The FMCT
and Cuts in Fissile Material Stockpiles

Frank N. von Hippel

In December 1993, the United Nations General Assembly adopted, by consensus, a resolution calling for negotiation of a "non-discriminatory, multilateral and international effectively verifiable treaty banning the production of fissile material for nuclear weapons or other nuclear explosive devices."[1] In March 1995, the Geneva-based Conference on Disarmament (CD) agreed to a mandate to begin negotiations on a Fissile Material Cut-off Treaty (FMCT). After several additional years of dispute over their scope and linkage with disarmament, it appears that negotiations on a FMCT may finally begin in 1999. Since no nuclear weapon can be made without using at least kilogram quantities of fissile material,[2] a verified ban on new production would make up a major portion of the regime required to monitor irreversible nuclear disarmament.

The most fundamental issues that will have to be negotiated at the CD concern how a FMCT will relate to:

- pre-existing stocks of military fissile materials in the nuclear-weapons states (NWS);
- extension into the NWS of the international safeguards regime that monitors civilian nuclear activities in non-nuclear-weapon states (NNWS) parties to the Non-Proliferation Treaty (NPT); and
- the separation and stockpiling by some countries of huge quantities of directly weapon-usable plutonium for non-weapon purposes.

In brief, the approach proposed here supports a FMCT with comprehensive safeguards on civilian nuclear facilities in all states, complemented by separate commitments from the states with the largest stockpiles of direct weapon-usable materials — civilian as well as military — to greatly reduce these stocks.

Pre-existing Stocks of Military Fissile Materials

The United States and the Russian Federation, which have the largest stockpiles, should declare their sizes and commit to reducing their total stocks of separated plutonium to levels commensurate with the warhead levels to which they have agreed for START III. Similar cuts should be made in their stocks of highly enriched uranium (HEU, uranium enriched to more than 20% U-235), although

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the situation there is complicated by stockpiles reserved for naval-reactor use.

International Monitoring

As a first step, the NWS should declare those facilities which contain fissile materials. An agreement should then be made to extend the IAEA's international safeguards regime into the NWS step-by-step until the same coverage of their civilian nuclear sectors is achieved as in NNWS. Thereafter, nuclear weapons reductions should be accompanied by transfers of fissile materials and nuclear facilities out of the exempted military nuclear sectors into the inspected sectors.

Civilian Separation of Plutonium

The goal should be to phase out the civilian separation of plutonium, which no longer has any economic rationale. In the interim, states with civilian plutonium activities should commit to disposing of all but minimal working stocks of separated plutonium.

Military Fissile Materials

None of the "P-5"[3] nations is currently thought to be producing fissile materials for nuclear weapons. Indeed, all but China have publicly announced that they have permanently ended their production of fissile materials for weapons. The "Group of 21" (G-21) non-aligned countries at the CD[4] and some other states would therefore like to see the FMCT negotiations push the P-5 to make further steps toward nuclear disarmament by requiring at least very deep cuts in their existing stocks of weapons materials. In the words of the Indonesian ambassador to the CD, "brushing aside the issue of stockpiles, would, once again, render the cut-off treaty a mere non-proliferation measure ...".[5]

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The 1995 Shannon Mandate for the FMCT negotiations recognizes this widespread interest in stockpile reductions and "does not preclude any delegation from raising for consideration of the *ad hoc* [negotiating] Committee ... past production ... and the management of such material ...".[6]

The P-5 nations insist that the most efficient route to nuclear reductions is through negotiations among themselves. Among the NWS, those with the smallest stockpiles insist that the United States and the Russian Federation must take the lead. The United States and the Russian Federation have, in fact, already declared excess significant quantities of HEU and plutonium. However, their stockpiles remaining after the reductions will still be huge (see Table 1). Thus, for example, the United States will retain about 47 tons of weapon-grade plutonium, virtually all in weapons or weapons components.[7]

Detailed information about American plutonium stocks is available because the United States has declared its total stockpile of plutonium, along with information concerning its past production and disposition. The United States has also been preparing to make a declaration of similar data about its HEU. The Russian Federation should make similar declarations and the two countries should exchange additional information and undertake joint "nuclear archaeology" projects to increase each other's confidence in their declarations of past fissile-material production and disposition activities. Having a better measure of each other's stockpiles should make both countries more willing to agree to further cuts. Other countries will have to join in these transparency measures in order for stockpile reductions to continue.

