to manufacture reactor fuel or when it is prepared for export.

Like HEU, virtually all US separated plutonium is military material. In its INFCIRC/549 declaration submitted to the IAEA, the United States identifies 49.4 tons of separated plutonium that was declared excess to military needs. However, with the exception of 2 tons of plutonium placed under IAEA safeguards at the K-Area Material Storage (KAMS) at the Savannah River Site, this material should still be considered military stock not available for verification.

One category of material that would be considered civilian is the HEU and plutonium in fresh and spent fuel that the United States repatriated from foreign countries under the fuel return programme. Repatriated irradiated HEU fuel is stored at the Savannah River Site and the Idaho National Laboratory. Plutonium is shipped to the Savannah River Site, and fresh HEU fuel is shipped to the Y-12 Plant.[111] The amount of material in this category is estimated to be about 3 tons of HEU (most of it irradiated) and 0.4 tons of plutonium.[112] These materials are likely to be stored separately from the military-related stock.

105 "Joint Actinide Shock Physics Experimental Research (JASPER)", August 2013. Available from http://www2.nstec.com/Documents/Fact%20Sheets/JASPER.pdf.

106 "Research Reactors: United States" (2017).

107 "Tritium and Enriched Uranium Management Plan" (2015), pp. 25–26.

108 "Research Reactors: United States" (2017).

109 "Research Reactors: United States" (2017).

110 "Tritium and Enriched Uranium Management Plan" (2015), p. 25.

111 "No Research Reactor Fuel Was Shipped to the United States since 2012", *IPFM Blog* (blog), 6 January 2015. Available from http://fissilematerials.org/blog/2015/01/no_research_reactor_fuel_.html; "United States Brings Plutonium from Germany, Switzerland, and Japan", *IPFM Blog* (blog), 22 February 2016. Available from http://fissilematerials.org/blog/2016/02/united_states_brings_plut.html.

112 "Tritium and Enriched Uranium Management Plan" (2015), p. 6; "INFCIRC/549/Add.6/20" (2017).

Disposition

The Waste Isolation Pilot Plant (WIPP) is a geological repository that was designed to accept plutonium military waste. By 2014, the United States had designated 5.7 tons of plutonium for disposition at WIPP, at least 4.5 tons of which has been physically placed underground.[113] A significant fraction of the plutonium sent to WIPP is in the form of scraps and residues. However, the United States is planning to use the repository to dispose other categories of plutonium as well. It has started disposition of up to 6 tons of non-pit plutonium stored at the Savannah River Site and may extend this programme to the 34 tons of plutonium covered by the US–Russian Plutonium Management and Disposition Agreement (PMDA).[114] This material will go through the dilute and dispose programme in which the Los Alamos National Laboratory converts dismantled pits into plutonium oxide and ships plutonium oxide to the Savannah River Site. There the plutonium oxide is mixed with an inert substance to prepare it for disposition at WIPP.

Disposition HEU is down blended to produce low-enriched uranium. This work is carried out at three sites: a private sector facility in Erwin, Tennessee, the Savannah River Site and at the Y-12 National Security Complex. The down-blended material is then made available for use in commercial nuclear reactors.[115]

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[113] The United States reported in its INFCIRC/549 report to the IAEA that 4.5 tons of plutonium had been placed in WIPP. "Disposition of Plutonium in Waste Isolation Pilot Plant (WIPP)" (2016); "INFCIRC/549/Add.6/20" (2017).

[114] Tom Clements, "United States to Dispose of 6 MT of Weapon-Grade Plutonium in the Waste Isolation Pilot Plant" (2016); "United States to Discontinue Construction of MOX Fuel Fabrication Facility", *IPFM Blog* (blog), 26 February 2016. Available from http://fissilematerials.org/blog/2016/02/united_states_to_disconti.html.

[115] "U.S. HEU Disposition Program", National Nuclear Security Administration, 26 September 2013. Available from https://nnsa.energy.gov/aboutus/ourprograms/dnn/fmd/heu.

Russian Federation

Facilities in the Russian Federation that handle nuclear weapons and weapons-related fissile materials. Operational-level bases that host nuclear weapons are not depicted.

Total amount of material and production facilities

The Russian Federation has not declared the size of its fissile material stock. It was estimated that in September 2010 the Russian Federation had about 770±120 tons of HEU (90% HEU equivalent).[116] As a result of the US–Russian HEU-LEU programme, 100 tons of HEU have been down-blended by the end of 2013. Another programme, the Material Conversion and Consolidation Project probably down-blended about 4.2 tons of HEU since 2010. Both programmes have been completed. As a result, the Russian Federation's HEU stock in 2017 was estimated to be 670±120 tons. Virtually all of this material can potentially be available for weapons with a possible exception of a small amount of HEU in the repatriated fuel of research reactors.

An independent estimate suggests that the amount of weapon-related plutonium is 128±8 tons.[117] In addition, the Russian Federation has declared to the IAEA that as of 31 December 2015 it had 57.2 tons of separated civilian plutonium.[118] The total amount of separated plutonium, civilian and military, is therefore about 185 tons.

Some weapon-grade plutonium is barred from use in nuclear weapons. Under US–Russian agreement on the shutdown of plutonium production reactors, no plutonium separated after September 1997 can be used for nuclear weapons.[119] In practice, this commitment covers about 18 tons of weapon-grade plutonium that was produced after October 1994, as this material has

[116] "Global Fissile Material Report 2010" (2010), p. 67.
[117] "Global Fissile Material Report 2010" (2010), p. 54.
[118] "INFCIRC/549/Add.9/19. Communication Received from the Russian Federation Concerning Its Policies Regarding the Management of Plutonium," 26 September 2017. Available from https://www.iaea.org/sites/default/files/publications/documents/infcircs/1998/infcirc549a9-19.pdf.
[119] "Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning Cooperation Regarding Plutonium Production Reactors," (1997), Article V.

never been part of the military stock. All this plutonium is currently stored as oxide at a facility in Zheleznogorsk.[120]

Under the US–Russian PMDA, the Russian Federation committed to dispose of 34 tons of weapon-grade plutonium. Of this amount, 25 tons is weapon-origin plutonium that is currently stored as metal at the Mayak Fissile Material Storage Facility (FMSF) and 9 tons of material in plutonium oxide that will come from the post-1997 stock stored in Zheleznogorsk.[121] The plutonium at Mayak is stored in the form of metal spheres rather than weapon components. The Russian Federation, however, may still treat these spheres as a material with classified attributes.

In 2016, the Russian Federation unilaterally suspended its participation in the PMDA. It did, however, confirm its commitment not to use the PMDA material in weapons. The US–Russian agreement regarding the plutonium that was separated after 1997 remains in force. This suggests that the amount of plutonium that is available for weapons is about 85 tons.

The Russian Federation halted the production of HEU for weapons purposes in 1989 and the production of plutonium for weapons in 1994.[122] Production of HEU for weapons was carried out by three enrichment facilities: the Siberian Chemical Combine at Seversk, the Electrochemical Plant at Zelenogorsk, and the Urals Electrochemical Plant at Novouralsk. These three enrichment plants as well as a fourth one, the Electrolyzing Chemical Combine in Angarsk, which was not involved in HEU production, are still operating today.[123] They are mostly producing low-enriched uranium for power reactors, although they may also produce some non-weapon-grade HEU for naval reactors and civilian applications.[124] In 2012 the Russian Federation re-opened an HEU production line in Zelenogorsk that has been producing weapon-grade HEU for export.[125]

The Russian Federation produced plutonium at three key facilities: the Mayak Production Association in Ozersk, the Siberian Chemical Combine in Seversk, and the Mining and Chemical Combine in Zheleznogorsk.[126] Production of plutonium for weapons ended in September 1994, but some production reactors continued to operate until 2010.[127] Radiochemical plants at Mayak, in Seversk and Zheleznogorsk that were dedicated to reprocessing the fuel of plutonium production reactors have been shut down or converted for civilian uses.[128]

Weapon-origin fissile materials are stored at facilities managed by Rosatom. It is believed that at least five Rosatom sites have large storage facilities: Sarov, Snezhinsk, Ozersk, Seversk, and Zheleznogorsk. Each of these facilities may hold tens of tons of HEU and weapon-grade

[120] "Russia Removed Weapon-Grade Plutonium from Seversk," *IPFM Blog* (blog), 17 April 2015. Available from http://fissilematerials.org/blog/2015/04/russia_removed_weapon-gra.html.

