ROUTLEDGE HANDBOOKS

Routledge Handbook of Nuclear Proliferation and Policy

Edited by Joseph F. Pilat and Nathan E. Busch

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POLICY AND TECHNICAL ISSUES FACING A FISSILE MATERIAL (CUTOFF) TREATY

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The largest obstacle to creating nuclear weapons, starting with the ones that destroyed Hiroshima and Nagasaki, has been to make sufficient quantities of fissile materials – highly enriched uranium (HEU) and plutonium – to sustain an explosive fission chain reaction.[1] Recognition of this fact has, for more than fifty years, underpinned both the support for and the opposition to adoption of an international treaty banning at a minimum the production of more fissile materials for nuclear weapons, commonly referred to as a fissile material cutoff treaty (FMCT).

The United States first proposed an FMCT during the Eisenhower administration in the mid-1950s, suggesting at the United Nations the need "to establish effective international control of future production of fissionable materials and to exchange firm commitments to use all future production exclusively for non-weapons purposes."[2] The Soviet Union rejected the proposal. The idea of an FMCT reemerged in the early 1980s, when the Soviet Union proposed at the United Nations a "cessation of production of fissionable materials for manufacturing nuclear weapons" as an early step in freezing the arms race and towards nuclear disarmament.[3] The United States rejected the offer.

With the end of the Cold War, and the United States and Soviet Union dramatically downsizing their nuclear arsenals, the two countries finally both decided to support an FMCT in the hopes of constraining nuclear buildups by other countries. In December 1993, the United Nations General Assembly adopted by consensus a resolution calling for negotiation of a "non-discriminatory, multilateral and internationally and effectively verifiable treaty banning the production of fissile material for nuclear weapons or other nuclear explosive devices."[4] The resolution declared that the General Assembly was "convinced" that a treaty meeting these criteria "would be a significant contribution to nuclear non-proliferation in all its aspects."[5] The United Nations Conference on Disarmament (CD) in Geneva was charged with conducting the negotiations. In 1995 the CD agreed to a negotiating mandate for FMCT talks, now known as the Shannon mandate after its author Canadian Ambassador Gerald Shannon.[6]

Negotiations on an FMCT have failed to start for two decades, however, despite the passage of repeated resolutions in support of negotiations by the General Assembly, by the 1995 Nuclear Nonproliferation Treaty (NPT) Review and Extension Conference and by subsequent NPT Review Conferences. Negotiations have been blocked by the CD's requirement for consensus on an annual agenda to proceed. This requirement has allowed individual countries

– Pakistan in recent years – to block the start of talks. In 2013, in an effort to at least allow preparatory work to proceed, the General Assembly voted to establish a Group of Government Experts on the FMCT to consider issues and make recommendations in 2015 "on possible elements which could contribute to such a treaty."[7]

This chapter lays out the international community's interests in establishing an FMCT. It then discusses the issues that confront its negotiation, focusing in particular on the possible scope of a treaty and challenges to its verifiability. Finally, it looks at the prospects for the successful negotiation of a treaty.

In the remainder of this chapter, we describe the proposed treaty as a Fissile Material (Cutoff) Treaty or FM(C)T to reflect the desire by many countries that it go beyond a simple cutoff and capture under international safeguards as much as possible of the pre-existing stocks of fissile materials not currently in nuclear weapons to preclude the possibility of their future use in nuclear weapons.

Benefits of an FM(C)T

A fissile material cutoff treaty would strengthen the nonproliferation regime, reduce the risk of nuclear terrorism, and help lay a basis for nuclear disarmament in a number of ways. The balance of these achievements and the extent to which they may be realized will depend on the specifics of an eventual treaty. The general benefits are summarized briefly below.

Strengthening the nonproliferation regime

An FM(C)T would contribute to strengthening collective trust and confidence that the nuclear-weapon states that are parties to the Nonproliferation Treaty are keeping their side of the bargain underlying the treaty. In Article 6 of the NPT, the weapon states committed "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament."[8] The final document of the 1995 NPT Review and Extension Conference, which served as the basis for the indefinite extension of the NPT, included an agreement by China, France, Russia, the United Kingdom, and United States (the NPT nuclear-weapon states) to "[t]he immediate commencement and early conclusion of negotiations on a non-discriminatory and universally applicable convention banning the production of fissile material for nuclear weapons or other nuclear explosive devices."[9]

This decision was reiterated as one of the thirteen steps toward nuclear disarmament agreed at the 2000 NPT Review Conference, and as part of the "Action Plan on Disarmament" agreed at the 2010 NPT Review Conference.[10]

Capping stockpiles

By the mid-1990s, four of the five NPT nuclear-weapon states, France, Russia, the United Kingdom, and United States had, in fact, declared that they had ended their production of fissile material for weapons. China communicated informally in the same time frame that it had suspended its production of HEU and plutonium for weapons. (See Table 14.1.) But China has been unwilling to renounce the option of restarting production – apparently motivated by concerns that a buildup of US ballistic missile defenses and long-range conventional strike weapons could threaten its nuclear deterrent.[11] An FM(C)T would turn this production moratorium into a legally binding irreversible ban for the NPT weapon states as well as nonnuclear-weapon states.

The other four nuclear-armed states, the Democratic People's Republic of Korea (North Korea), Israel, India, and Pakistan, are not parties to the NPT and are believed to be still producing fissile materials in their weapons programs (see Table 14.1.) Indeed, in South Asia, Pakistan and India both appear to be increasing their rates of production by building new fissile material production facilities.[12] For the NPT nuclear-weapon states and for nonnuclear-weapon states, therefore, a major incentive to pursue an FM(C)T is to cap the nuclear arms buildup in South Asia.

Expanding safeguards to Weapon States

The NPT requires mandatory International Atomic Energy Agency (IAEA) safeguards in nonnuclear-weapons states but requires no international monitoring of even civilian fissile materials in nuclear-weapon states. The NPT weapon states have made voluntary offers of facilities and fissile materials that are available for IAEA safeguards.[13] The United Kingdom and the United States have offered all their civilian nuclear facilities, while France, Russia, and China have made more limited offers. But the IAEA has actually applied safeguards at only a few facilities because it has very limited resources and sees the safeguarding of facilities in the weapon states as a low priority – at least in the absence of an FM(C)T. Some facilities in the non-NPT weapon states have facility-specific IAEA safeguards in place as a result of the condition of supply of these facilities.

An FM(C)T would help reduce this discriminatory aspect of the NPT by extending mandatory safeguards to at least enrichment and reprocessing plants in nuclear-weapon state parties to the treaty and to any new fissile materials that those plants produced. A broader Fissile Material Treaty that also obliged weapon states to not use for weapons pre-existing stocks of fissile materials in civilian nuclear fuel cycles or declared excess for military purposes would place those materials under international safeguards as well.