Under START II, the United States and the Russian Federation have agreed to limit their number of deployed strategic warheads to 3,000–3,500 each. However, according to the United States Natural Resources Defense Council (NRDC), even after full implementation of the treaty, the United States plans to keep a total of about 10,000 warheads plus approximately 5,000 "reserve pits" that could be reassembled into an additional 5,000 warheads.[8] Judging from Table 1, the Russian Federation appears to be keeping at least as much weapons material.

Table 1. Stockpiles of directly weapon-usable fissile materials in 1996 in metric tons

When not otherwise indicated, the source is David Albright, Frans Berkhout and William Walker, *Plutonium and Highly Enriched Uranium, 1996: World Inventories, Capabilities and Policies,* SIPRI/Oxford University Press, 1997.

1 Estimated 80% average enrichment.
2 All but 33 tons of this material is less than weapon-grade, i.e. less than 92% U-235.
3 *Plutonium: The First 50 Years*, Figure 3.
4 *Plutonium Disposition Statement* (Clinton-Yeltsin Summit, Moscow, 1 September 1998). The United States apparently added 14.5 tons fuel and reactor-grade plutonium to the 38.2 tons of weapon-grade plutonium previously declared excess.
5 Approximate amount committed for blending down to LEU and sale to the United States under the *Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted from Nuclear Weapons*, 18 February 1993.
6 *Plutonium Disposition Statement,* ibid.
7 The Russian Federation's 1998 declaration to the IAEA under the *International Guidelines for the Management of Plutonium,* ibid., www.iaea.org/worldatom/infcirc/infcirc549/a9.pdf.
8 *Strategic Defense Review*, ibid. Enrichment level not specified.
9 *Strategic Defense Review,* ibid. Of the plutonium declared excess, 0.3 tons is weapon grade.
10 British Department of Trade and Industry, 2 June 1998. In addition, Britain was storing 6.1 tons of foreign separated plutonium. Declaration to the IAEA under the *International Guidelines for the Management of Plutonium,* ibid., INFCIRC549/add. 8/1.
11 Declaration to the IAEA under the *International Guidelines for the Management of Plutonium,* ibid., INFCIRC549/add5/1. France was also storing 33.6 tons of foreign separated plutonium.
12 Declaration to the IAEA under the *International Guidelines for the Management of Plutonium*, ibid., INFCIRC549/add. 7.

In their March 1997 Helsinki Summit Statement, Presidents Clinton and Yeltsin agreed that the objective of the START III negotiations will be to reduce the number of strategic nuclear weapons deployed by each country to 2,500 or less by the year 2007. The Russian Government would like to reduce this limit to 1,500 or less, since it may be forced by its currently severe economic constraints to cut its deployed strategic warheads down to fewer than 1,000.[9]

The United States National Academy of Sciences has used "as a planning figure" for plutonium disposition the estimate that an average American warhead contains four kilograms of plutonium. On this basis, the United States and the Russian Federation could each declare excess all but 15 tons of weapon-grade plutonium and still have enough left for a few thousand warheads plus R&D and buffer stocks.