[121] "Plutonium Management and Disposition Agreement" (2010), Annex on Quantities, Forms, Locations, and Methods of Disposition; Anatoly Dyakov, "Nuclear Warheads and Weapons-Grade Materials," in *Nuclear Reset: Arms Reductions and Nonproliferation*, Alexei Arbatov, Vladimir Dvorkin, and Natalia Bubnova, eds. (Moscow: Carnegie Moscow Center, 2012), pp. 233–56. Available from http://armscontrol.ru/pubs/en/Diakov-NucWarheads.pdf.

[122] "Russia," International Panel on Fissile Materials, 5 August 2016. Available from http://fissilematerials.org/countries/russia.html.

[123] "Global Fissile Material Report 2010" (2010), pp. 58–70.

[124] Pavel Podvig, ed., *The Use of Highly-Enriched Uranium as Fuel in Russia* (International Panel on Fissile Materials, 2017), p. 102. Available from http://fissilematerials.org/library/rr16.pdf.

[125] "Russia Launches HEU Production Line," *IPFM Blog* (blog), 29 October 2012. Available from http://fissilematerials.org/blog/2012/10/russia_launches_heu_produ.html; "Russia Confirmed Supplying HEU to the FRM-II Reactor in Germany," *IPFM Blog* (blog), 18 July 2016. Available from http://fissilematerials.org/blog/2016/07/russia_confirmed_supplyin.html.

[126] "Global Fissile Material Report 2010" (2010), pp. 46–57.

[127] "Russia No Longer Produces Weapon Materials," *IPFM Blog* (blog), 15 April 2010. Available from http://fissilematerials.org/blog/2010/04/russia_no_longer_produces.html.

[128] Pavel Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex* (International Panel on Fissile Materials, 2009), p. 8; "Former Defense Reprocessing Plant in Seversk to Be Decommissioned," *IPFM Blog* (blog), 26 June 2015. Available from http://fissilematerials.org/blog/2015/06/seversk_reprocessing_plan.html; "Radiochemical Plant," Mining and Chemical Combine. Available from http://www.sibghk.ru/activity/radiochemical-plant.html (accessed 24 October 2017).

plutonium.[129] There is very little information about fissile material storage arrangements in the Russian Federation. It is known, however, that weapon-grade plutonium that was separated after 1997 has been consolidated at a storage site in Zheleznogorsk, where it is subject to US monitoring.[130] Another known facility that stores plutonium is the FMSF that was built at the Mayak Plant with US assistance. That facility stores about 25 tons of plutonium that will be disposed of as part of the PMDA arrangement.[131]

Deployed and non-deployed weapons

The Russian Federation is estimated to have about 4,300 nuclear warheads that would be considered part of the active arsenal. In addition, it is estimated to have about 2,700 warheads that are awaiting dismantlement, adding up to a total of 7,000 assembled warheads.[132] Assuming that a modern warhead contains about 4kg of plutonium and 20kg of HEU, the amount of fissile materials in assembled warheads is estimated to be 28 tons of plutonium and 80 tons of HEU.

The Russian Federation's nuclear force includes strategic delivery systems—ICBMs, SLBMs, and bombers—as well as a range of non-strategic systems. Operationally deployed ICBM and SLBM warheads are normally installed on missiles. Each of the 11 ICBM divisions and the two naval bases that host ballistic missile submarines—Gadzhiyevo in the Northern Fleet and Vilyuchinsk in the Pacific Fleet—have base-level storage facilities that support maintenance of the deployed warheads. Weapons assigned to strategic bombers are stored at two base-level storage sites located at the Engels and Ukrainka air bases.[133]

Nuclear weapons assigned to non-strategic delivery systems can be located at one of the about 20 other base-level storage facilities, normally located in the vicinity of non-strategic naval, air, or missile bases. The Russian Federation, however, has repeatedly stated that all its non-strategic warheads are consolidated at central storage sites. There are 12 national-level storage facilities that can contain a variety of weapons of different types and deliver them to base-level facilities or directly to operational units when necessary. All weapon storage facilities, national-level or base-level, are managed by the 12th Main Directorate of the Ministry of Defense.[134]

The two main assembly and disassembly facilities for the Russian Federation's stockpile are the Electrochemical Instrument Combine in Lesnoy and the Instrument Building Plant in Trekhgorny. Lesnoy is the primary assembly/disassembly site, and probably manufactures nuclear weapons for the Russian Federation's arsenal. Trekhgorny is believed to be involved only in assembly and disassembly of physics packages; it may not have a capability to manufacture weapon components. Decommissioned warheads that are awaiting dismantlement are probably stored at the 12th Main Directorate storage facilities Lesnoy-4 and Trekhgorny-1 located nearby. They are transferred to the disassembly facilities as necessary. Both Lesnoy and Trekhgorny production plants seem to have some on-site storage as well.[135]

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[129] Pavel Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex* (2009), p. 2.
[130] "Russia Removed Weapon-Grade Plutonium from Seversk" (2015).
[131] "Mayak Storage Facility Is in Business," *Russian Strategic Nuclear Forces* (blog), 15 November 2006. Available from http://russianforces.org/blog/2006/11/mayak_storage_facility_is_in_b.shtml.
[132] Hans M. Kristensen and Robert S. Norris, "Russian Nuclear Forces, 2017," *Bulletin of the Atomic Scientists* 73, no. 2 (4 March 2017), pp. 115–26. Available from https://doi.org/10.1080/00963402.2017.1290375.
[133] Pavel Podvig and Javier Serrat, "Lock Them Up: Zero-Deployed Non-Strategic Nuclear Weapons in Europe" (UNIDIR, 2017). Available from http://unidir.org/files/publications/pdfs/lock-them-up-zero-deployed-non-strategic-nuclear-weapons-in-europe-en-675.pdf.
[134] For details of storage arrangements, see Podvig and Serrat (2017).
[135] Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex* (2009), p. 15.

Research and development facilities

The Russian Federation operates two central nuclear weapons research and development labs. The Scientific Research Institute of Experimental Physics at Sarov (VNIIEF), the first Soviet nuclear weapons laboratory, conducts a wide range of nuclear research, including small scale pit production and work on new nuclear warheads. The second laboratory is the Scientific Research Institute of Technical Physics at Snezhinsk (VNIITF), which also conducts small scale pit production and warhead research.[136]

VNIIEF and VNIITF operate a number of research reactors and critical assemblies that are used to conduct weapon-related and civilian research. These facilities contain substantial amounts of HEU and plutonium.[137]

Non-proscribed military use

The Russian Federation's nuclear submarines and surface ships use nuclear reactors of several different types with HEU enriched to 21–45% or 90%. The Russian Federation does not provide detailed information about the use of HEU in naval fuel, but according to an independent estimate, nuclear reactors of submarines and military surface ships would consume up to 4.2 tons of HEU (1.3 tons of 90% HEU equivalent) annually over the next decade.[138] The Russian Federation does not maintain a separate HEU reserve for naval reactors. In fact, it may be continuing production of HEU for naval reactors, as this production is not covered by the commitment to stop production of HEU for weapons.

