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Mitigating Security Risks from Separated Plutonium: Some Near-Term Steps

SUMMARY

Separated plutonium is a sensitive material, presenting both proliferation and nuclear security risks. However, mitigating the risks associated with separated plutonium has not been given the same level of attention as highly enriched uranium (HEU). This paper addresses the need to mitigate the risks from separated plutonium by minimizing stocks and taking specific actions in production, storage, and use of the material, including developing a code of conduct.

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This document is an updated version from the original, to reflect corrections to Table 1.

Introduction

Separated plutonium, that is, plutonium separated from irradiated fuel (or targets) by reprocessing, presents both proliferation risks and nuclear security risks. Accordingly, it is internationally recognized that separated plutonium is a sensitive material requiring special precautions during separation, storage, and use. However, mitigating the risks associated with separated plutonium has not been given the same level of attention as highly enriched uranium (HEU). HEU has been the subject of global minimization programs for some four decades.[1] There are no corresponding programs for separated plutonium.

Proliferation risks and security risks are not unrelated—some measures to mitigate security risks can also address proliferation risks, and vice versa.

Globally around 54 percent of all separated plutonium is currently held in peaceful nuclear programs, and around 46 percent is held in military programs.[2] Consideration of international action with respect to separated plutonium is limited to plutonium in peaceful programs. Regarding plutonium in military programs, it is an essential aspect of nuclear disarmament that plutonium considered excess to military requirements will be transferred irreversibly to peaceful programs, or will be rendered irrecoverable and disposed of. Plutonium transferred from military programs to peaceful programs would become subject to the measures discussed in this paper.

Although plutonium poses both proliferation risks and security risks, this paper focuses primarily on proposals to address the security risks—namely, the risk that separated plutonium could be seized or stolen by terrorists and used to build a nuclear explosive device or a radiological dispersal device. However, proliferation risks and security risks are not unrelated—some measures to mitigate security risks can also address proliferation risks, and vice versa—so this paper has some remarks with respect to mitigating proliferation risks.

A principal way to mitigate both proliferation and security risks from separated plutonium is to minimize stocks of this material, particularly eliminating non-essential holdings. Risk mitigation should also be a key consideration in handling plutonium—that is, the ways in which plutonium is produced, stored, processed, transported, and used.

The need to minimize separated plutonium stocks has been recognized by the 2014 and 2016 Nuclear Security Summits, although not as directly and specifically as is the case with HEU. The communiqué from the 2014 Nuclear Security Summit declared:

> We encourage States to … keep their stockpile of separated plutonium to the minimum level, … as consistent with national requirements.[3]

[1] The Reduced Enrichment for Research and Test Reactors (RERTR) Program dates from 1978.

[2] International Panel on Fissile Materials, *Global Fissile Material Report 2015: Nuclear Weapon Fissile Material Stockpiles and Production* (2015), available at http://fissilematerials.org/library/gfmr15.pdf.

[3] https://2009-2017.state.gov/documents/organization/237002.pdf, paragraph 21.

This is a relatively soft statement, an expression of encouragement rather than an explicit standard.

Separated plutonium was not mentioned in the 2016 Summit communiqué, but it was referred to in the Summit Action Plan in support of the International Atomic Energy Agency (IAEA). In this Action Plan, Summit participants undertook to:

> Advocate for the IAEA to support States' efforts to keep their stockpiles of separated plutonium to the minimum level, consistent with their national requirements.

As with the 2014 Summit communiqué, advocating for the IAEA to "support states' efforts" falls short of a commitment to make such efforts. The 2016 Summit communiqué affirms that the communiqués from the previous Summits will continue to guide the efforts of the participating states. In other words, what applies now is the 2014 Summit communiqué and the 2016 Summit IAEA Action Plan read together—states are encouraged keep their stockpiles of separated plutonium to the minimum level, and participants are to advocate for the IAEA to support such efforts.