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Fissile material declared excess to military needs should be placed under IAEA safeguards. At the April 1996 G-8 "Nuclear Safety and Security Summit" in Moscow, the United States and the Russian Federation, along with Britain and France, "pledged 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 IAEA safeguards ... as soon as it is practicable to do so."[11]

For the United States and the Russian Federation to go further and actually destroy these stocks might require additional, far-reaching actions. The United States might, for example, insist that the Russian Federation dispose of its large stockpile of reactor-grade plutonium (see below). Further reductions might also require the commitments of additional NWS to both stockpile transparency and reductions. Britain has already declared its stockpiles of military fissile materials and committed to reductions in its military plutonium stockpile.[12]

The situation with reductions in the HEU stockpiles is more complex because, in the case of the United States at least, they include very large stocks reserved for American and British naval-reactor fuel use, which amounts to a few tons per year.[13] The Russian Federation, with a smaller and less active nuclear navy, uses less HEU for this purpose but does use HEU to fuel tritium-production reactors.[14]

The United States and the Russian Federation should each declare the total stocks of HEU that they have set aside for military reactor use to facilitate judgements of when these stockpiles may become obstacles to further nuclear disarmament.

The alternative to maintaining large unsafeguarded stockpiles of HEU for military reactors would be to place them under IAEA safeguards and then remove the HEU from safeguards when needed. Even countries that have declared themselves NNWS under the NPT are permitted to withdraw material from safeguards to fuel military reactors.[15]

Extension of the International Safeguards Regime in the NWS

The FMCT verification proposal preferred by the United States has raised concern because it would apply much less stringent verification requirements to the civilian nuclear-energy sectors of the NWS than are required of states that have signed the NPT as NNWS. The consensus United

Nations resolution and the Shannon Mandate explicitly call for a "non-discriminatory" treaty.

The United States favours a verification regime focused narrowly on:

- uranium enrichment plants, to determine whether or not HEU is being produced;
- spent fuel "reprocessing" plants at which plutonium or other artificial fissile isotopes made by neutron absorption[16] can be separated from highly radioactive fission products; and
- fissile materials produced after the FMCT comes into force and the facilities in which these materials are present.

This regime would be supplemented by challenge inspections involving managed access to suspect sites. This will be termed the "narrow inspection option" below.

Safeguards in NNWS cover in addition all power and research reactors fuelled by natural and low enriched uranium (LEU), and facilities at which their fuel is produced or stored. In the absence of such coverage, some LEU could be diverted without detection to a small clandestine uranium-enrichment facility to be further enriched to HEU, or some spent LEU or natural uranium fuel could be diverted to a large hot cell where the plutonium could be separated out.

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Following the discovery of the extent of Iraq's clandestine nuclear-weapons activities, the IAEA is requesting declarations of and is making spot inspections at facilities not currently involved in the nuclear fuel cycle, and of equipment and even components that could contribute to a fissile-material production programme. Monitoring is also being extended to include environmental sampling and radiation measurements at locations where activities involving fissile materials might have taken place, and to wide-area environmental sampling to detect such activities. An Additional Protocol (INFCIRC/540) authorizing such monitoring was approved by the IAEA Board of Governors in May 1997 and had been signed by thirty-two countries as of September 1998.[17]

Environmental monitoring will have to be more discriminating in NWS than NNWS because of past and continuing releases from the processing in weapon-production facilities of large quantities of unsafeguarded military materials. This strengthens the case for monitoring the entire civilian fuel cycle in NWS.

Realistically, given the large number of facilities to which safeguards will have to be applied and the large number of expert personnel that will be required, international monitoring in the NWS will have to be implemented in stages. The narrow coverage favoured by the United States is an obvious first step. However, coverage should be expanded as quickly as practicable until it is as comprehensive *outside declared military nuclear facilities* as the coverage that has been accepted by the NNWS. Even declared military nuclear facilities will have to be eligible for challenge inspections to verify that they do not contain clandestine reprocessing or enrichment facilities. All facilities in the NNWS that have accepted the Additional Protocol are already subject to "managed-access" challenge inspections by the IAEA — as they are states parties to the Chemical Weapons Convention. Managed access arrangements allow inspected countries to provide information required by international inspection teams while protecting sensitive military or proprietary information.