Another military non-weapons use of HEU in the Russian Federation is the fabrication of fuel for its tritium production reactors. The two reactors located at the Mayak Production Association, Ruslan and LF-2, are currently used mostly to produce civilian industrial isotopes. However, they do maintain a tritium production capability. When both reactors are operating, they are believed to consume up to 1.1 tons of 90% HEU annually.[139]

The Russian Federation's two weapon laboratories, VNIIEF in Sarov and VNIITF in Snezhinsk, operate a number of pulsed reactors and critical and subcritical assemblies that are used for military and civilian research. As of 2017, these facilities were estimated to contain about 2.5 tons of 90% HEU. Some HEU is associated with two naval prototype reactors and a critical facility used in defence-related research.[140] This would be considered military material as well.

The use of plutonium in military non-weapons applications appears to be limited to experiments that are conducted in one of the weapon laboratories or at the Novaya Zemlya test site, where the Russian Federation may be conducting explosive non-nuclear tests.

Civilian material

The Russian Federation operates a large number of research reactors and critical facilities that use HEU fuel. There are 36 research facilities of this kind located outside of the weapon laboratories and other defence research organizations. While some of them may be involved in military research, their material would normally be considered civilian. The amount of HEU associated with pulsed reactors and critical facilities is about 3.6 tons of 90% HEU equivalent. Steady-state civilian research reactors are estimated to consume about 0.28 tons of HEU annually.[141]

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[136] Podvig (2009), pp. 13–15.
[137] Podvig, *The Use of Highly-Enriched Uranium as Fuel in Russia* (2017), pp. 16–17.
[138] Podvig (2017), p. 102.
[139] Podvig (2017), p. 6.
[140] Podvig (2017), pp. 16–17.
[141] Podvig (2017), pp. 16–17, 35.

Substantial amounts of HEU are consumed by the civilian fast neutron reactors. The annual consumption of the BN-600 reactor is estimated to be 3.7 tons of HEU (0.98 tons of 90% HEU equivalent).[142] The Russian Federation also maintains a fleet of nuclear-powered icebreakers that are believed to require about 0.4 tons of HEU (0.23 tons of 90% HEU equivalent) annually.[143]

As noted earlier, the Russian Federation reported having a stock of 57.2 tons of civilian plutonium. This is the material separated from spent fuel of power reactors at the RT-1 civilian reprocessing facility at Mayak. Even though the Russian Federation is under no legal obligation not to use this material in weapons, it is highly unlikely to do so.

Disposition

The Russian Federation has already completed elimination of a significant fraction of its HEU stock. 500 tons of weapon-origin HEU was eliminated as part of the US–Russian HEU-LEU deal. The HEU was down-blended to low-enriched uranium and then sent to the United States where it was used to produce fuel for power reactors. A different programme, the Material Conversion and Consolidation project, down-blended almost 17 tons of HEU, primarily associated with various research facilities.[144] After these programmes were completed, the Russian Federation indicated that it had no plans to eliminate additional HEU.

The Russian Federation has made a commitment to eliminate 34 tons of weapon-grade plutonium as part of the PMDA agreement with the United States. The agreement stipulates that this plutonium will be used to manufacture MOX fuel that will then be used in BN-600 and BN-800 reactors.[145] The fuel will be manufactured at the MOX fuel fabrication facility in the Mining and Chemical Combine at Zheleznogorsk. In 2016, the Russian Federation announced that it unilaterally suspended implementation of the PMDA. It confirmed, however, that the excess plutonium that was covered by that agreement will not be used for weapons.[146] The suspension can potentially allow the Russian Federation to use a different disposition route, such as irradiation of plutonium in new types of breeder reactors. It is highly unlikely that the Russian Federation will decide to dispose of plutonium in a geological repository.

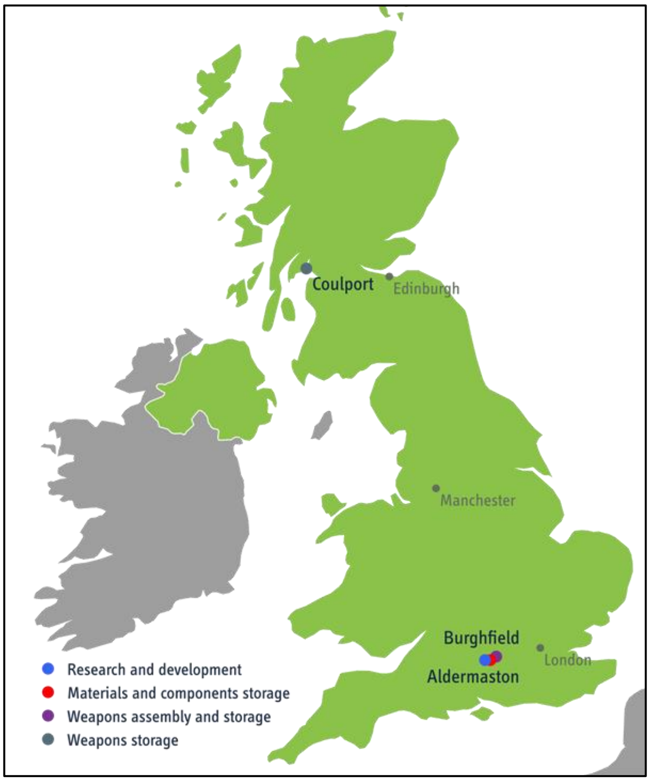
[142] Podvig (2017), p. 7.
[143] Podvig (2017), p. 102.
[144] Podvig (2017), p. 11.
[145] "Plutonium Management and Disposition Agreement" (2010), Article III, Annex on Key Program Elements.
[146] "Russia Suspends Implementation of Plutonium Disposition Agreement" (2016).

United Kingdom

Total amount of material and production facilities

In 2006, the United Kingdom declared to have had a total of 21.86 tons of military HEU as of 31 March 2002.[147] Since 2002 various UK programmes, primarily naval reactors, consumed about 2.5 tons of HEU, bringing the total amount of military HEU in the United Kingdom to 19.4 tons.[148] This number includes irradiated HEU in spent fuel of naval and research reactors, which was estimated to be about 8 tons in 2010 and would be about 9–10 tons in 2016.[149] This means that the amount of HEU available for weapons is closer to 10 tons. The United Kingdom has also reported that at the end of 2015 it had 1.404 tons of civilian HEU under Euratom safeguards.[150]

Based on the official UK accounts of plutonium production, the amount of plutonium in UK military stock stands at 3.2 tons of weapon-grade plutonium.[151] In addition to the military stock, the United Kingdom owns at least 106.8 tons of civilian plutonium.



Facilities in the United Kingdom that handle nuclear weapons and weapons-related fissile materials.

The United Kingdom produced weapons HEU at the Capenhurst Gaseous Diffusion Plant from 1952 until 1962. Capenhurst continued to produce civilian LEU until 1982 and was decommissioned after that. In addition to domestic production, the United Kingdom received about 15 tons of HEU from the United States.[152] Transfers from the United States continue to this day.[153] Details of these transfers are classified, but it is possible that this material is used in the UK naval programme.[154] Today, the United Kingdom operates a gaseous centrifuge enrichment plant at Capenhurst. This plant produces LEU for civilian power reactors and is subject to Euratom safeguards.

Plutonium for weapons was produced mainly at the Sellafield complex, which consisted of six production reactors and a reprocessing facility. Plutonium was also produced at an additional four dual-use reactors at Chapelcross. Production of military plutonium stopped in 1989 and all reactors involved in

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147 "Historical Accounting for UK Defence Highly Enriched Uranium" (2006).

148 Based on the estimate in "Global Fissile Material Report 2015" (International Panel on Fissile Materials, 2015), 15. Available from http://ipfmlibrary.org/ipfm15.pdf.

149 "Global Fissile Material Report 2010" (2010), p. 75.