The references to separated plutonium in the 2014 Summit communiqué and the 2016 Summit IAEA Action Plan are expressed in very broad terms, raising questions such as, "What should minimization mean in practice?" "What set of principles could be developed and applied?" and "How should states collaborate to encourage implementation of agreed principles?"

What Is Meant by Separated Plutonium?

Separated plutonium generally refers to *unirradiated plutonium,* that is, plutonium that has been separated from fission products and other elements by reprocessing of irradiated fuel (or targets), through fabrication into new fuel until such time that the plutonium is loaded in a reactor and irradiated. This meaning is reflected in the Convention on the Physical Protection of Nuclear Material (CPPNM) which, in its Table on the Categorization of Nuclear Material, distinguishes between unirradiated plutonium and plutonium contained in irradiated fuel.[4] This distinction is also reflected in the Guidelines for the Management of Plutonium (INFCIRC/549), discussed below, which refer to "proliferation risks during any period of storage before the plutonium is either irradiated as fuel in a reactor or permanently disposed of."

International practice is to treat mixtures that include unirradiated plutonium on a similar basis to pure plutonium.

International practice is to treat mixtures that include unirradiated plutonium on a similar basis to pure plutonium. Thus, the category of "unirradiated plutonium" includes MOX (a mix of plutonium oxide and uranium oxide), which is the form of fuel in which plutonium is generally used in current power reactor types. As noted below, however, the different isotopic, chemical, and physical forms in which unirradiated plutonium can exist have varying degrees of attractiveness for potential terrorist use.

The principal fissile isotope of plutonium is Pu-239. Plutonium used in nuclear weapons, commonly referred to as *weapon-grade plutonium,* has a Pu-239 content of more than 90 percent.[5] Currently plutonium separated from civilian spent fuel typically has a Pu-239 content ranging between 50 and 65 percent. Although such plutonium is not weapon-grade, it is described as weapons-usable, and could possibly be used by terrorists to produce a crude explosive device. Some plutonium in the civilian cycle has a Pu-239 content closer to weapon-grade,[6] and fast breeder reactors can produce weapon-grade plutonium in the breeding blanket (the fertile zone surrounding the core). Also, plutonium used in laboratories may be weapon-grade. This paper considers all forms of separated plutonium, whether weapon-grade or weapons-usable, except Pu-238.[7]

[4] *Unirradiated* is defined by the Convention on the Physical Protection of Nuclear Material as "Material not irradiated in a reactor or material irradiated in a reactor but with a radiation level equal to or less than 100 rads/hour at one metre unshielded." www.iaea.org/publications/documents/conventions/convention-physical-protection-nuclear-material.

[5] There is no internationally agreed definition of *weapon-grade plutonium,* but in the Plutonium Management Disposition Agreement (PMDA), the United States and Russia have applied a definition referring to plutonium with a Pu-240/Pu-239 ratio of less than 0.10.

[6] For example, fuel from initial core loads.

[7] Pu-238 exists in separated form only in very small quantities, outside the nuclear fuel cycle, and is not a practical material for use as the basis for a nuclear explosive. The CPPNM does not apply to plutonium comprising 80 percent or more Pu-238.

What Is Meant by Minimization?

Minimizing stocks of separated plutonium has two aspects:

1. Drawing down existing stocks and eliminating non-essential holdings of plutonium (discussed below); and
2. Bringing **supply** (separation of plutonium) into line with **demand** (consumption as reactor fuel).

The Guidelines for the Management of Plutonium (INFCIRC/549) refer to the importance of **balancing supply and demand,** allowing for **reasonable working stocks.** Once a "reasonable working stock" has been established, this indicates the goal of supply (the rate of plutonium separation) not exceeding demand (the rate of loading plutonium-based fuel in reactors) in order to avoid building up a plutonium surplus. Put another way, the Guidelines suggest that plutonium should not be separated if it is intended for stockpiling beyond the requirements for working stocks for near-term use, because such stockpiling would be clearly inconsistent with the principle of minimizing stocks.