One argument that has been made for the narrow inspection option is that, since it would only cover tens of facilities, it should be much less costly than NPT-type broad coverage of the civilian sectors of the NWS, which would require the monitoring of approximately 1,000 additional nuclear facilities worldwide. However, a large fraction of the facilities that would have to be safeguarded under the broad coverage are reactors fuelled by LEU. Such reactors require only about one hundredth as much inspection effort as large reprocessing facilities or uranium-plutonium "mixed-oxide" (MOX) fuel fabrication plants,[18] and even that level of effort is being reduced as the IAEA introduces remote monitoring of spent-fuel pools.[19] As a result, a 1995 IAEA comparison of the annual cost of "full verification of separated fissile material and facilities capable of producing such material" (i.e. the narrow inspection option) was $90 million, only one-third less than the estimate of $140 million per year for full safeguards on all civilian facilities in the NWS.[20]

A still low-cost version of the narrow option considered by the IAEA would verify only the inputs and outputs of reprocessing plants and MOX and HEU fuel-fabrication facilities. Its weakness is that it might not detect clandestine reprocessing or enrichment of undeclared feed materials, even at the covered facilities. However, it might make sense to have such limited monitoring at military reprocessing facilities in the course of shutdown, when the implementation of full in-process safeguards for a relatively short period would be extremely costly and time-consuming.

The safeguards operations budget of the IAEA in 1997 was $60 million.[21] It would be tripled to $200 million/year for the most costly comprehensive FMCT verification approach considered in the 1995 IAEA working paper. This $140 million increase would be tiny, however, in comparison with the operational cost savings realized by the NWS as a result of shutting down their fissile-material production complexes. From 1984 through 1993, the United States alone spent about $2 billion per year on plutonium production for weapons. From 1954 through 1963, before the United States ended the production of HEU for weapons and began shutting down many of its plutonium-production reactors, the annual American rate of expenditure for the production of fissile materials for weapons averaged about $7 billion.[22]

Approximately one-half of the estimated additional safeguards burden under the comprehensive verification option would be from reprocessing and the associated plutonium recycling and storage activities.[23] This cost would therefore be saved if these activities are phased out, as recommended below.

The Problem of Large Civilian Inventories of Plutonium

The very large existing and proposed civilian programmes under which reactor-grade plutonium is being separated and stockpiled will inevitably become an issue in negotiations over a FMCT and over reduction of the stocks of military fissile materials. Twenty-five years ago, India's 1974 nuclear test demonstrated that a nominally civilian programme can be used as a cover for the production of plutonium for nuclear weapons.

The fact that most civilian plutonium is reactor grade rather than weapon grade provides small comfort.[24] According to American weapons experts: "At the lowest level of sophistication, a potential proliferating state or sub-national group using designs and technologies no more sophisticated than those used in first-generation nuclear weapons [e.g. the Nagasaki bomb] could build nuclear weapons from reactor-grade plutonium that would have an assured reliable yield of one or a few kilotons (and probable yield significantly higher than that). At the other end of the spectrum, advanced NWS such as the United States and the Russian Federation, using modern designs, could produce weapons from reactor-grade plutonium having reliable explosive yields, weight, and other characteristics generally comparable to those of weapons made from weapon-grade plutonium...".[25]

As already noted, the Russian Federation's large stockpile of reactor-grade plutonium may become a consideration in the willingness of the United States to further reduce its stockpile of weapon-grade plutonium. If the United States raises this issue, the Russian Federation may point to the very large stocks of reactor-grade plutonium in Britain and France. Similarly, China may not be willing to reduce its stockpile of military fissile material if Japan continues to maintain a very large stockpile of separated reactor-grade plutonium. Pakistan may not be willing to join in a FMCT if India continues to build up a large stockpile of separated plutonium for its breeder-reactor programme. These concerns provide one more reason why countries with very large stockpiles of separated reactor-grade plutonium should dispose of them as quickly as possible.