Reducing the risk of nuclear terrorism

After the end of the Cold War, it was learned that accounting for fissile materials had been very loose in some weapon states. This increased the possibilities for the undetected diversion of

Table 14.1 HEU and Plutonium production history in the nuclear-weapon States

Country	*Highly enriched uranium*		*Plutonium for weapons*	
	Production start	*Production end*	*Production start*	*Production end*
United States	1944	1992	1944	1988
Russia	1949	1987/88	1948	1997
United Kingdom	1953	1963	1951	1995
France	1967	1996	1956	1992
China	1964	1987/89 (moratorium)	1966	1991 (moratorium)
Israel	?	?	1963/64	Continuing
India	1992	Continuing	1960	Continuing
Pakistan	1983	Continuing	1998	Continuing
North Korea	?	?	1986	Continuing

Source: International Panel on Fissile Materials, *Global Fissile Material Report 2010: Balancing the Books: Production and Stocks*. Princeton University Press, 2010, http://fissilematerials.org/library/gfmr10.pdf (except for North Korea).

some of these materials for use by would-be nuclear terrorists. An FM(C)T would require that nuclear-weapon states meet internationally agreed standards for the control and accounting of at least fissile materials that the treaty made subject to international monitoring.

Laying the basis for nuclear disarmament

An FM(C)T would begin to extend into all the nuclear-weapon states institutions and practices necessary for the eventual achievement of a nuclear-weapon-free world in which all nuclear-weapon states place all their fissile material stocks and production facilities under strict international safeguards.

More immediately, the global stock of fissile materials available for nuclear weapons would be further reduced if a fissile material treaty required weapon states to explicitly declare excess for weapons use all civilian fissile material and committed them to transfer fissile materials excess to their weapons requirements to civilian use or disposal under international safeguards.

Scope of a fissile material (cutoff) treaty

An early vision of the basic goals or scope of an FM(C)T was laid out in 1957 in United Nations General Assembly Resolution 1148, which called for a "disarmament agreement" that would include:

a) "the cessation of the production of fissionable materials for weapons purposes,"
b) "the complete devotion of future production of fissionable materials to non-weapons purposes under effective international control," and,
c) "the reduction of stocks of nuclear weapons through a program of transfer, on an equitable and reciprocal basis and under international supervision, of stocks of fissionable materials from weapons uses to non-weapons uses."[14]

This resolution was in part a United States effort to lock in a situation in which, at the time, the United States had larger stockpiles of HEU and plutonium than the Soviet Union.[15] The resolution had broader support, however, because other countries saw in an FM(C)T an opportunity to restrain and rollback the superpower arms race.

Reporting on the 1994–1995 discussions at the CD on the mandate for an ad hoc committee to negotiate an FM(C)T, Ambassador Shannon noted that:

> many delegations expressed concerns about a variety of issues relating to fissile material, including the appropriate scope of the Convention. Some delegations expressed the view that this mandate would permit consideration in the Committee only of the future production of fissile material. Other delegations were of the view that the mandate would permit consideration not only of future but also of past production. Still others were of the view that consideration should not only relate to production of fissile material (past or future) but also to other issues, such as the management of such material. It has been agreed by delegations that the mandate for the establishment of the Ad Hoc Committee does not preclude any delegation from raising for consideration in the Ad Hoc Committee any of the above noted issues.[16]

During the Cold War, the NPT nuclear-weapon states, especially the United States and Soviet Union, built very large nuclear arsenals. The number of US warheads peaked at about 30,000 in the mid-1960s, and the Soviet/Russian arsenal reached 40,000 in the 1980s. Since the end of the Cold War, the United States, Russia, France, and the United Kingdom have all cut back their nuclear arsenals. (See Table 14.2.) In the case of the United States and Russia, reductions have amounted to tens of thousands of weapons. The United Kingdom and France have reduced proportionately by hundreds of weapons each.

These nuclear arsenal reductions have freed up huge quantities of excess fissile material. Indeed, Russia has sold to the United States for power reactor fuel 500 metric tons of weapon-grade uranium (≥90 percent U-235), after down-blending it to an enrichment of about 5 percent U-235. This is often described as being the equivalent of the amount of HEU in 20,000 nuclear warheads.[17] The last of the 500 tons of blended-down Russian weapons HEU was shipped in November 2013. The United States has committed to down-blend about 200 tons of less than weapon-grade HEU and has allocated 152 tons of excess weapon-grade uranium to a reserve for future use as naval reactor fuel.[18]

Russia and the United States also have each declared 34 tons of plutonium from weapons to be excess for weapon use. France has declared no fissile material excess despite the reduction of its nuclear arsenal to half its Cold War peak.[19] The United Kingdom declared 0.9 tons of weapon-grade plutonium excess in 1998 but, in 2013, announced that fissile material from dismantled warheads will be returned to its military stockpile and will not be placed under IAEA safeguards.[20] Globally, roughly half of the material from weapons reductions has been declared as excess to military requirements. In addition, there are huge stockpiles of civilian plutonium that are a legacy of failed efforts in the industrialized states to commercialize plutonium breeder reactors. (See Table 14.3.)

Under the 1998 agreement on Plutonium Management Guidelines, all five NPT nuclear-weapon states committed to declare annually and publicly to the IAEA the quantities of plutonium in their civilian nuclear fuel cycles.[21] Although there is no explicit obligation in the guidelines that this plutonium will not be used for nuclear weapons, this level of transparency does imply an intention not to do so.

Pre-existing stocks under an FM(C)T

The NPT weapon states have agreed among themselves only to support a treaty that would ban future production of fissile materials for nuclear weapons. As in 1957, however, other states are concerned about how a treaty will deal with the very large stockpiles of weapon-usable

Table 14.2 Declared and estimated nuclear warhead stockpiles

Country	*Nuclear warheads (current)*	*Nuclear warheads (historic peak)*
United States	~ 7,700 (including retired)	31,255 (declared)
Russia	~ 10,000 (including retired)	~ 40,000 (high uncertainty)
United Kingdom	fewer than 225 (declared)	~ 520
France	fewer than 300 (declared)	~ 540
China	~ 240	~ 240
Israel	100–200	(unknown)
India	80–100	80–100
Pakistan	100–120	100–120
North Korea	Fewer than 10	Fewer than 10

Source: Adapted from Hans M. Kristensen and Robert S. Norris, "Global Nuclear Weapons Inventories, 1945–2013," *Bulletin of the Atomic Scientists*, Vol. 69, No. 5 (September/October 2013), pp. 75–81.