For the few states that currently have an active program of using plutonium fuel, there is a practical requirement for working stocks—some plutonium needs to be on hand to allow for the time required to fabricate fuel and for fuel to be stored until it can be loaded in reactors. The question is, what scale of working stocks can be considered "reasonable"? This would have to consider overall fuel requirements in the state concerned, fabrication flow rates, schedule of reactor loading, facility-specific considerations, and so on. Also, there may be a case for having spare fuel assemblies on hand in case of a need to replace defective assemblies. A working stock exceeding two to three years of throughput might, however, be considered unreasonable. Currently, several states have stockpiles of civilian separated plutonium that greatly exceed this threshold, which makes the issue a sensitive one.

In current circumstances, with limited use of plutonium fuel, actions to maintain a supply/demand balance could include closing reprocessing plants (as the United Kingdom is doing), postponing the start-up of reprocessing plants, deferring new plants, and operating large plants on reduced throughput or on a campaign basis.

Guidelines for the Management of Plutonium (INFCIRC/549)

INFCIRC/549, published by the IAEA in 1998, sets out the only internationally agreed statement of management principles for plutonium in peaceful nuclear activities. The Guidelines are intended to increase transparency of the management of civilian plutonium through each participating state:

1. Declaring that its policies for the management of plutonium are based on these Guidelines; and
2. Publishing annual statements of its holdings of separated plutonium.[8]

Currently nine states subscribe to these Guidelines.[9] Other states are invited to join.

Under the heading of *Policies for the Management of Plutonium,* INFCIRC/549 refers, *inter alia,* to:

> … the need to avoid contributing to the risks of nuclear proliferation, especially during any period of storage before the plutonium is either irradiated as fuel in a reactor or permanently disposed of; … [and] … the importance of balancing supply and demand, including demand for reasonable working stocks for nuclear operations, as soon as practical.[10]

INFCIRC/549 also contains important guidelines on international transfers (including consideration of the recipient's plutonium management strategy and timetable for utilization) and levels of security. Currently, France is the only state transferring plutonium to other states (this plutonium is owned by the states concerned under reprocessing contracts).

[8] The INFCIRC/549 reporting *pro forma* does not indicate the isotopic composition of plutonium holdings.

[9] The nine states currently participating in the INFCIRC/549 arrangements are the five NPT nuclear-weapon states (China, France, Russia, the United Kingdom, and the United States) plus Belgium, Germany, Japan, and Switzerland.

[10] INFCIRC/549, paragraph 13.

Near-Term Proposals for Plutonium Management

Minimizing Stocks

As already noted, minimizing stocks of separated plutonium would involve actions to bring **supply** (separation of plutonium) into line with **demand** (consumption as reactor fuel). Ensuring a balance in plutonium supply and demand will be an ongoing effort, that is, extending over the medium- and longer-terms. In the near-term, action is required to arrest the continuing growth in stocks.

Complicating factors in balancing plutonium supply and demand include:

1. Major reprocessing states storing plutonium on behalf of customer states as well as for themselves (so inevitably they have some stocks surplus to their own requirements);
2. Growth in stocks may reflect not only ongoing plutonium separation but also transfers of excess plutonium from military stocks (an issue primarily for Russia and the United States);
3. Fuel fabricators require working stocks; and
4. Unintended delays in consumption due to plutonium-fuel-use program postponements or cancellations. Therefore, achieving a balance between supply and demand is not straightforward.

Current Status

As shown in the Appendix, overall quantities of separated plutonium in civilian programs are growing steadily—by some 54 metric tons (19 percent) over the 13-year period 2003–2016. The figures show considerable variation among different states. Putting aside the major reprocessors and the United States ex-military material, significant changes over the period include the major reduction in German holdings (Germany stopped sending spent fuel to be reprocessed in France and the United Kingdom in 2005), and the substantial increase in holdings in Japan.