Recently, the Royal Society considered the problem of Britain's growing national stockpile of reactor-grade plutonium, which is expected to exceed 100 metric tons by 2010.[26] Its report found this stockpile to be a "radio-toxicity and proliferation risk" and that "the chance that the stocks of plutonium might, at some stage, be accessed for illicit weapons production is of extreme concern." It therefore urged the British Government to examine various options for disposing of the stockpile, suggesting specifically "that steps could be taken to reduce the amount added to it each year, primarily by reducing the amount of reprocessing carried out."

In fact, the end of the era of large-scale commercial reprocessing may be in sight. France and Britain, which together account for about 90% of global commercial plutonium separation (about 20 tons per year) are rapidly losing their customers. Most of their smaller reprocessing customers (Belgium, Spain, Sweden and Switzerland) have already opted for the less costly alternative of interim spent fuel storage.[27] Italy has abandoned nuclear power altogether and the Netherlands plans to do so by 2004.[28]

And now Germany and Japan, the principal foreign reprocessing customers of France and Britain (see Table 2), are also beginning to opt for storage over reprocessing. The new German Government has decided to encourage at-reactor storage of spent fuel until shutdown — thereby completing the reversal of the original German policy, which required reprocessing.[29] Japan's nuclear utilities have also begun to build more on-site storage rather than enter into new reprocessing contracts with the French or British reprocessors or complete their own very costly reprocessing plant.[30] In an era of electric power deregulation and increased price competition, the British and French nuclear utilities are likely to follow suit.

Table 2. Oxide fuel reprocessing contracts as of 1995

in metric tons heavy metal

Source: *Plutonium and Highly Enriched Uranium 1996*, ibid., pp. 162, 168.
[1] Not including fuel that had been reprocessed as of the end of 1993.

Work on the construction of a huge commercial reprocessing facility near the Russian military "plutonium city" of Krasnoyarsk-26 was halted by lack of funds in 1990.[31] Russia's Ministry of Atomic Energy (MinAtom) continues to operate the relatively small "Mayak" commercial reprocessing facility at a second closed city, Chelyabinsk-65, separating 1–2 tons of plutonium a year out of Hungarian, Bulgarian, Slovenian, Ukrainian and Russian spent fuel.[32] However, three previous customers (the Czech and Slovak Republics and Finland) have switched to interim storage; Ukraine plans to do so;[33] Hungary, currently the Russian Federation's most profitable reprocessing customer, has built an interim spent-fuel storage facility; and Bulgaria is finding its shipments of spent fuel to the Russian Federation facing increasing political opposition in the region.

India has a civilian reprocessing programme to provide plutonium for a planned prototype breeder reactor that is unlikely to be built.[34] The United States, Germany, Britain and France each spent billions of dollars on major breeder reactors demonstrating commercial applications during the 1970s and later. However, after concluding that such reactors would not be economical for the foreseeable future, they all abandoned or postponed these programmes.

To seek an immediate ban on commercial reprocessing as a part of a FMCT would doom near-term progress because France, Britain, the Russian Federation and India would all adamantly oppose any such broadening. States with civilian plutonium activities should be pressed, however, to at least dispose of all but minimum working stocks of separated plutonium. This was one of the original objectives of the Vienna-based negotiations of international "Guidelines for the Management of Plutonium". Unfortunately, these negotiations yielded only a vaguely worded, lowest common denominator commitment to "the importance of balancing supply and demand, including demand for reasonable working stocks for nuclear operations, as soon as practical."[35] Stronger commitments should be sought.