150 The amount of HEU is reported as 1,404kg. "INFCIRC/549/Add.8/19. Communication Received from the United Kingdom of Great Britain and Northern Ireland Concerning Its Policies Regarding the Management of Plutonium", IAEA, 18 January 2017. Available from https://www.iaea.org/sites/default/files/publications/documents/infcircs/1998/infcirc549a8-19.pdf.

151 "Global Fissile Material Report 2010" (2010), p. 77.

152 "Global Fissile Material Report 2010" (2010), pp. 73–74.

153 "Tritium and Enriched Uranium Management Plan" (2015), p. 27; "Ongoing Transfers of Weapon Materials between the United States and the United Kingdom" (2016).

154 For an overview of the link between US and UK naval reactor programs, see Nick Ritchie, "The UK Naval Nuclear Propulsion Programme and Highly Enriched Uranium," February 2015. Available from https://fas.org/wp-content/uploads/2015/03/2015-FAS-UK-NNPP-HEU-final2.pdf.

production were shut down by 2004.[155] The United Kingdom operates two civilian reprocessing facilities, B-205 and THORP (Thermal Oxide Reprocessing Plant), which are expected to be shut down in the near future.

Deployed and non-deployed weapons

In January 2015, the UK Government announced that it had met the goal of reducing the number of "operationally available warheads" to 120.[156] Since 2000, the only warheads in this category are the warheads deployed on UK Trident II missiles. The total number of warheads in the UK stockpile is somewhat larger as it includes warheads in reserve. Decommissioned warheads awaiting dismantlement also appear to be considered part of the stockpile. In 2010, the UK government reduced the number of warheads in its stockpile to 225 and made a commitment to reduce it to "no more than 180". This goal is expected to be reached in the mid-2020s.[157]

Some warheads that are awaiting dismantlement have been disabled to render them unusable. Others are stored without modification.[158] The dismantlement is reported to proceed at a rate of about three warheads a year.[159] For the purposes of this estimate we assume that the UK stockpile consists of about 200 warheads.

Using the assumptions adopted in this report, about 0.8 tons of plutonium and 4 tons of HEU are in assembled warheads. The United Kingdom has a policy of returning the material from disassembled warheads to the military stock, which means that all 3.2 tons of plutonium and about 10 tons of HEU are either in weapons or available for weapons.

The United Kingdom's nuclear forces are deployed on four Vanguard class submarines, which carry the Trident II SLBM. The submarines are housed at the Clyde naval base in Faslane, Scotland. The active warheads are either operationally deployed on SLBMs or stored at the Coulport Royal Navy Ammunition Depot, located nearby.[160] The depot has facilities to install nuclear warheads on SLBMs before a submarine goes on patrol.[161] The depot is managed jointly by the ABL Alliance that includes the Atomic Weapons Establishment, Babcock and Lockheed Martin UK.[162]

The Coulport depot also serves as a long-term storage for warheads that are awaiting dismantlement or are being refurbished. When warheads are ready for dismantlement they are transferred to the Atomic Weapons Establishment site at Burghfield. Refurbished warheads are returned to Coulport for storage or deployment.[163]

Burghfield is the only site that carries out warhead assembly and disassembly.[164] The site probably has some weapon components storage capacity that supports its operation, but it does not appear

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[155] "Global Fissile Material Report 2010" (2010), p. 76.

[156] "House of Commons Hansard Ministerial Statements for 20 Jan 2015. The Secretary of State for Defence (Michael Fallon) on Nuclear Deterrent," 20 January 2015. Available from http://www.publications.parliament.uk/pa/cm201415/cmhansrd/cm150120/wmstext/150120m0001.htm.

[157] United Kingdom, Ministry of Defence, "Request for Information under the Freedom of Information (FOI) Act", 25 July 2013. Available from http://robedwards.typepad.com/files/mod-foi-response-on-dismantling-nuclear-weapons.pdf.

[158] "Request for Information under the Freedom of Information (FOI) Act" (2013).

[159] Rob Edwards, "UK's Nuclear Weapons Being Dismantled under Disarmament Obligations", *The Guardian*, 11 August 2013. Available from http://www.theguardian.com/uk-news/2013/aug/11/uk-nuclear-weapons-dismantled-trident.

[160] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).

[161] Tamara Patton, Pavel Podvig and Phillip Schell, "A New START Model for Transparency in Nuclear Disarmament. Individual Country Reports" (UNIDIR, 2013), p. 40. Available from http://unidir.org/files/publications/pdfs/a-new-start-model-for-transparency-in-nuclear-disarmament-individual-country-reports-en-415.pdf.

[162] "Our Locations," Atomic Weapons Establishment. Available from http://www.awe.co.uk/about-us/our-locations/ (accessed 25 October 2017).

[163] This pattern can be inferred from warhead movements between Coulport and Burghfield. "Doubling of Nuclear Transports May Indicate Delivery of Upgraded Warheads," *Nuclear Information Service* (blog), 15 August 2017. Available from https://www.nuclearinfo.org/article/transport/doubling-nuclear-transports-may-indicate-delivery-upgraded-warheads.

[164] "Our Locations" (2017).

to have a component manufacturing capability. This means that Burghfield is unlikely to have any material apart from weapon components on site. Weapon-related plutonium and HEU as well as weapon components are stored at the main production site at Aldermaston.[165]

Research and development facilities

The United Kingdom's nuclear arsenal is managed by the Atomic Weapons Establishment, which is owned by the Ministry of Defence. The AWE operates four facilities: Aldermaston, Burghfield, Blacknest, and Coulport. Aldermaston is responsible for the design, production and maintenance of nuclear warheads. It also stores and processes HEU for fabrication into naval reactor fuel. To support nuclear warheads and naval fuel operations, a new Enriched Uranium Facility (Project Pegasus) is being constructed at Aldermaston.[166]

As noted earlier, Burghfield assembles and maintains warheads while in service and disassembles decommissioned warheads and Coulport maintains nuclear warheads.[167] Blacknest is mostly a forensic seismology lab.

Non-proscribed military use

The naval reactor programme is the main user of HEU in the United Kingdom. The Government of the United Kingdom has made no declaration of naval HEU reserve, so the material for this programme will be taken from the common military stock.

HEU is also used in the Viper pulsed reactor located at Aldermaston. The reactor is presumably involved in defence research, so this HEU would be accounted for as military material.

Civilian material

The United Kingdom has reported that at the end of 2015 it had 1.404 tons of civilian HEU, of which 1.261 tons is unirradiated.[168] This material is currently under Euratom safeguards.

In its most recent INFCIRC/549 report, the amount of separated civilian plutonium owned by the United Kingdom was 106.2 tons (as of 31 December 2015).[169] In 2017, the United Kingdom took ownership of about 600kg of foreign plutonium stored in the country, so the total amount of United Kingdom civilian plutonium is at least 106.8 tons.[170]

The civilian plutonium stock includes the material declared excess to military needs in the 1998 Strategic Defence Review.[171] All this material—4.4 tons, including 0.3 tons of weapon-grade plutonium—has been transferred to the civilian stock and is being reported as such in the United Kingdom's INFCIRC/549 reports submitted to the IAEA.[172]

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[165] "Assessing the Risk of Terrorist Attacks on Nuclear Facilities", Parliamentary Office of Science and Technology, July 2004, p. 11. Available from http://www.parliament.uk/documents/post/postpr222.pdf.
[166] Nick Ritchie, "The UK Naval Nuclear Propulsion Programme and Highly Enriched Uranium" (2015), pp. 7–8.
[167] "Our Locations" (2017).
[168] "INFCIRC/549/Add.8/19" (2017).
[169] "INFCIRC/549/Add.8/19" (2017).
[170] "United Kingdom Takes Ownership of Some Spanish and German Plutonium," *IPFM Blog* (blog), 19 January 2017. Available from http://fissilematerials.org/blog/2017/01/united_kingdom_takes_owne_1.html.
[171] "Strategic Defence Review" (2010), para. 26.
[172] "Global Fissile Material Report 2013: Increasing Transparency of Nuclear Warhead and Fissile Material Stocks as a Step toward Disarmament" (International Panel on Fissile Materials, 2013), p. 21. Available from http://ipfmlibrary.org/gfmr13.pdf.