By storing separated plutonium for customer states, the commercial reprocessors are helping to avoid an increase both in the size of plutonium holdings in these states and in the number of states with such holdings (this primarily concerns Japan's separated plutonium stored in France and the United Kingdom.)

Challenges

A major challenge to arresting the growth of stocks of separated plutonium and balancing supply and demand is the absence of any international agreement on limitation of separated plutonium stocks. Although the management policies set out in INFCIRC/549 are a good start, not every relevant state participates in the INFCIRC/549 arrangements (a significant non-participant is India[11]), and the Guidelines lack specificity. The Guidelines also lack normative force, as can be seen by the steady growth in global stocks of separated plutonium (see Appendix, Table 1).

What Might Be Done

Specific actions recommended in this paper for states include:

1. Committing to keep separation (reprocessing) in balance with consumption (fabrication/use in reactors). To assist in this, states could work on developing guidelines to help determine what "reasonable working stocks" mean in practice. The principles of supply/demand balance and limiting surpluses to reasonable working stocks are in INFCIRC/549, but require elaboration.
2. Ensuring that the rate of reprocessing output is consistent with the capacity to consume such output. Consistent with this objective, any new reprocessing facility or capacity should be brought on stream only at a rate corresponding to the capacity to consume the product after working down excess pre-existing stocks.
3. Exercising due care in authorizing international transfers of plutonium, including assuring that transferred plutonium will be used within a reasonable time and will not add to stockpiles in the recipient state. This principle is in INFCIRC/549.
4. Considering mechanisms and incentives to encourage states to declare surplus or excess plutonium (for example, if there is no plan to use plutonium within a defined period). Excess plutonium could be made available for consumption elsewhere (see point 5), or could be placed under IAEA control (see point 6), possibly in a state such as France or the United Kingdom that already holds plutonium on behalf of others.
5. In the medium-term, consuming or disposing plutonium accumulations; if necessary, consider international collaboration to increase the rate of consumption. Such international collaboration should include only states that already use plutonium fuel.
6. Considering development of regional or multinational plutonium storage schemes, for example as envisaged by the IAEA Statute.[12] Although this recommendation is most relevant to non-nuclear-weapon states today, on non-proliferation grounds, in the future it may also be relevant to nuclear-armed states as part of confidence-building measures in support of disarmament.

A major challenge to arresting the growth of stocks of separated plutonium and balancing supply and demand is the absence of any international agreement on limitation of separated plutonium stocks.

[11] India has been invited in the past, but has so far declined to join.

[12] IAEA Statute Article IX. Article XII.A.5 is also relevant.

A plutonium bank along the lines of the IAEA's LEU fuel bank in Kazakhstan could raise problems of cost and security (including with transport of plutonium to and from the bank). Also, adding to the states with plutonium stockpiles should be avoided. However, the concept of bringing national plutonium stockpiles under IAEA oversight could be examined. Stockpiles could be consolidated in states such as France and the United Kingdom.

7. In the medium-term, taking appropriate actions for management and disposition of excess plutonium from military programs.
8. Considering dilution and direct disposal in a deep geological repository when use of plutonium as a fuel is not practical—as currently appears to be the case in the United Kingdom and the United States.
9. Increasing transparency. The annual declarations under INFCIRC/549 are very helpful, but the declarations could be improved by not rounding the figures (participants should follow the lead of Japan, which reports to the kilogram), and if the states that hold foreign plutonium would provide a breakdown by owners (or if the owners reported on plutonium held elsewhere on their behalf, again following the lead of Japan). Transparency is also an important reason for pressing India to join the INFCIRC/549 group.

Mitigating Risks

Even small quantities could be of interest to terrorists if they see opportunities for acquiring plutonium in a number of locations or for use in a radiological dispersal device.