Table 14.3 Estimated and Declared (D) fissile material stockpiles of the nuclear-weapon states

Country	*Highly Enriched Uranium*		*Separated Plutonium*	
	Military	*Civilian*	*Military*	*Civilian*
United States	512 tons (D)	83 tons (D)	38.3 tons (D)	49.3 (D)
Russia	646 tons	20 tons	88	89.5 tons (D)
United Kingdom	19.8 tons (D)	1.4 tons (D)	3.2 tons (D)	91.2 tons (D)
France	26 tons	4.7 tons (D)	6.0 tons	57.5 tons (D)
China	16 tons	–	1.8 tons	0.01 (D)
Israel	0.3 tons	–	0.84 tons	–
India	2.4 tons	–	0.5 tons	5 tons
Pakistan	3.0 tons	–	0.15 tons	–
North Korea	?	–	0.03 tons	–

Note: Fissile material declared excess for military purposes is counted as civilian even though it is not under international safeguards, as is India's five tons of unsafeguarded plutonium intended for use as fast-breeder reactor fuel.

Source: International Panel on Fissile Materials, *Global Fissile Material Report 2013: Increasing Transparency of Nuclear Warhead and Fissile Material Stocks as a Step toward Disarmament*, Princeton University, October 2013, www.fissilematerials.org/library/gfmr13.pdf.

material that have already accumulated worldwide – estimated at about 1,400 metric tons of highly-enriched uranium and 500 tons of separated plutonium as of the end of 2012.[22] Almost all of this material is in the nuclear-weapon states and is still sufficient to increase many-fold the approximately 10,000 operational nuclear warheads in the global nuclear-weapon stockpile today.[23]

Assuming an average of 4 kg of plutonium and 25 kg of HEU per warhead, as suggested by the historical quantities produced by the Soviet Union and the United States, they each would require only 20 tons of plutonium and 125 tons of HEU for arsenals of 5,000 warheads. Even adding in 100 and 50 tons of HEU, respectively, to fuel US and Russian nuclear-powered ships and submarines for the next fifty years, the two countries could declare much more fissile material excess for military purposes. Russia could reduce its military stocks by about 400 tons of HEU and 60 tons of separated plutonium, and the United States by about 200 tons of HEU and 20 tons of plutonium. France and the United Kingdom also have more weapons materials than they need since each of them has downsized its nuclear-warhead stockpile by about a factor of two since the end of the Cold War.[24] The combined stocks of separated civilian but weapon-usable plutonium owned by United Kingdom, France, and Russia amount to about 200 tons. Altogether, the weapons states could declare over 600 tons of HEU and 250 tons of separated plutonium excess for military purposes and place these materials under IAEA safeguards.

For most of the past two decades, Pakistan has been the most vocal state in insisting that an FM(C)T address existing stockpiles as well as future production. Pakistan points specifically to a stockpile of about 5 tons of separated non-weapon-grade but weapon-useable plutonium accumulated by India for its breeder-reactor program.[25] Pakistan is not alone, however, in wanting to broaden the cutoff treaty proposal into a fissile material treaty that would include reductions of existing stocks of fissile material available for nuclear-weapons use. Many nonnuclear-weapon states see this as a means for the treaty to make nuclear disarmament more irreversible.[26]

As far back as 1996, at their Nuclear Safety and Security Summit in Moscow, four of the weapon states (France, Russia, the United Kingdom, and the United States) declared their intention to do exactly this: "We pledge our support for efforts to ensure that all sensitive nuclear material (separated plutonium and highly enriched uranium) designated as not intended for use for meeting defence requirements is safely stored, protected and placed under I.A.E.A. safeguards (in the Nuclear-Weapon States, under the relevant voluntary offer I.A.E.A.-safeguards agreements) as soon as it is practicable to do so."[27]

At the 2000 NPT Review Conference, all five of the NPT weapon states, including China, agreed to a final conference document that included a call for

> all nuclear-weapon States to place, as soon as practicable, fissile material designated by each of them as no longer required for military purposes under IAEA or other relevant international verification and arrangements for the disposition of such material for peaceful purposes, to ensure that such material remains permanently outside military programmes."[28]

Verification has not been totally absent from the HEU-disposal programs thus far. The United States verified that the blend-down of the 500 tons of excess weapon-grade HEU that Russia sold to the United States during 1993–2013 came from metal stated to be shredded nuclear-weapon components, and the IAEA monitored the blend-down of about 50 tons of excess US HEU.[29] Also, in their bilateral agreement to each eliminate 34 tons of weapon-grade plutonium, Russia and the United States committed that the IAEA will be allowed to verify the disposal process.[30] Nevertheless, the five NPT weapon states argue today against broadening a FM(C)T to cover pre-existing fissile materials on the ground that it would make negotiation of an FM(C)T impossible.

Production for civilian and naval-reactor fuel

It is generally agreed that an FM(C)T will permit production of fissile materials for civilian and naval-reactor fuel. This is despite the fact that neither use is necessary. The economic benefits of civilian plutonium separation and recycle in fuel are negative today. The value of plutonium-containing fuel is only a small fraction of the cost of separating the plutonium,[31] and there are no significant environmental benefits from recycling plutonium in the reactors that produced it.[32]

Also, the danger that reprocessing will destabilize the nonproliferation regime is very significant. Currently, Japan is the only nonnuclear-weapon state that separates plutonium, but South Korea is demanding the same "right."[33] In the past, Argentina, Brazil, South Korea, and Taiwan all pursued nominally civilian reprocessing programs that were later revealed to be covers for the development of nuclear-weapon capabilities. China, France, India, Japan, and Russia all separate plutonium from spent power-reactor fuel for recycle or use in breeder reactor development programs, however, so it currently appears to be politically infeasible to ban plutonium separation for civilian purposes in an FM(C)T.

Similarly, the United States, United Kingdom, Russia, and India all use HEU for naval propulsion reactor fuel. Here again, the example of the weapon states could destabilize the nonproliferation regime. Brazil is the first nonnuclear-weapon state to launch a program to develop nuclear submarines. It is planning to initially use low-enriched uranium (LEU) fuel but has left its options open with regard to the possible use of HEU in the future.

Large stockpiles of HEU for naval reactor use also could make nuclear reductions more difficult in the future. The United States is the only weapon state that has publicly declared a stockpile of HEU for future use in naval-reactor fuel but the huge size of this stockpile makes the problem apparent: 152 metric tons of weapon-grade uranium is enough, by the conventional metric of 25 kg per warhead, for 6,000 nuclear weapons.

France uses LEU for its naval reactors and China is believed to as well. In January 2014, the US Navy acknowledged the possible feasibility of switching to LEU fuel. The United Kingdom depends on the United States for naval nuclear technology. There is no indication that the Russian and Indian navies are interested in switching to LEU fuel.[34] Until the US Government becomes actively engaged in promoting LEU fuel for naval reactors, an agreement to ban HEU production or use for naval reactor fuel at some time in the future seems politically infeasible. As will be seen below, this creates a verification problem for the FM(C)T.