Disposition

In the 1998 Strategic Defence Review, the United Kingdom identified 4.4 tons of plutonium (which included 0.3 tons of weapon-grade plutonium) as excess to its military needs. All that material was added to the UK civilian plutonium stock and placed under Euratom safeguards. This plutonium however, was never part of the weapon-related stock, so it probably had no sensitive attributes.

If the United Kingdom identifies additional excess material, it may be difficult to find a suitable disposition route for plutonium. The United Kingdom already has more than 100 tons of civilian plutonium and no programme that can use this material. The Government has been exploring a range of options for dealing with its civilian plutonium stock.[173] If a disposition route for that material is found, any excess military plutonium could be disposed of in a similar way.

173 Martin Forwood and Mycle Schneider, "Plutonium Disposition in the United Kingdom - Immobilization Option Re-Opened?," *IPFM Blog* (blog), 30 June 2015. Available from http://fissilematerials.org/blog/2015/06/plutonium_disposition_in_.html.

France

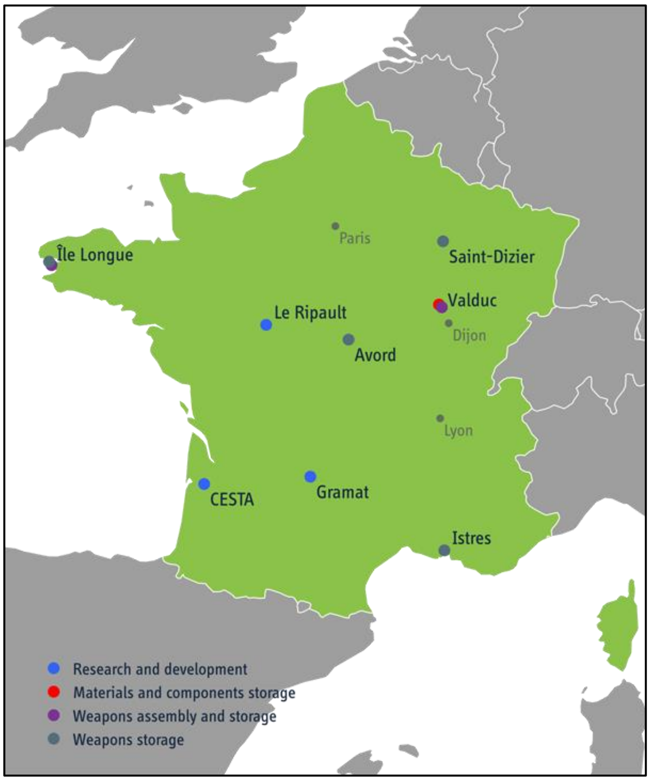
Total amount of material and production facilities

France has not published an official account of its weapon fissile material stocks or detailed information about its production programme. As a result, there is significant uncertainty about France's current military HEU and plutonium stockpiles. The estimates of the HEU stock range from 6 tons to 26 tons of HEU, depending on production history details. This estimate assumes that the current HEU stock is 26±2 tons.[174]

France's current military plutonium stockpile is estimated to be 6±1 tons.[175] In addition to that, France reports owning 65.4 tons of separated civilian plutonium.

France ceased the production of HEU for weapons purposes in 1996. The facility that produced HEU for weapons, Pierrelatte, was shut down and is being dismantled. The civilian gaseous diffusion plant, George Besse, was closed in 2012. It was replaced by a centrifuge plant, George Besse II, which is producing LEU for civilian reactors.[176]

Production of plutonium for weapons purposes in France was ended in 1992. The dedicated plutonium production reactors located at Marcoule as well as other reactors involved in plutonium production have been shut down and decommissioned. The dedicated reprocessing plant at Marcoule has been decommissioned as well. France continues reprocessing spent fuel of civilian reactors at its La Hague facility. Plutonium separated there is treated as civilian material and is placed under Euratom safeguards.[177]



Facilities in France that handle nuclear weapons and weapons-related fissile materials.

Deployed and non-deployed weapons

In 2008 France officially declared that it will decrease the number of warheads in its arsenal to fewer than 300 and that there are no warheads outside of this "operational stockpile."[178] This probably means that all 300 warheads would be considered active.

Using the assumption of 4kg of plutonium and 20kg of HEU in a warhead, about 1.2 tons of plutonium and 6.0 tons of HEU is in assembled warheads.

French nuclear forces consist of four Triomphant class submarines that carry SLBMs and land-based and aircraft-carrier-based fighter-bombers. SLBM warheads not deployed on missiles are stored and serviced at a storage facility at Saint-Jean, south of the Île

[174] "Global Fissile Material Report 2013" (2013), p. 13.
[175] "Global Fissile Material Report 2010" (2010), p. 85.
[176] "Global Fissile Material Report 2010" (2010), pp. 85–87; "Georges Besse Enrichment Plant Ceases Production," *IPFM Blog* (blog), 7 June 2012. Available from http://fissilematerials.org/blog/2012/06/georges_besse_enrichment_.html.
[177] "Global Fissile Material Report 2010" (2010), pp. 88–96.
[178] "Presentation of SSBM 'Le Terrible'—speech by M. Nicolas Sarkozy, President of the Republic" (Cherbourg, 21 March 2008). Available from http://carnegieendowment.org/2008/03/24/presentation-of-le-terrible-in-cherbourg/ynb.

Longue submarine base.[179] Warheads for air-launched cruise missiles (ALCMs) carried by fighter-bombers are stored at two air bases where the aircrafts are deployed—Istres and Saint-Dizier. The latter may also store weapons for bombers deployed on the Charles de Gaulle aircraft carrier. In addition, the Avord air base serves as the storage and maintenance site for the ALCMs.[180]

All nuclear activities in France are managed by the Atomic Energy Commission (Commissariat à l'Energie Atomique, or CEA). Technically, warheads remain the CEA's responsibility even when they are in military custody.[181] CEA operates two warhead storage and dismantlement facilities—at the Île Longue submarine base (for SLBM warheads) and at the "special military centre" at the Valduc research centre site (for air-delivered weapons). These sites appear to store some warheads that are part of the active arsenal but are not operationally deployed, as well as the warheads that are awaiting dismantlement. The two facilities also have some warhead dismantlement capacity; nuclear charges are removed and sent to the Valduc research centre for further dismantlement.[182]

The Valduc research centre is the main nuclear warhead production facility. It is likely that most military plutonium and HEU that is not in active warheads is stored at the Valduc site. The site might also store weapon components.

Research and development facilities

France currently operates five laboratories that work on stockpile maintenance and development. The five facilities are CESTA (Aquitaine), Île-de-France, Gramat, Le Ripault, and Valduc. In France, all nuclear facilities, civilian and nuclear, are managed by the DAM (Direction des Applications Militaires), a department of the CEA.[183] In some cases, the same facilities were used to produce material for military and civilian purposes.