Risk mitigation for separated plutonium involves considering risks from the form and isotopic content of the material and the ways in which it is handled, that is, the way it is produced, stored, processed, transported, and used. Regarding the form of plutonium, broadly speaking, the level of security risk might be assessed on a spectrum running from weapon-grade plutonium metal through to high-burnup plutonium fabricated as MOX fuel elements. Regarding the handling of plutonium, the **number of locations** where it is held and used and the **number of transport movements,** etc., become key factors in assessing and addressing risk.

Another area of risk mitigation is the **elimination of non-essential holdings** of separated plutonium. In this context, *non-essential* refers to separated plutonium not proposed for energy production, where the need for this plutonium no longer applies (for example, there are no current research uses or other materials could be substituted). Plutonium has been less widely used than HEU, but nonetheless was supplied to a number of laboratories around the world, mainly in small quantities but in some cases in much larger quantities for critical assemblies and other research activities. Even small quantities could be of interest to terrorists if they see opportunities for acquiring plutonium in a number of locations or for use in a radiological dispersal device.

Although there have been long-running international programs aimed at HEU minimization, particularly conversion of United States and Soviet-supplied research reactors to LEU and removal of HEU, it is notable that there is no program of equivalent scale for plutonium—although the United States Department of

Energy's Global Threat Reduction Initiative (GTRI), mainly concerned with HEU, has been active with respect to plutonium.

Current Status

A basic problem in considering current status is that only limited information is available on how states handle separated plutonium and store small plutonium holdings. According to the annual reports lodged by participants in the INFCIRC/549 arrangements, at the end of 2016, approximately 70 percent of the total separated plutonium in civilian programs was held in storage at reprocessing plants, 4 percent was in the course of fabrication, 12 percent was in the form of MOX fuel, and 14 percent was held elsewhere (mostly excess military plutonium held by the United States).

What Might Be Done

Specific actions recommended in this paper include:

1. Thoroughly reviewing the technical and economic rationales for reprocessing, and where possible deferring reprocessing until the issues raised in this paper can be fully addressed.
2. Committing to convert plutonium into less sensitive forms where technically and economically feasible, and to convert plutonium into MOX fuel[13] as early as practicable, to increase the time needed for any attempt at weaponization.
3. Minimizing the number of sites with separated plutonium holdings and the number of transport movements of separated plutonium. This principle is in INFCIRC/549.
4. Regularly reviewing the adequacy of security for separated plutonium and developing appropriate mechanisms for providing related assurances.
5. Operating reactors to avoid production of weapon-grade plutonium where possible.
6. Where there is weapon-grade plutonium in irradiated material (for example, breeder blanket assemblies), avoiding separation that results in a weapon-grade plutonium product (for example, through in-process blending with higher burnup fuel, as Japan undertook to do with blanket assemblies if the Recycle Equipment Test Facility (RETF) at Tokai had proceeded).
7. Identifying non-essential holdings of plutonium and undertaking appropriate actions to deal with these, as has been done for HEU. Actions could include consolidating holdings (reducing the number of locations), and where possible, removal to the supplier or other suitable state.
8. In the medium-term, if reprocessing cannot be deferred, encouraging/developing reprocessing technologies that avoid output of plutonium in readily accessible form to reduce the risk of sub-national theft.
9. Including proliferation-resistance and safeguards-by-design as design objectives for new technologies.

[13] Or possibly uranium-plutonium nitride fuel, as being developed by Russia for fast reactors.

10. Encouraging facilities already using plutonium or MOX to use excess separated plutonium, or MOX fuels belonging to other utilities or states, where technically and economically feasible.
11. Placing all civilian stocks of separated plutonium under IAEA safeguards (or in the case of plutonium designated as excess to military requirements but still in classified form, placing such material under monitoring arrangements).
12. For spent fuel subject to bilateral nuclear cooperation agreements, discouraging reprocessing, and instead encouraging direct disposal or interim storage, until the conditions set out in this paper can be met.