Challenges to the verification of an FM(C)T

Much of the verification of an FM(C)T in weapon states could be carried out using the same procedures that have been developed to verify that nonnuclear-weapon states are living up to their commitments under the NPT not to divert fissile material to weapons purposes. Originally, these techniques focused on assuring nondiversion of declared fissile materials from facilities offered for IAEA inspection. Since the discovery by the IAEA of Iraq's clandestine enrichment program in 1991, however, there has been increasing concern about the possibility of undeclared nuclear activities. This led to the development of the Additional Protocol to the safeguards agreements of nonnuclear-weapon states, which requires states that have ratified it to declare to the IAEA nuclear-related activities, such as the production of gas centrifuges, as well as activities in which nuclear material is actually being processed. The Additional Protocol also provides the IAEA with some limited inspection options if it has grounds to believe that a country's declaration is not complete.

Still, the challenge of detecting clandestine fissile material production activities has not been definitively dealt with and would be an issue in verifying an FM(C)T just as it is today for verifying the NPT in nonnuclear-weapon states. We therefore offer here a brief overview.

Detection of clandestine plutonium production

Plutonium production and separation have signatures that may be detected at a distance. The production of one gram of weapon-grade plutonium in a reactor requires the fission of about one gram of U-235, which also releases about one megawatt-day of heat. Disposal of this heat can be detected by infrared sensors.[35]

The separation of plutonium from irradiated uranium in a reprocessing plant can be detected from the radioactive gases that are released when spent fuel is chopped up and dissolved. The radioisotope that has been the focus of such detection efforts is the 11-year half-life radioisotope krypton-85.[36]

Detection of clandestine HEU enrichment

Gaseous diffusion uranium enrichment plants (GDPs) were huge and energy intensive and therefore easy to detect from space. The gas centrifuge enrichment plants (GCPs) that have replaced them are much more difficult to detect. A GCP that could produce enough HEU for a few weapons a year would be relatively small and its energy usage per square meter would be comparable to that of buildings housing light industry or offices.[37]

Also, the UF_6 gas in GCP centrifuges is below atmospheric pressure and leakage is therefore mostly inward. A small amount of gas does escape when tanks of UF_6 feed and product are attached and detached from the piping, however. The resulting deposits on surfaces are invaluable for on-site inspections, see below.

The tunneling and security arrangements associated with Iran's underground Fordow enrichment plant are clearly identifiable with even commercial satellite imaging. (See Figure 14.1.) Determination that this facility is a centrifuge enrichment plant most probably was the result of "human intelligence," i.e., reports from individuals with access to the site.

New verification challenges in the nuclear-weapon States

Beyond the common challenge to the NPT and the FM(C)T of potential clandestine production activities, an FM(C)T would pose new verification challenges involving on-site inspections in the weapon states. Below we discuss the four most important challenges that we have identified:

1. Reprocessing plants not designed for safeguards;
2. Enrichment plants that previously produced HEU;
3. HEU in naval fuel cycles; and
4. Military nuclear facilities.

Reprocessing plants not designed for safeguards

When a nonnuclear-weapon state decides to build a reprocessing plant, it must share the design information with the IAEA and allow the IAEA to verify the design during construction to

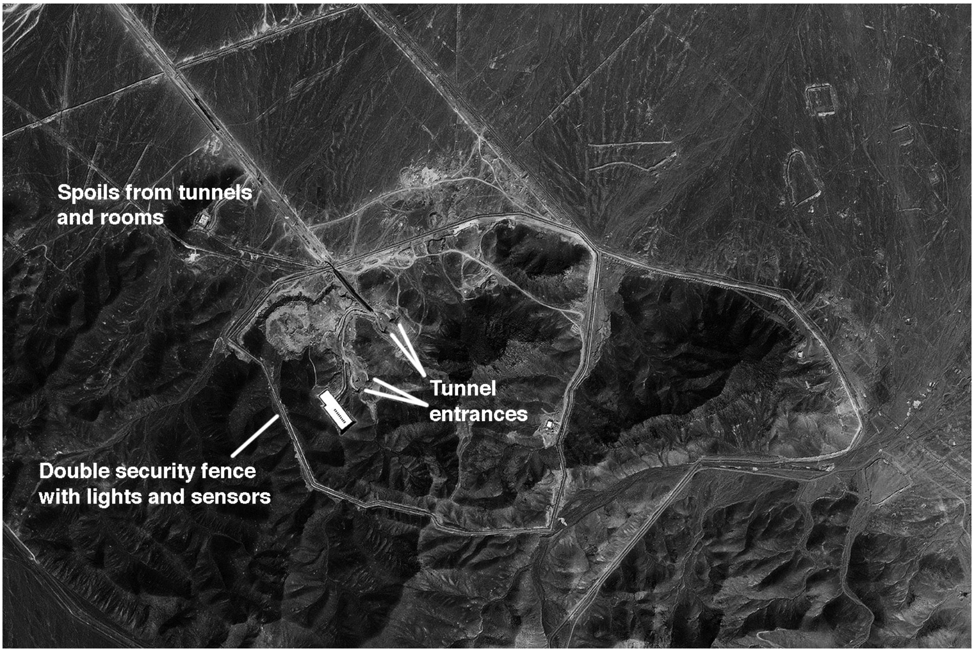

Figure 14.1 Iran's Fordow enrichment plant, May 10, 2013

assure, for example, that there is no undeclared piping that could be used to divert significant quantities of plutonium-bearing solution from the monitored process. But some of the weapon states have already operating reprocessing plants where such "design information verification" would be impossible.[38] It also would be impossible for the IAEA to install its own independent devices to measure plutonium concentrations and tank volumes in some process areas, because radiation levels are too high to allow access for the necessary installation work. This would apply to reprocessing plants in China, India, Israel, North Korea, Pakistan, Russia, and the United States.

IAEA verification of nondiversion of plutonium therefore would depend heavily on a mass balance between the plutonium in spent fuel entering the reprocessing plant and measurements of the plutonium product exiting in pure oxide form and the residual in the radioactive waste. This mass balance would be done in connection with an annual cleanout of the reprocessing plant.[39]

Even in new reprocessing plants, measurement accuracy is a problem, however. For Japan's Rokkasho Reprocessing Plant, the annual amount of plutonium separated at its design throughput of 800 metric tons per year would be about 8 tons per year. The measurement uncertainty of about 1 percent would correspond to about 80 kg per year, enough for ten Nagasaki or twenty modern implosion weapons. Having to start with an estimate of the amount of plutonium in the incoming spent fuel would exacerbate the situation since, currently, the uncertainty of these estimates is on the order of 5 percent.

Enrichment plants that previously produced HEU

Given the huge amount of excess HEU in the United States and Russia, there is no foreseeable need for either country to produce more HEU for either naval or research reactor fuel. However, Russia announced in 2012 that it has resumed the production of HEU of unspecified enrichment at one of its enrichment plants for possible use as fuel in nuclear-powered icebreaker ships and in fast reactors, both of which are civilian applications.[40] The United Kingdom depends upon the United States for its naval reactor HEU supply. France uses LEU fuel for its naval propulsion reactors, and China is believed to as well. India, however, reportedly is producing HEU to use as fuel for its growing nuclear submarine fleet.