As noted above, the Valduc research centre manufactures nuclear weapons components and dismantles nuclear weapons retired from service. Valduc also assists with the simulation programme and manages nuclear waste from DAM. Valduc is working with the Atomic Weapons Establishment of the United Kingdom to construct an X-ray and hydrodynamics research centre called EPURE.[184] Valduc operates HEU-fuelled research facilities that are probably used in weapon-related research.[185]

Although it appears that activities that involve fissile materials are concentrated at Valduc, other research centres might also use some materials in their research. The Centre d'Etudes Scientifiques et Techniques d'Aquitaine (CESTA) designs warheads, re-entry vehicles, and certifies weapons performance. The facility conducts large scale physics experiments using X-ray generators, fusion environments and anechoic chambers. CESTA hosts the Mejoule facility, which is designed to study fusion.[186]

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[179] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017"; "Rapport d'information déposé en application de l'article 145 du Règlement par la Commission de la défense nationale et des forces armées sur la fin de vie des équipements militaires et présenté par M. Michel Grall, Député" (Paris: National Assembly, 16 March 2009), pp. 11–12.
[180] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).
[181] "Rapport d'information" (2009), p. 19.
[182] "Rapport d'information," (2009), pp. 11–12.
[183] "Organisation et compétences", CEA / Direction des applications militaires, 1 July 2016. Available from http://www-dam.cea.fr/organisation-competences/index.html.
[184] "Organisation et compétences" (2016).
[185] "Research Reactors: France," International Panel on Fissile Materials. Available from http://fissilematerials.org/facilities/research_reactors/france.html (accessed 25 October 2017).
[186] Hans M. Kristensen, "France," in *Assuring Destruction Forever. Nuclear Weapon Modernization Around the World*, Ray Acheson, ed. (Reaching Critical Will, 2012), p. 31. Available from http://www.reachingcriticalwill.org/images/documents/Publications/modernization/assuring-destruction-forever.pdf; "Organisation et compétences" (2009).

The DAM Île-de-France facility designs and certifies nuclear weapons using the large computing centre of the CEA. Gramat conducts effects testing, weapons hardening, and studies the vulnerability of conventional forces to various weapons effects, including electromagnetic pulse. The Centre d'Etudes du Ripault preforms stockpile maintenance, researches nuclear propulsion and manufactures high explosive components.[187]

Non-proscribed military use

Although strategic submarines operated by France used HEU fuel in the past, the current submarine reactors use LEU-based fuel, so there is no significant amount of HEU associated with the naval fuel cycle.

Research centres of the CEA operate a number of pulsed reactors and critical facilities that use HEU as fuel.[188] Some of these facilities are involved in defence-related research, so the material they use would be considered military material.

Civilian material

France has reported that at the end of 2015 it had 4.806 tons of civilian HEU, which includes 3.004 tons of unirradiated material.[189] This HEU is currently under Euratom safeguards. France has a number of civilian research reactors that use HEU and is involved in manufacturing of fuel and irradiation targets for European countries.[190]

In its most recent INFCIRC/549 report, the amount of separated civilian plutonium owned by France was 65.4 tons (as of 31 December 2015).[191] France is using its reactor plutonium to produce MOX fuel for civilian power reactors.

Disposition

France has not declared any material produced for its weapon programme as excess to military needs, even though it has dramatically reduced the size of its nuclear arsenal after the end of the Cold War. Should France make a decision to do so, it could dispose of the weapon-origin plutonium by using it in MOX fuel for civilian power reactors. Excess HEU, if France declares any, can be down-blended and used for civilian purposes as well.

[187] "Organisation et compétences" (2009).
[188] "Research Reactors: France" (2017).
[189] The amount of HEU is reported as 4,806kg, of which 3,004kg is unirradiated. "INFCIRC/549/Add.5/21. Communication Received from France Concerning Its Policies Regarding the Management of Plutonium", IAEA, 29 September 2017. Available from https://www.iaea.org/sites/default/files/publications/documents/infcircs/1998/infcirc549a5-21.pdf.
[190] "Research Reactors: France" (2017).
[191] "INFCIRC/549/Add.5/21" (2017).

China

Facilities in China that handle nuclear weapons and weapons-related fissile materials. Facilities that store bulk materials and components are unknown.

Total amount of material and production facilities

China has not published information about its military HEU and plutonium holdings. The most recent independent estimate suggests that China's current inventory of plutonium for weapons is about 2.9±0.6 tons and the inventory of weapon-grade HEU is about 14±3 tons.[192] China has also reported having a small amount of separated civilian plutonium.

China has produced HEU for weapons at two complexes: the Lanzhou gaseous diffusion plant and the Heping gaseous diffusion plant. Plutonium has been produced at the Jiuquan Atomic Energy Complex and the Guangyuan plutonium production complex. It is assumed that plutonium production ended in 1990 and HEU production ended in 1987.[193]

Deployed and non-deployed weapons

China is believed to have about 230 warheads in its active arsenal. China is also estimated to have about 30 warheads outside of its active arsenal, including spares and warheads awaiting dismantlement.[194] Using the assumptions adopted in this report, about 1 ton of plutonium and 5.2 tons of HEU are in assembled warheads.

China's nuclear forces include a range of delivery systems. Land-based missiles constitute the core of the force while other systems—SLBMs, cruise missiles, and aircraft—also have nuclear capability.[195] China is believed to store nuclear warheads separately from delivery systems. The system of weapons handling and storage facilities is managed by the People's Liberation Army (PLA)

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[192] Hui Zhang, *China's Fissile Material Production and Stockpile* (International Panel on Fissile Materials, forthcoming).
[193] "Global Fissile Material Report 2010" (2010), pp. 97–106.
[194] Hans M. Kristensen and Robert S. Norris, "Chinese Nuclear Forces, 2016", *Bulletin of the Atomic Scientists* 72, no. 4 (3 July 2016): pp. 205–11. Available from https://doi.org/10.1080/00963402.2016.1194054.
[195] Kristensen and Norris, "Chinese Nuclear Forces, 2016" (2016).

Rocket Force (formerly known as the Second Artillery). It is distinct from the system of missile bases that is also managed by the Rocket Force.[196]

The central warhead storage facility, known as the 22 Base, stores and maintains weapons that are ready for deployment. It can service the weapons and is believed to have the capability to assemble nuclear warheads, probably starting from assembled physics packages.[197] In addition to the 22 Base, there are six regional facilities that appear to have the capability to store and service nuclear warheads for land-based missiles. The Longpo (Yulin) naval base may also have a facility that can store nuclear warheads for SLBMs.[198] It is unclear if warheads are stored there on a permanent basis.

Warhead assembly and disassembly as well as storage of weapon components and fissile materials takes place at the facilities of the Chinese Academy of Engineering Physics (CAEP). Two facilities in the Sichuan province have been identified as weapon manufacturing and storage—in the Pingtongzhen area and the Zitong area.[199]

Research and development facilities

The CAEP complex is responsible for development of China's nuclear weapons. The complex consists of 11 institutes, eight of which are located around around Mianyang in the Sichuan Province.[200] Some, but probably not all these institutes, conduct weapon-related research that involves weapon fissile materials.

Non-proscribed military use

China's nuclear submarines are believed to use LEU fuel, so there is no weapon-grade material associated with naval propulsion.

Institutes of the CAEP may operate research facilities that use HEU and plutonium. If that is the case, the material associated with these facilities would be considered belonging to the military stock.

Civilian material

As of 31 December 2014 China's civilian stock of separated plutonium was 25.4kg.[201] China operates two research reactors that use HEU and an experimental fast neutron reactor that uses HEU fuel supplied by the Russian Federation.[202]

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[196] Mark A. Stokes, *China's Nuclear Warhead Storage and Handling System* (Project 2049 Institute, 2010), p. 2. Available from http://project2049.net/documents/chinas_nuclear_warhead_storage_and_handling_system.pdf.
[197] Stokes (2010), p. 3.
[198] Stokes (2010), p. 7; Kristensen and Norris, "Chinese Nuclear Forces, 2016" (2016).
[199] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).
[200] "Chinese Academy of Engineering Physics (CAEP)," Nuclear Threat Initiative, 2011. Available from http://www.nti.org/learn/facilities/702/.
[201] "INFCIRC/549/Add.7/14. Communication Received from China Concerning Its Policies Regarding the Management of Plutonium", IAEA, 28 August 2015.
[202] "Research Reactors: China," International Panel on Fissile Materials. Available from http://fissilematerials.org/facilities/research_reactors/china.html (accessed 26 October 2017); "Russia to Supply More HEU Fuel for Chinese Experimental Fast Reactor," *IPFM Blog* (blog), 29 December 2016. Available from http://fissilematerials.org/blog/2016/12/russia_to_supply_more_heu.html.