Notes

1. *Prohibition of the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices*, United Nations General Assembly resolution 48/75L.
2. Fissile material can sustain an explosive fission chain reaction. The fissile materials known to have been used in weapons are plutonium and natural uranium enriched to more than 20% in the chain-reacting isotope U-235. In addition to plutonium, however, other artificial fissile isotopes, such as U-233, can be made by neutron capture in "fertile" natural material.
3. The United Kingdom, China, France, the Russian Federation and the United States, the five permanent members of the Security Council, are also the only countries recognized as NWS in the NPT.
4. The G-21 (originally twenty-one and now thirty countries) are members of both the CD and the "Non-Aligned Movement", countries not allied with either the United States or the Soviet Union during their Cold War.
5. Agus Tarmidzi, Indonesian Ambassador to the CD, Geneva, 20 February 1997, CD/PV.756.
6. *Report of Ambassador Gerald E. Shannon of Canada on Consultations on the Most Appropriate Arrangement to Negotiate a Treaty Banning the Production of Fissile Material for Nuclear Weapons or Other Nuclear Explosive Devices*, CD/1299, 24 March 1995.
7. As of September 1994, 66.1 tons of American plutonium were either in weapons or in the "pits" of dismantled weapons stored at the Department of Energy's Pantex site (*Plutonium: The First 50 Years,* United States Department of Energy, DOE/DP-0137, February 1996, Figure 4). Out of a total of 38.2 tons of weapon-grade plutonium declared excess, 21.3 tons to be stored in Pantex in pits had been declared excess (*Fact Sheets* released at the Department of Energy's Openness Press Conference, 6 February 1996). The difference is 44.8 tons. Since the United States is retaining 47 tons of weapon-grade plutonium, this leaves approximately 2 tons of weapon-grade plutonium for R&D and working stocks.
8. Robert S. Norris and William M. Arkin, U.S. Nuclear Stockpile, *Bulletin of the Atomic Scientists*, July/August 1998, pp. 69–71. According to this report, in addition to 3,500 deployed strategic warheads, the United States plans to keep approximately 1,000 non-strategic warheads, 500 spares, 2,500 "hedge" warheads that could be re-deployed