Mechanisms for Achieving Change

Establishing a Forum for Addressing Separated Plutonium Issues

Given the existence of the INFCIRC/549 Guidelines, and the fact that its participants encompass the main plutonium producers and users, with the exception of India, the INFCIRC/549 group would appear to be a good foundation on which a forum could be established, especially if India can be persuaded to join.

Currently, however, activities pursuant to INFCIRC/549 are largely limited to participants publishing annual statements on their plutonium, and in some cases HEU, holdings. Although the INFCIRC/549 participants have convened for annual consultations in the past, it is understood this group does not function as a regular forum for cooperation or policy coordination at present. Its meetings serve as a forcing function for producing the annual reports and sharing any changes in plutonium management policies. In its annual meetings since 1997, its only substantive actions have been to amend the Guidelines to update the reference to "INFCIRC/225, Rev.3" to "INFCIRC/225 as revised." There does not appear to be any other forum that readily provides a mechanism for pursuing minimization and risk mitigation issues, except to some extent the IAEA's International Conferences on Nuclear Security.

The IAEA has the role of facilitator for the INFCIRC/549 group and could act as facilitator for an INFCIRC/549 forum. The first step would be to gain the support of the members for initiating a dialogue process. Currently the INFCIRC/549 forum is not being used in any dynamic way—turning the group into a coordinating mechanism would represent a major change. This requires key members of INFCIRC/549—the United States, the United Kingdom, France, and Japan—to actively promote this change with other members and the IAEA. Pending establishment of the forum, key members might initiate dialogue with India on stockpile and utilization issues, and the other key members could discuss these issues with Japan.

A major function of the proposed forum (or working group/committee) would be to share experience and promote best practices.

Although an INFCIRC/549 forum has some advantages, many other states have an interest in plutonium issues, so there is also a need for a process that allows broader participation. Participation in INFCIRC/549 is open-ended and other states are invited to join, but to date, membership has been focused on including states that have separated plutonium stocks, because the focus of the Guidelines is on managing existing stockpiles. The group has not sought the views of other states that might have an interest but have no stocks. INFCIRC/549 could form the basis of a broader group, or the IAEA could be asked to convene a working group or committee on plutonium management, either in parallel with or in lieu of an INFCIRC/549 forum.

A major function of the proposed forum (or working group/committee) would be to share experience and promote best practices. The forum might also develop a code of conduct, discussed below. A code of conduct could also be a key aspect of promoting best practices.

Recognizing that domestic or practical factors could make it difficult for some states to achieve a supply/demand balance in the near term, the forum could develop concepts such as placing plutonium stocks under a regional or multinational storage scheme, for example, as envisaged in the IAEA Statute (Article XII.A.5)—maybe building on the experience of the commercial reprocessors in storing plutonium on behalf of others.

What Might Be Done

Announcing the establishment of a forum on separated plutonium, or at least the intention to work toward this, would contribute to international confidence that minimization of stocks and other risk mitigation measures will receive the necessary attention. Outreach to India, to ensure participation of all states producing and using plutonium, should be an important aspect of this proposal.

Developing a Code of Conduct for Separated Plutonium

A mechanism that the proposed forum or working group/committee might consider is developing an international code of conduct for plutonium management, building on the principles in INFCIRC/549. Some ideas for elements that might be included in such a code are outlined in the numbered points in the sections above. Those elements currently included in INFCIRC/549 are indicated.

What Might Be Done

Announcing an international project to develop a code of conduct for separated plutonium would contribute to international confidence that minimization and other risk mitigation measures are being addressed.

Conclusion

Although there is general agreement, reflected in the 2014 Nuclear Security Summit communiqué and 2016 Summit IAEA Action Plan, on the need to keep stocks of separated plutonium to the minimum level, currently these stocks are continuing to increase. The INFCIRC/549 arrangement should be strengthened and turned into a mechanism for consultation and coordination on this issue and for taking forward other risk mitigation actions with respect to this material. The forum would also develop guidelines, promote best practices, and so on.