The IAEA's most sensitive technique for the detection of undeclared HEU production in a facility is to take swipes of micron-sized dust particles from interior surfaces of the plant. The collected uranium particles are then subjected to secondary ion mass spectroscopy (SIMS) to determine their enrichment. Figure 14.2 depicts images with a SIMS of a 0.15 x 0.15 mm area of a planchette with uranium particles on its surface. U-235 ions are selected on the left and U-238 ions on the right. The pixels in the images become brighter the more ions they collect. Particles that are much brighter in the left image are HEU and those much brighter on the right are natural or low-enriched uranium. (See Figure 14.2.)

In a nonnuclear-weapon state, detection of HEU in such particles would be evidence of clandestine HEU production. The complication in the weapon states is that, in the past, some of the enrichment plants were used to produce HEU. There is also the problem that in some cases shut-down GDPs that produced HEU are adjacent to and have cross-contaminated operating GCPs that produce LEU.

The challenge therefore is to age-date the older HEU particles or to precisely measure isotopic ratios to determine the technology that produced the HEU.[41] Age-dating should be facilitated by the fact that the NPT weapon states mostly ended their production of HEU over two decades ago. The more-recently HEU-producing enrichment plants in India, Israel, North

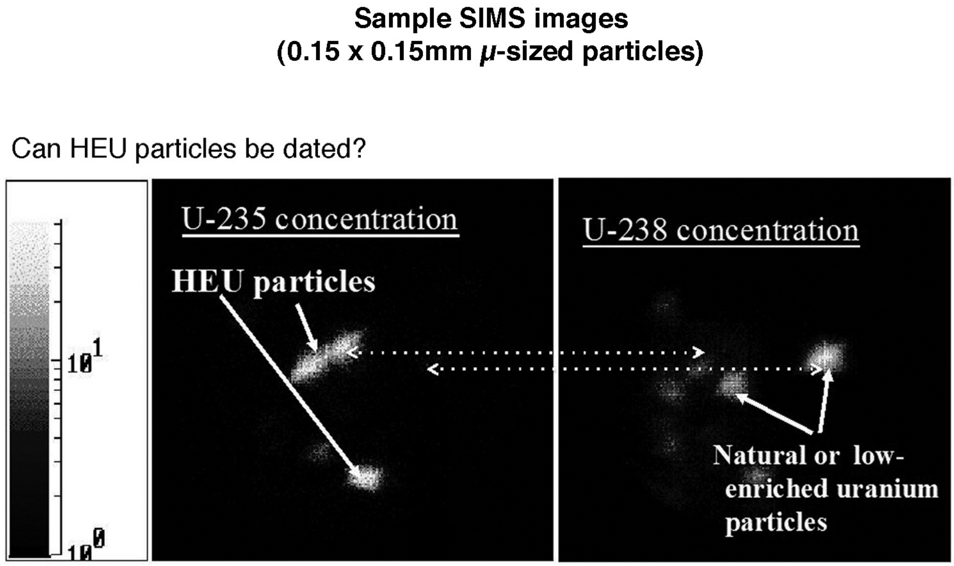

Figure 14.2 Mass spectrometer image of uranium particles

Source: Image provided by the International Atomic Energy Agency.

Korea, and Pakistan are relatively small and therefore could probably be safeguarded adequately without the use of uranium particle analysis.

HEU in naval fuel cycles

For the foreseeable future, it should not be necessary for any country other than India to produce HEU for naval fuel. For India – and the United States and Russia if IAEA monitoring is extended to pre-existing stocks of HEU for civil and nonproscribed military uses – the challenge would be to verify that HEU was not diverted from the naval fuel cycle to weapons. This challenge would be exacerbated by the fact that some countries – certainly the United States – consider the designs of their naval reactors and fuel to be sensitive information that cannot be exposed to IAEA inspectors.

A complete solution will only be possible through cooperative negotiations. In this context, it is relevant that the IAEA and Brazil, the first nonnuclear-weapon state to embark on a program to develop a nuclear-powered submarine, are engaged in discussions of how the IAEA can monitor the use of enriched uranium in Brazil's naval-reactor fuel cycle. Brazil currently plans on using LEU fuel but the IAEA monitors LEU in nonnuclear-weapon states to protect against the possibility that it might be used as feed for a small clandestine enrichment plant. The results of the IAEA's negotiations with Brazil will provide an important precedent for verification of nondiversion of HEU from weapon-state naval fuel cycles under an FM(C)T.[42]

If fuel designs are considered sensitive, it will be necessary to treat at least part of a naval fuel fabrication facility as a black box. The amount of HEU entering the fuel fabrication facility could be measured. The challenge would be to measure the amount of U-235 in the fabricated fuel – perhaps while it was concealed in a container. If the fuel were "thin," as measured by fast-neutron mean-free paths, this might be done by active interrogation with neutrons with energies less than the fission threshold of U-238, to measure U-235 fissions per incident neutron. Also, the fuel fabrication facility could be designed so that HEU could only enter or leave through monitored portals with the inspectors allowed to check for HEU within when there was no fabricated fuel present. The idea would be to ensure that no HEU left except inside a container that could be assayed. Such "containment and surveillance" is used in plutonium handling facilities to make up for material measurement uncertainties but it is doubtful that it would be considered adequate as a stand-alone arrangement without material measurements.

After fuel fabrication, the issue would become one of assuring that the fuel was loaded into a submarine or ship reactor and that no HEU remained in the container. This would require the inspectors to be present when the fuel was loaded and arrangements to assure that the fuel was actually being introduced into the reactor while not revealing its design.[43]

Finally, the reactor or reactor compartment would have to be sealed in a way that could be checked periodically to assure that it had not been opened until it was time for refueling, at which time inspectors would again observe the process to assure that all the spent fuel was transferred to a cask that could be sealed and subsequently monitored. Of course, after it was irradiated, concerns about diversion of HEU fuel would be somewhat reduced by the fact that the fuel would have to be reprocessed to recover its remaining HEU.

Military nuclear facilities

Under the FM(C)T, the IAEA would need the right to inspect any facility that it thought might house an undeclared enrichment or reprocessing facility. In the case of a reprocessing facility, the inspection would not have to be intrusive. The detection of fission products in the environment at concentrations significantly above the regional background could provide the basis for a compelling case that reprocessing was actually going on in a facility.

In the case of a nonnuclear-weapon state, the IAEA is willing to negotiate "managed access" at sensitive facilities to protect the host's sensitive military or business information while assuring that there are no undeclared nuclear activities. There are no sensitive facilities with nuclear activities in them in nonnuclear-weapon states – except potentially now in Brazil with its naval propulsion program.

Determining nonintrusively whether uranium enrichment was going on in a facility might require some on-site measurements. In the case of weapon states, however, the IAEA would likely not be allowed to make measurements that would reveal information relating to the military nuclear activities at the site.