on strategic missiles and bombers, and 3,000 "inactive-reserve" warheads.
9. David Hoffman, Troubles Invigorate Debate on Start II: Russian Crisis Saps Budget for Missiles, *Washington Post*, 19 November 1998.
10. *Management and Disposition of Excess Weapons Plutonium*, National Academy Press, 1994, p. 40.
11. *Moscow Nuclear Safety and Security Summit Declaration*, 20 April 1996.
12. *Strategic Defense Review,* United Kingdom, July 1998, www.mod.uk/policy/sdr.htm.
13. In the early 1980s, the United States was buying about 5 tons of weapon-grade uranium per year for naval reactors (T.B. Cochran, W.M. Arkin, R.S. Norris and M.M. Hoenig, *U.S. Nuclear Warhead Production*, Ballinger, 1987, p. 71). Since that time, the number of American nuclear-powered ships has declined significantly.
14. The Russian Federation uses a range of HEU enrichments in naval and ice-breaker reactor fuel. Bukharin estimates that Russian fuel use for these purposes is equivalent to about 0.4 tons of weapon-grade uranium per year. He also estimates a consumption of 1.5 tons of 90% HEU per year by two 1,000 MW (thermal) tritium-production reactors operating at an average 60% capacity factor and 30% U-235 burn-up (Oleg Bukharin, Securing Russia's HEU Stocks, *Science & Global Security 7*, 1998, pp. 311–33). However, this tritium-production capacity was sized to support a Soviet nuclear arsenal containing 30,000–40,000 warheads. The future HEU demands of Russian tritium-production reactors will therefore be much lower. The United States plans to use a power reactor fuelled by LEU to produce its weapons tritium. Neither country will need to produce tritium if the size of their warhead stockpiles continues to decline faster than the 5.5% annual decay rate of tritium.
15. Article 14 of INFCIRC/153, the safeguards agreement between the IAEA and countries that have declared themselves NNWS under the NPT.
16. "Plutonium" will hereafter be used as a shorthand to refer to all artificial fissile isotopes that would be subject to the FMCT. Today, significant quantities of artificial fissile materials are made only by use of nuclear reactors. In the future, this might also be possible using neutrons produced with high-current particle accelerators.
17. *IAEA News Briefs,* October/November 1998.
18. According to guidance provided by *IAEA Safeguards Implementation at Nuclear Fuel Cycle Facilities* (IAEA, 1985), a reprocessing plant separating 1–2 tons of plutonium per year would require 850 person-days of inspection (PDI) effort. This level of effort might be doubled for large reprocessing plants such as those operated by Britain and France, whose design outputs are about 6 and 13 tons of plutonium per year respectively. The level of inspection effort for a MOX plant might be up to 600 PDI/year. By contrast, the expected level of effort at a light-water reactor fuelled with LEU was estimated at about 15 PDI.
19. Safeguards at Light-Water Reactors: Current Practices, Future Directions, *IAEA Bulletin,* 4/1996, pp. 16–19.
20. *A Cut-off Treaty and Associated Costs*, IAEA Secretariat working paper presented at the Workshop on a Cut-Off Treaty, Toronto, Canada, 17–18 January 1995. "This paper has not been updated. The assumptions on which the paper was based have to some extent changed ... No detailed consideration was given at the time to the Euratom factor [i.e. the fact that British and French civilian nuclear facilities are already under Euratom safeguards]. So neither the arrangements under the New Partnership approach [the use of remote monitoring and other arrangements to reduce the need for on-site inspections at reactors], nor earlier arrangements have been factored in [the fact that some facilities in the NWS are already under IAEA safeguards due to "voluntary offers" and tri-lateral or other arrangements]..." (personal communication, Piet de Klerk, Director, Office of External Relations and Policy Coordination, IAEA, 1 December 1998).
21. IAEA, *Annual Report for 1997*, p. 49.
22. *Atomic Audit: The Costs and Consequences of U.S. Nuclear Weapons Since 1940,* Stephen I. Schwartz (ed.), Brookings Institution Press, 1998, pp. 560–61 (in 1996 dollars).
23. Chemical reprocessing (34%), MOX- and HEU-fuel fabrication (10%), Pu and HEU conversion (5%), and Pu and HEU storage (3%) (*A Cut-off Treaty and Associated Costs*, ibid.).
24. Weapon-grade plutonium contains less than 7% Pu-240. Reactor-grade plutonium contains more than 18%.
25. *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives,* United States Department of Energy report DoE/NN-0007, January 1997, pp. 38–39.
26. *Management of Separated Plutonium,* British Royal Society, February 1998.
27. *Nukem Market Report*, February 1998; Belgium Cancels 1991 Reprocessing Contract, Postpones Debate on MOX, *Nuclear Fuel*, 14 December 1998, pp. 16–17.
28. *Nukem Market Report,* October 1998, p. 9.
29. *Nuclear Fuel*, 2 November 1998, pp. 3–4.
30. Rokkasho Completion Delay Might Extend Until 2007, *Nuclear Fuel*, 23 February 1998, p. 9; Plans for Central Intermediate Storage Facilities for Spent Nuclear Fuel, *Nuke Info Tokyo*, May/June 1998, p. 4.
31. MinAtom Ends Plan to Reprocess at Krasnoyarsk, Will Upgrade Mayak, *Nuclear Fuel,* 2 November 1998, p. 5.
32. MinAtom Seeks to Revive Foreign Reprocessing Contracts for RT-1, *Nuclear Fuel*, 30 June 1997, p. 7.
33. Ukraine Wants EC Cooperation Pact to Add Value to Ziconium, Uranium, *Nuclear Fuel*, 5 October 1998, p. 9.

34. Despite Chronic Delays, DAE [Department of Atomic Energy] Maintains Prototype Breeder to be Built Soon, *Nuclear Fuel*, 1 December 1997, p. 9.
35. *Guidelines for the Management of Plutonium* signed by Belgium, China, France, Germany, Japan, the Russian Federation, Switzerland, the United Kingdom and the United States, and deposited with the IAEA, 1 December 1997. India was not invited to participate in these discussions because it is not a party to the NPT.