It is recommended that INFCIRC/549 participants and other interested states, together with the IAEA, should consult on the issues discussed in this paper, with the object of announcing the strengthening of the INFCIRC/549 forum, or at least progress toward this, at an early opportunity. Meanwhile, states should commit to arresting growth in separated plutonium stocks as a necessary first step in minimizing plutonium stocks and bringing plutonium supply into line with consumption. In addition, non-essential holdings of separated plutonium should be identified and appropriate actions taken to deal with them.

Appendix

Table 1. Civilian Stocks of Separated Plutonium (Metric Tons)

	End 2003			End 2016		
	A. Holdings in-country	B. Holdings in other states	C. Holdings for others (included in A)	A. Holdings in-country	B. Holdings in other states	C. Holdings for others (included in A)
Belgium	3.5	0.4	—	[a]	—	—
France	78.6	—	30.5	81.7	—	16.3
Germany	12.5	13.5	—	0.5	1.5[b]	—
India	1.5	—	—	2.9[b]	—	—
Japan	5.4	35.2	—	9.9	37.1	—
Russia	38.2	—	—	57.2	—	—
USA	45.0	—	—	49.4	—	—
UK	96.3	0.9	22.5	133.5	—	23.2
Others	—	6.1	—	—	1.5[b]	—
Totals (rounded)	**281.0**	**56.1**	**53.0**	**335.1**	**40.1**	**39.5**

[a] < 50 kg.
[b] estimate for end 2014.

Sources: National INFCIRC/549 reports (except for India, which does not participate), supplemented by ISIS *Plutonium Watch,* August 2005, http://isis-online.org/uploads/isis-reports/documents/plutonium_watch2005.pdf, some breakdowns from International Panel on Fissile Materials website, http://www.fissilematerials.org, and ISIS *Civil Plutonium Stocks Worldwide, End of 2014,* http://isis-online.org/uploads/isis-reports/documents/Civil_Plutonium_Stocks_Worldwide_March_14_2015_FINAL.pdf.

Table 2. World Commercial Reprocessing Capacity (Metric Tons/Year)

	Metric Tons Spent Fuel	Maximum Output: Metric Tons Plutonium
Operating		
France—La Hague	1,700	15.0
UK—Sellafield (THORP)[a]	900	8.0
Sellafield Magnox[b]	1,500	2.5
Russia—Ozersk (Mayak—RT-1)[c]	400	4.0
India—3 plants	260	1.0
TOTAL	**4,760**	**30.5**
Operation Pending		
Japan—Rokkasho[d]	800	8.0
Under Construction		
Russia—Zheleznogarsk (Pilot Demonstration Centre)[e]	250	2.0
Zheleznogarsk (RT-2)[f]	700	7.0
China—Gansu	200	2.0

[a] Shutdown planned for 2018.
[b] Shutdown planned for 2020.
[c] Current capacity 200 metric tons, output 2 metric tons/yr, to be replaced by RT-2 in 2030.
[d] Start-up postponed until 2021.
[e] Start-up planned for 2020.
[f] Start-up planned for 2025.

Sources: Capacity—European Nuclear Society, http://www.euronuclear.org/info/encyclopedia/r/reprocessing-plants-ww.htm; World Nuclear Association, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel.aspx; SNF Management System Deployment and Development in Russia, https://www.iaea.org/INPRO/10th_Dialogue_Forum/Day3/Session4/02.Khaperskaya_Russia.pdf. Output—these references and author's estimates.

About the Author

John Carlson, based in Australia, is an NTI counsellor on international nuclear security, safeguards, and verification; management of the nuclear fuel cycle; and arms reduction. Carlson is a nonresident fellow at the Lowy Institute, a member of the Advisory Council of the International Luxembourg Forum, an associate of the Project on Managing the Atom, Belfer Center, Harvard University, a member of VERTIC's International Verification Consultants Network, and a member of the Asia-Pacific Leadership Network for Nuclear Nonproliferation and Disarmament. Carlson was an official in the Australian government for more than four decades.

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