The nuclear-weapon states that are parties to the Chemical Weapons Convention (all but Israel and North Korea) have already committed themselves to allow inspections anywhere – with managed access if necessary. This includes at chemical plants that consider their processes sensitive proprietary information. To enable verification in such facilities, the Organisation for the Prohibition of Chemical Weapons has developed a gas-chromatograph mass spectrometer that is blinded to all information except for the unique signatures of chemical weapon-related materials. The electronic measurements made by the instrument are compared to a library that contains only the characteristic signatures of chemical-weapon-related species, precursors, and degradation products. Beyond the positive or negative results of these comparisons, the instrument has no memory to store the measurements that it has made.

The characteristic signature of a centrifuge enrichment plant would be degradation products of UF_6, typically UF_2O_2. The spectral analysis program of a laser induced breakdown spectrometer could be designed to give a positive signal only if it detected the atomic spectra of uranium and fluorine at the same spot. An instrument for this purpose appears to have been developed at the US Los Alamos National Laboratory. In Figure 14.3 below, laser induced breakdown spectrometry (LIBS) uses a laser to create plasma from a small amount of surface material. A spectrograph analyzes the light emitted from the plasma to identify the elements that it contains. The Mars rover, *Curiosity*, contains such an instrument. The figure on the right shows a LIBS instrument developed by Los Alamos National Laboratory for IAEA safeguards applications. (See Figure 14.3.)

Prospects for an FM(C)T

Breaking the logjam of negotiations at the United Nations Conference on Disarmament will require decisions by key states to give priority to this goal. In the short term, the most obvious policy shift will be required from Pakistan. It will have to drop its objections to allowing the start of FM(C)T negotiations at the CD. Blocking talks on an FM(C)T enables Pakistan to continue to build up its fissile material stockpile and to highlight to the international community its concerns about a fissile material gap with India and the consequences of India's current military buildup, especially India's search for missile defenses, and the consequences of the 2005 US-India nuclear deal. Holding up an FM(C)T also allows Pakistan's nuclear establishment to keep open the prospect of a nuclear deal of its own.[44]

As of 2014, Pakistan has been able to block progress on an FM(C)T at the CD for over a decade because the United States and other leading states have been unwilling to give priority to an FM(C)T relative to more pressing issues such as the war in Afghanistan since 2001 for which Pakistan's cooperation has been required. When that war winds down it may be possible to give the FM(C)T more priority, especially for the United States. States wishing to begin work on an FM(C)T might also assure Pakistan that they will join an effort to find ways for

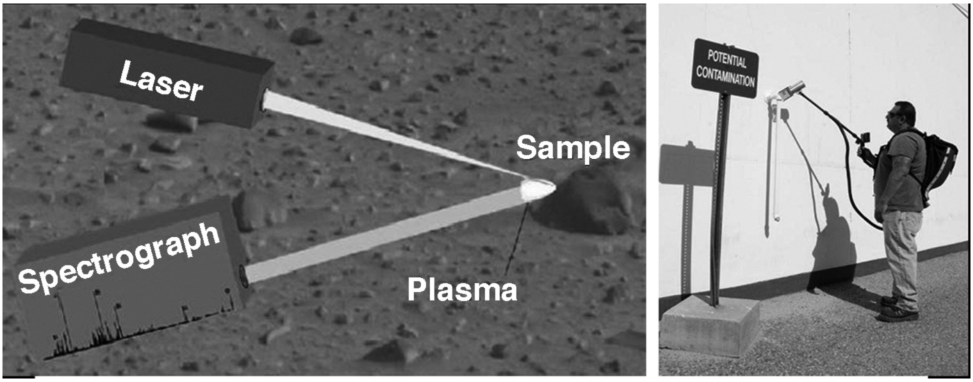

Figure 14.3 Laser-induced spectral analysis

Source: The image on the left is taken from US National Aeronautics and Space Administration, "Schematic of Laser-Induced Breakdown Spectroscopy," NASA mission website, www.nasa.gov/mission_pages/msl/multimedia/pia15103_prt.htm. The image on the right is reproduced from J.E. Barefield II, S.M. Clegg, Loan A. Le, and Leon Lopez, "Development of Laser Induced Breakdown Spectroscopy Instrumentation for Safeguards Applications," paper presented at Preparing for Future Verification Challenges: Symposium on International Safeguards, International Atomic Energy Agency, Vienna, November 1–5, 2010, www.iaea.org/safeguards/Symposium/2010/Documents/PapersRepository/134.pdf.

the treaty to cover at least some fissile material stockpiles in an effective way. One focus could be a willingness to address Pakistan's concerns about India's stockpile of unsafeguarded separated power reactor plutonium.[45]

Pakistan is not the only hold-out to progress on an FM(C)T. Israel's current prime minister, Benjamin Netanyahu, has made clear that, while it will not join Pakistan in blocking negotiations, Israel does not currently have any intention to sign an FM(C)T.[46] Israel sees the FM(C)T in the context of its larger security diplomacy with its neighbors and insists that a peace settlement with its Middle East neighbors must come before it accepts any treaty limitations on its nuclear program. Depending on how they progress, recent developments in the region such as Syria's accession in 2013 to the Chemical Weapons Convention, the prospect of a negotiated resolution of the crisis over Iran's nuclear program, and growing support, including in Israel, for a Middle East zone free of nuclear and all other weapons of mass destruction, could lead to increased pressure for a change in Israel's policy.[47]

China, like Israel, has reservations about joining an FM(C)T and thereby permanently capping its nuclear arsenal until other security issues are dealt with first. In the case of China, these issues are related to the potential of US long-range conventional precision strike weapons and ballistic-missile-defenses becoming a threat to the survivability of China's nuclear weapons and to the likelihood that these weapons would reach their intended targets.

For any FM(C)T treaty to be a meaningful contribution to the larger and longer term goal of verifiable nuclear disarmament will require a willingness by weapon states to open parts of their military programs to managed access by international inspectors. A key challenge will be military naval fuel cycles – some of which contain large amounts of HEU. Establishing a verification approach for naval fuel will require cooperative work in advance of an FM(C)T by nuclear-weapon states, nonnuclear-weapon states, and the IAEA. An alternative approach with additional security benefits would be a parallel agreement to design future nuclear propulsion reactors to be fueled by LEU.[48]

To verify an FM(C)T, the extra safeguards costs could double the IAEA's current safeguards budget for its activities in nonnuclear-weapon states – on the order of $250 million in 2013.[49] However, this is less than 1 percent of the current annual cost of US nuclear forces alone.[50] One option would be for all IAEA member states to pay for the extra safeguards effort. Not all members of the IAEA would initially be parties to the FM(C)T, however. A second option could be for all states parties to the FM(C)T to pay the additional safeguards costs. Under a third option, the nuclear-weapon states would pay for the extra safeguards costs. Regardless, since disarmament and nonproliferation are common interests, the international community should not have too much trouble finding a way to fund the verification of a treaty once it is agreed.