India

Total amount of material and production facilities

India's stock of separated weapons plutonium consisted of 0.59±0.20 tons of material. In addition to that, India has separated about 5.5±3.0 tons of reactor-grade plutonium from spent fuel of power reactors.[203] This material appears to be reserved for future use in breeder reactors, potentially to produce weapon-grade material. The total amount of India's plutonium is taken to be 6.1 tons.

India is believed to limit the use of HEU to its naval reactor programme. As of 2014 India was estimated to have 3.2 tons of HEU that was produced for use in naval propulsion systems.[204]

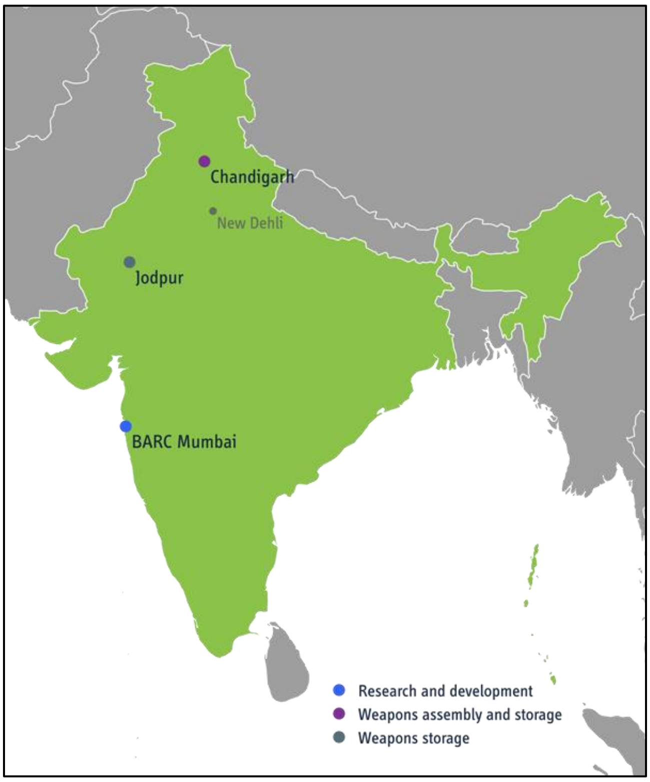
India is producing fissile material for its weapons programme. It operates the Dhruva plutonium production reactor located at the Bhabha Atomic Research Center (BARC). HEU enrichment currently occurs at the Rare Materials Project centrifuge plant in Rattehalli.[205] A third enrichment facility, in Chitradurga, may be under construction. It appears that the plant, while not safeguarded, will be used primarily for civilian applications.[206]

Deployed and non-deployed weapons

It is estimated that India has produced about 100–130 nuclear warheads, which are considered part of the active arsenal (even though they may not be operationally deployed).[207] Assuming that these warheads contain about 4kg of plutonium on average, the total amount of plutonium in active warheads is about 400–520kg. It is therefore assumed that all India's weapon-grade plutonium is in active weapons.

India has not produced HEU for weapons and does not seem to have assembled weapons that are not part of the active arsenal.

India currently possesses ballistic missiles, cruise missiles, and gravity bombs and is developing nuclear capable submarines and SLBMs. India operates two Sukanya-class patrol ships that can carry ship-launched ballistic missiles.[208] The Jodhpur Storage Facility in Rajasthan may store warheads for land-based ballistic missiles. It is believed that individual services have their own storage facilities, but their locations are unknown.



Facilities in India that may be involved in handling nuclear weapons and weapons-related fissile materials. Locations of sites that store weapons for delivery by aircraft and land- and sea-based missiles are not known.

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203 "Global Fissile Material Report 2015" (2015), pp. 26, 32.
204 "Global Fissile Material Report 2015" (2015), p. 16.
205 A pilot enrichment plant may be operating at the BARC. "Global Fissile Material Report 2010" (2010), pp. 122–25.
206 "Some Details of India's Nuclear Program," *IPFM Blog* (blog), 26 November 2011. Available from http://fissilematerials.org/blog/2011/11/some_details_of_indias_nu.html.
207 Hans M. Kristensen and Robert S. Norris, "Indian Nuclear Forces, 2017", *Bulletin of the Atomic Scientists* 73, no. 4 (4 July 2017): pp. 205–9. Available from https://doi.org/10.1080/00963402.2017.1337998.
208 Kristensen and Norris, "Indian Nuclear Forces, 2017" (2017).

Nuclear weapons are believed to be assembled at the Chandigarh Plant in Punjab.[209]

Research and development facilities

BARC designs and develops warheads, and hosts a reprocessing plant, enrichment facilities, and a uranium metal plant. BARC is the lead lab designing India's nuclear-powered propulsion systems.[210]

Non-proscribed military use

About 5.1 tons of the reactor-grade plutonium produced by India has been designated as a strategic stock.[211] This material is not placed under IAEA safeguards and India may use this material in the future to produce weapon-grade plutonium (for example, in breeder reactors). This material is therefore considered part of the military stock.

The entire stock of 3.2 tons of HEU is considered to be naval material. This material is believed to be enriched to about 30% of uranium-235.

Civilian material

India has separated 0.40 tons of reactor-grade plutonium that is under IAEA safeguards and therefore is considered civilian material.

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209 Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).
210 "Bhabha Atomic Research Center," Nuclear Threat Initiative, 2003. Available from http://www.nti.org/learn/facilities/829/.
211 "Global Fissile Material Report 2015" (2015), p. 32.

Pakistan

Total amount of material and production facilities

Pakistan is believed to have had about 3.1 tons of weapon-grade HEU and 0.19 tons of weapon-grade plutonium by 2014.[212] Since Pakistan has continued to produce weapon material, the amounts are probably somewhat larger in 2017.

It appears that all Pakistan's weapon material is in the country's 140 weapons, even though the weapons are believed to be stored as components.[213]

Deployed and non-deployed weapons

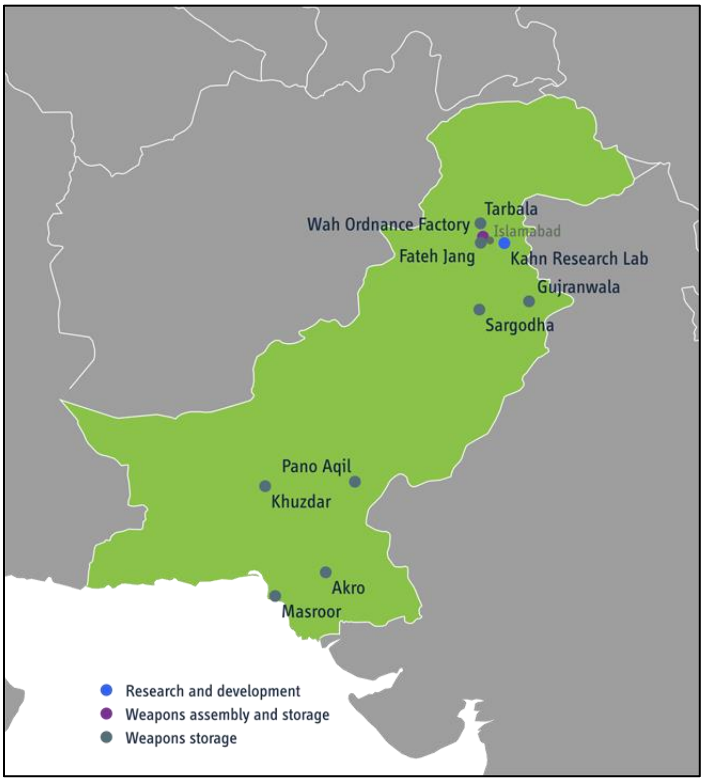
Pakistan's nuclear forces consist of short and medium range ballistic missiles, cruise missiles and strategic bombers.[214] Pakistan is believed to store nuclear weapons scattered through various depots and storage facilities across the country. At least nine sites have been identified as potential storage areas. The Sargodha Depot and Masroor may store bombs for aircraft delivery. Short range ballistic missiles may be stored at the Gujranwala Garrison and at Pano Aqil. Medium range ballistic missiles may be stored at the Khuzdar Garrison. Fatehjang appears to be involved in ballistic missile assembly and component storage. Ground launched cruise missiles may be stored at Akro; Tarbala may store various types of warheads.[215]

Pakistan's main nuclear weapons assembly and disassembly facility is likely the Wah Ordnance Facility in Punjab.[216] This facility is one of 14 locations in the Pakistan Ordnance Factories complex.