Notes

1. Key parts of this essay are based on a longer discussion of these issues in *Global Fissile Material Report 2008* by the International Panel on Fissile Materials (IPFM) and its companion volume reviewing the perspectives of some key states towards an FM(C)T. *Global Fissile Material Report 2008: Scope and Verification of a Fissile Material (Cutoff) Treaty* (Princeton, NJ: Princeton University Press, 2008). The companion volume is International Panel on Fissile Materials, *Country Perspectives on the Challenges to a Fissile Material (Cutoff) Treaty* (Princeton, NJ: Princeton University Press, 2008).
2. United Nations, "United States Memorandum Submitted to the First Committee of the General Assembly," United Nations document A/C.l/783, 12 January 1957. For a history of early United States discussions on an FMCT and related primary documents, see William Burr, "'We can't go on the way we are': US Proposals for a Fissile Material Production Cutoff and Disarmament Diplomacy during the 1950s and 60s," National Security Archive, June 16, 2010, www2.gwu.edu/~nsarchiv/nukevault/ebb321.

3. United Nations, "Statement by Andrei A. Gromyko, Minister of Foreign Affairs of the USSR," Plenary Meeting of the Second Special Session of the United Nations General Assembly Devoted to Disarmament, June 12, 1982; for a transcript see provisional verbatim record United Nations General Assembly twelfth special session, A/S-12/PV.12, June 18, 1982.
4. United Nations General Assembly Resolution A/RES/48/75L, 16 December 1993.
5. Ibid.
6. United Nations Conference on Disarmament, "Report of Ambassador Gerald E. Shannon of Canada on Consultations on the most Appropriate Arrangement to Negotiate a Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices," CD/1299, March 24, 1995, available at www.fas.org/programs/ssp/nukes/armscontrol/shannon.html.
7. United Nations General Assembly Resolution A/RES/67/53, 4 January 2013, www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/67/53. It calls for the Secretary General to seek the views of member states on an FMCT and for the creation of a United Nations Group of Governmental Experts (GGE) from twenty-five states (based upon equitable geographic representation) to meet in 2014 and 2015 and report in 2015 to the General Assembly and to the Conference on Disarmament.
8. For the text of the Nuclear Nonproliferation Treaty, see United Nations Office for Disarmament Affairs, "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)," July 1, 1968, www.un.org/disarmament/WMD/Nuclear/NPTtext.shtml.
9. The initial duration of the NPT was set at twenty-five years, after which "a conference shall be convened to decide whether the Treaty shall continue in force indefinitely, or shall be extended for an additional fixed period or periods." Final Document, NPT Review and Extension Conference 1995, NPT/CONF.1995/32 (PARTI). See United Nations Office for Disarmament Affairs, "Decision 2: Principles and Objectives for Nuclear Non-Proliferation and Disarmament," NPT/CONF.1995/32, 1995 Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, New York, April 17–May 12, 1995, www.un.org/disarmament/WMD/Nuclear/1995-NPT/pdf/NPT_CONF199501.pdf.
10. For the final documents of the 2000 and 2010 NPT Review Conferences, see United Nations Office of Disarmament Affairs, www.un.org/disarmament/WMD/Nuclear/NPT_Review_Conferences.shtml.
11. Li Bin, "China," in *Country Perspectives on the Challenges to a Fissile Material (Cutoff) Treaty,* International Panel on Fissile Materials, Princeton University, 2008, pp. 7–13, http://fissilematerials.org/library/gfmr08cv.pdf.
12. Pakistan is building additional plutonium production reactors while India is expanding its uranium enrichment plant, building a second enrichment plant, and constructing new reprocessing plants.
13. International Panel on Fissile Materials, *Global Fissile Material Report 2007*, Princeton University, 2007, http://fissilematerials.org/library/gfmr07.pdf.
14. United Nations General Assembly "Resolution 1148 (XII)," November 14, 1957, www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/1148(XII)&Lang=E&Area=RESOLUTION.
15. International Panel on Fissile Materials, *Global Fissile Material Report 2010: Balancing the Books: Production and Stocks*, Princeton University, 2010, http://fissilematerials.org/library/gfmr10.pdf. See also, e.g., US Arms Control and Disarmament Agency, "A Cutoff of Production of Fissionable Materials for Weapons Use with Demonstrated Destruction of Nuclear Weapons and Transfer of Fissionable Material Therefrom to Non-Weapons Uses," October 18, 1965, www2.gwu.edu/~nsarchiv/nukevault/ebb321/21.PDF.
16. United Nations Conference on Disarmament, "Report of Ambassador Gerald E. Shannon."
17. United States Enrichment Corporation, "Megatons to megawatts," www.usec.com/russian-contracts/megatons-megawatts.
18. International Panel on Fissile Materials, *Global Fissile Material Report 2010.*
19. Ibid.
20. For details of the United Kingdom's statement see "UK Nuclear Warhead Dismantlement Program," IPFM blog, August 26, 2013, fissilematerials.org/blog/2013/08/uk_nuclear_warhead_disman.html. For primary sources see Rob Edwards, "Three of Britain's nuclear warheads are being dismantled every year," August 11, 2013, www.robedwards.com/2013/08/three-of-britains-nuclear-warheads-are-being-dismantled-every-year.html.
21. International Atomic Energy Agency, "Communication Received from Certain Member States Concerning their Policies Regarding the Management of Plutonium," INFCIRC/549, March 16, 1998, www.iaea.org/Publications/Documents/Infcircs/1998/infcirc549.pdf.

22. International Panel on Fissile Materials, *Global Fissile Material Report 2013: Increasing Transparency of Nuclear Warhead and Fissile Material Stocks as a Step toward Disarmament*, Princeton University, October 2013, http://fissilematerials.org/library/gfmr13.pdf.
23. Hans M. Kristensen and Robert S. Norris, "Global Nuclear Weapons Inventories, 1945–2013," *Bulletin of the Atomic Scientists*, Vol. 69, No. 5 (September/October 2013), pp. 75–81.
24. The United Kingdom presumably is keeping its excess weapons HEU for future naval fuel use. France has shifted to using fuel enriched to the level that it produces for its nuclear power plants.
25. Zia Mian and A.H. Nayyar, "Playing the Nuclear Game: Pakistan and the Fissile Material Cutoff Treaty," *Arms Control Today*, Vol. 40, No. 3 (April 2010), pp. 17–24, www.armscontrol.org/act/2010_04/Mian.
26. In 2013, at the Conference for Disarmament, Iran, Ireland, South Africa, and Switzerland argued that an FMCT should include stockpile reductions if it was to make a contribution to disarmament. See Reaching Critical Will, "Stockpiles or No Stockpiles," *CD Report*, March 12, 2013, http://reachingcriticalwill.org/disarmament-fora/cd/2013/reports/7501-stockpiles-or-no-stockpiles. Previously at the Conference on Disarmament, Brazil, Japan, and New Zealand also raised the need for including stocks in an FM(C)T.
27. "Moscow [G8] Nuclear Safety and Security Summit Declaration," April 20, 1996, www.g7.utoronto.ca/summit/1996moscow/declaration.html.
28. United Nations Office of Disarmament Affairs, "Review Conference of the Parties to the Treaty on the Nonproliferation of Nuclear Weapons," final document, 2000, www.un.org/disarmament/WMD/Nuclear/NPT_Review_Conferences.shtml.
29. International Atomic Energy Agency, "Management of High-Enriched Uranium for Peaceful Purposes: Status and Trends," IAEA-TECDOC-1452, June 2005, pp. 16, 18, www-pub.iaea.org/mtcd/publications/pdf/te_1452_web.pdf.
30. United States Department of State, "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 the 2010 Protocol," April 13, 2010, www.state.gov/documents/organization/18557.pdf.
31. See e.g. Matthew Bunn, Steve Fetter, John Holdren and Bob van der Zwaan, "The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel," *Nuclear Technology,* Vol. 150 (June 2005), p. 209; and Frank von Hippel, "The Costs and Benefits of Reprocessing," in *Nuclear Power's Global Expansion: Weighing Its Costs and Risks*, edited by Henry Sokolski (Carlisle, PA: Strategic Studies Institute, 2010).
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33. Frank von Hippel, "South Korean Reprocessing: An Unnecessary Threat to the Nonproliferation Regime," *Arms Control Today*, Vol. 40, No. 3 (March 2010), pp. 22–29, www.armscontrol.org/act/2010_03/VonHippel.
34. US Department of Energy, "Report on Low Enriched Uranium for Naval Reactor Cores," Report to Congress, Office of Naval Reactors, January 2014.
35. Barbara G. Levi, David H. Albright, and Frank von Hippel, "Stopping the Production of Fissile Materials for Weapons," *Scientific American*, Vol. 253, No. 3 (September 1985), pp. 40–47; Hui Zhang and Frank N. von Hippel, "Using Commercial Imaging Satellites to Detect the Operation of Plutonium-Production Reactors and Gaseous-Diffusion Plants," *Science & Global Security*, Vol. 8, No. 3 (September 2000), pp. 219–271.
36. R. Scott Kemp, "A Performance Estimate for the Detection of Undeclared Nuclear-fuel Reprocessing by Atmospheric ^{85}Kr," *Journal of Environmental Radioactivity*, Vol. 99, No. 8 (August 2008), pp.1341–1348.
37. The building housing Iran's Natanz Pilot Enrichment Plant, with over 1,000 centrifuges, has an area of only about 2,000 m^2. Urenco centrifuges consume only about 5 Watts per SWU per year, www.urenco.com/page/20/Centrifuge-cascades.aspx. To produce 4,000 SWUs per year, sufficient to produce enough HEU for a weapon, would therefore require about 20 kWt.
38. For a list of reprocessing plants, see International Panel on Fissile Materials, *Global Fissile Material Report 2013.* The military reprocessing plants in Israel and North Korea would most likely shut down under an FM(C)T. The civilian reprocessing plants in France and the United Kingdom have been subject to Euratom safeguards.

39. Shirley Johnson, "Safeguards at Reprocessing Plants under a Fissile Material (Cutoff) Treaty," IPFM Research Report #6, International Panel on Fissile Materials, Princeton University, February 2009 , http://fissilematerials.org/library/rr06.pdf.
40. Pavel Podvig, "Russia is Set to Produce New Highly-enriched Uranium," International Panel on Fissile Materials blog, June 1, 2012 fissilematerials.org/blog/2012/06/russia_to_resume_producti.html.
41. A. Glaser and S. Burger, "Verification of a Fissile Material Cutoff Treaty: The Case of Enrichment Facilities and the Role of Ultra-trace Level Isotope Ratio Analysis," *Journal of Radioanalytical and Nuclear Chemistry*, Vol. 280, No.1 (April 2009), pp. 85–90. http://link.springer.com/article/10.1007%2Fs10967-008-7423-0.
42. At this stage, Brazil is using conventional pressurized water reactor fuel for its submarine reactor and does not treat the reactor or fuel design as sensitive.
43. Sébastien Philippe, "Safeguarding the Military Naval Nuclear Fuel Cycle," *Journal of Nuclear Materials Management*, Vol. 42, No. 3 (Spring 2014), pp. 40–52.
44. In late 2011, Zamir Akram, Pakistan's Ambassador to the CD, said Pakistan was willing to allow the start of talks if Pakistan received the same exemption from existing nuclear trade rules that had been granted to India in 2009 by the Nuclear Suppliers Group, the organization of nuclear technology and material exporters. Tom Collina and Daniel Horner, "The South Asian Nuclear Balance: An interview with Pakistani Ambassador to the CD, Zamir Akram," *Arms Control Today*, Vol. 41, No. 10 (December 2011), pp. 8–13, www.armscontrol.org/act/2011_12/Interview_With_Pakistani_Ambassador_to_the_CD_Zamir_Akram.
45. International Panel on Fissile Materials, *Global Fissile Material Report 2013*.
46. Avner Cohen and Marvin Miller, "Israel," in *Banning the Production of Fissile Materials for Nuclear Weapons: Country Perspectives on the Challenges to a Fissile Material (Cutoff) Treaty*, International Panel on Fissile Materials, Princeton University, September 2008, pp. 27–33, http://fissilematerials.org/library/FMCT-Perspectives.pdf.
47. Frank von Hippel, Seyed Hossein Mousavian, Emad Kiyaei, Harold Feiveson, and Zia Mian, "Fissile Material Controls in the Middle East: Steps toward a Middle East Zone Free of Nuclear Weapons and all other Weapons of Mass Destruction," International Panel on Fissile Materials, Princeton, October 2013, http://fissilematerials.org/library/rr11.pdf.
48. Chunyan Ma and Frank von Hippel, "Ending the Production of Highly Enriched Uranium for Naval Reactors," *Nonproliferation Review*, Vol., No. 1 (Spring 2001), pp. 86–101, http://cns.miis.edu/npr/pdfs/81mahip.pdf.
49. Including management and administrative overhead. The IAEA's total budget appropriations for 2013 were €344 million of which: €131 million was for "nuclear verification" (mostly safeguards) including development; €108 for other activities relating to nuclear power and radioisotopes; €97 million for policy, management and administration; and €8 million for capital improvements, International Atomic Energy Agency, *Regular Budget Appropriations for 2013,* GC(56)/RES/5, September 2012, www.iaea.org/About/Policy/GC/GC56/GC56Resolutions/English/gc56res-5_en.pdf.
50. Russell Rumbaugh and Nathan Cohn, "Resolving Ambiguity: Costing Nuclear Weapons", Stimson Center, Washington, DC, June 2012, Table 4, www.stimson.org/images/uploads/research-pdfs/RESOLVING_FP_4_no_crop_marks.pdf.