Pakistan apparently keeps all its fissile material stockpile in the form of components in deployed warheads or as stored warhead components.[217]

Research and development facilities

The Khan Research Laboratories is Pakistan's main nuclear weapons laboratory. This facility is also involved in Pakistan's missile development.[218]



Facilities in Pakistan that may be involved in handling nuclear weapons and weapons-related fissile materials. Some additional nuclear facilities may be unknown.

[212] "Global Fissile Material Report 2015" (2015), pp. 16, 27.

[213] Hans M. Kristensen and Robert S. Norris, "Pakistani Nuclear Forces, 2016," *Bulletin of the Atomic Scientists* 72, no. 6 (1 November 2016): 368–76. Available from https://doi.org/10.1080/00963402.2016.1241520.

[214] Kristensen and Norris, "Pakistani Nuclear Forces, 2016" (2016).

[215] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).

[216] Jeffrey Richelson, *Spying on the Bomb: American Nuclear Intelligence from Nazi Germany to Iran and North Korea* (W. W. Norton & Company, 2007), pp. 331–32, 343.

[217] "Pakistan Outlines Scope for FM(C)T Intended to Establish Parity with India," *IPFM Blog* (blog), 11 August 2014. Available from http://fissilematerials.org/blog/2014/08/pakistan_outlines_scope_for_fmct.html.

[218] "Kahuta - Pakistan Special Weapons Facilities", Federation of American Scientists, 2000. Available from https://fas.org/nuke/guide/pakistan/facility/kahuta.htm.

Israel

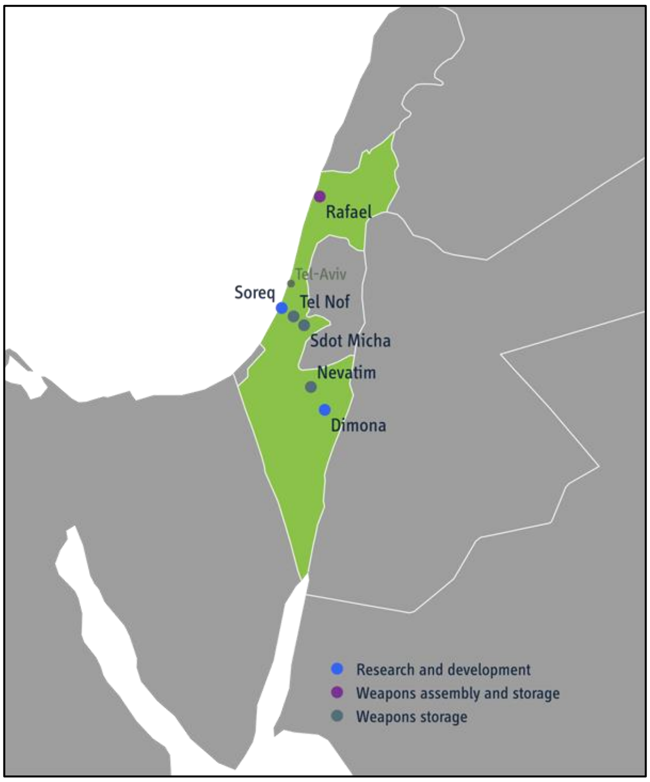
Total amount of material and production facilities

Israel's stock of plutonium produced for weapons is estimated to be 0.86 tons.[219] Most of this material appears to be in active weapons. Israel has an estimated 80–85 warheads.[220] Israel may own as much as 300kg of HEU.[221]

The centre of Israel's nuclear weapons programme is the Negev Nuclear Research Center in Dimona, where a nuclear reactor and plutonium production facility was built by France in the 1950s and 1960s. Dimona produces weapons plutonium, tritium, and warheads.[222]

Deployed and non-deployed weapons

While Israel has never officially confirmed that it possesses nuclear weapons, abundant information is available showing that the capability exists. Israel's nuclear force is believed to include land-based and sea-based missiles and bombers.[223] Land-based ballistic missiles are likely stored at the Sdot Micha missile base. Nuclear-capable aircrafts are based at the Nevatim and Tel Nof air bases. It is likely that nuclear weapon components are stored near these bases.[224] Israel's Dolphin-class submarines are based in Haifa. It is not clear if they can carry nuclear-capable missiles.



Facilities in Israel that may be involved in handling nuclear weapons and weapons-related fissile materials.

Israel likely assembles and disassembles weapons at the Rafael design laboratory, also known as Yodefat.[225]

Research and development facilities

The Soreq Nuclear Research Center may conduct research into warhead design and fabrication.[226] Soreq also conducts civilian research. The facility hosts a research reactor under IAEA safeguards, a proton cyclotron accelerator and a superconducting linear accelerator.

[219] "Global Fissile Material Report 2015" (2015), p. 26.
[220] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).
[221] "Global Fissile Material Report 2010" (2010), p. 115.
[222] "Global Fissile Material Report 2010" (2010), pp. 107–16.
[223] Hans M. Kristensen and Robert S. Norris, "Israeli Nuclear Weapons, 2014," *Bulletin of the Atomic Scientists* 70, no. 6 (1 November 2014): 97–115. Available from https://doi.org/10.1177/0096340214555409.
[224] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).
[225] "Yodefat," Nuclear Threat Initiative, 2011. Available from http://www.nti.org/learn/facilities/380/.
[226] Kristensen and Norris, "Worldwide Deployments of Nuclear Weapons, 2017" (2017).

The Democratic People's Republic of Korea

Total amount of material and production facilities

The Democratic People's Republic of Korea (DPRK) is believed to have a small stock of weapon-grade plutonium. One estimate puts it at 0.03 tons.[227] The DPRK may also have the capacity to produce HEU, but it is not known if it has produced any weapon-grade material.

Known nuclear-weapons related research and development facility in the DPRK. Locations of other nuclear-weapons and weapons-related fissile material facilities are not known.

The DPRK operates a plutonium production reactor and a centrifuge enrichment facility, both at Yongbyon. The DPRK may also operate a second enrichment plant.[228]

Deployed and non-deployed weapons

Little information is known about the DPRK nuclear weapons programme. The storage of delivery systems, key research facilities, and processes for developing weapons are largely unknown. The DPRK has been developing an ICBM capability.

[227] "Global Fissile Material Report 2015" (2015), p. 28.
[228] "North Korea", International Panel on Fissile Materials. Available from http://fissilematerials.org/countries/north_korea.html (accessed 25 October 2017).

Deferred Verification

Verifiable Declarations of Fissile Material Stocks

The report describes a verification arrangement that would allow the future Fissile Material Cut-off Treaty to include declarations of existing fissile material stocks covering all categories of materials, including materials in nuclear weapons. This arrangement, referred to as “deferred verification”, would allow declarations to be legally binding and verifiable. Combined with a ban on the production of new materials that would be established by the FMCT, this arrangement could support verification of initial declarations of fissile material stocks and the gradual elimination of all weapon-related fissile materials.

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