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Civil Plutonium Stocks Worldwide

End of 2014[1]

By David Albright, Serena Kelleher-Vergantini, and Daniel Schnur

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Plutonium is a key ingredient in nuclear weapons, making it one of the most dangerous materials in existence. It is also a dangerous radioactive material, which requires special handling and disposition.

Plutonium is produced in reactors, since only trace amounts of it can be found in nature. This report addresses plutonium produced in nuclear power reactors, which are the primary sources of plutonium production in the world. However, in addition to these stocks, there are smaller stocks of civilian plutonium that have either been produced in other types of reactors or obtained from military programs, which viewed the plutonium as excess to defense requirements and supplied relatively small quantities to emerging civilian nuclear programs. The biggest supplier in this category was the United States, which exported over a tonne of unirradiated plutonium in the 1960s and 1970s.

The plutonium produced in civil power reactors comes primarily in two forms: irradiated and unirradiated plutonium. Irradiated plutonium is defined as plutonium contained in the reactor's irradiated fuel, while unirradiated plutonium has been separated from the highly radioactive fission products and other actinides in the spent fuel. Unirradiated plutonium can be pure, in the process of being fabricated into mixed-oxide (MOX) fuel, or in fresh MOX fuel. However, once the MOX fuel has been irradiated, the plutonium ends up, once again, in spent fuel.

Plutonium in spent fuel is considered more proliferation resistant than unirradiated plutonium because of the difficulties associated with the separation of the plutonium from the other radioactive components of the spent fuel. From a proliferation standpoint, the unirradiated forms of plutonium

[1] This report is part of a series on national and global stocks of nuclear explosive materials in both civil and military nuclear programs, found at http://isis-online.org/studies/category/global-stocks-of-nuclear-explosive-material/. This work was generously funded by a grant from the Nuclear Threat Initiative (NTI) and builds on previous ISIS Reports, in particular *Global Stocks of Explosive Nuclear Material-End 2003* (updated 2005), January 1, 2005, http://isis-online.org/isis-reports/detail/global-stocks-of-nuclear-explosive-materials/17 and Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities, and Policies* (Oxford: Stockholm International Peace Research Institute [SIPRI] and Oxford University Press, 1997).

are much more dangerous because they are more readily usable in nuclear weapons compared to the irradiated forms.

Plutonium Holdings, end of 2014

At the end of 2014, there were about 2,400 tonnes[2] of irradiated and unirradiated plutonium from civilian nuclear power reactors located in 33 countries. If we assume that about 8 kilograms (kg) of plutonium are enough to build one nuclear weapon, this total inventory of plutonium is enough for 300,000 nuclear weapons. Over the last ten years, this plutonium stock has grown at an average rate of almost 50 tonnes per year.[3]

Of this total amount, about 275 tonnes of plutonium, or about 12 percent, were in the more dangerous unirradiated forms in approximately 10 countries (see figure 1). Figure 2 shows the growth in the unirradiated plutonium inventory in power reactor programs.[4] From 1996 to 2005, the world's stock of civil unirradiated plutonium in civil programs grew at an average rate of about 10 tonnes per year. From 2005 to the end of 2014, the average growth rate has slowed to about two tonnes per year.

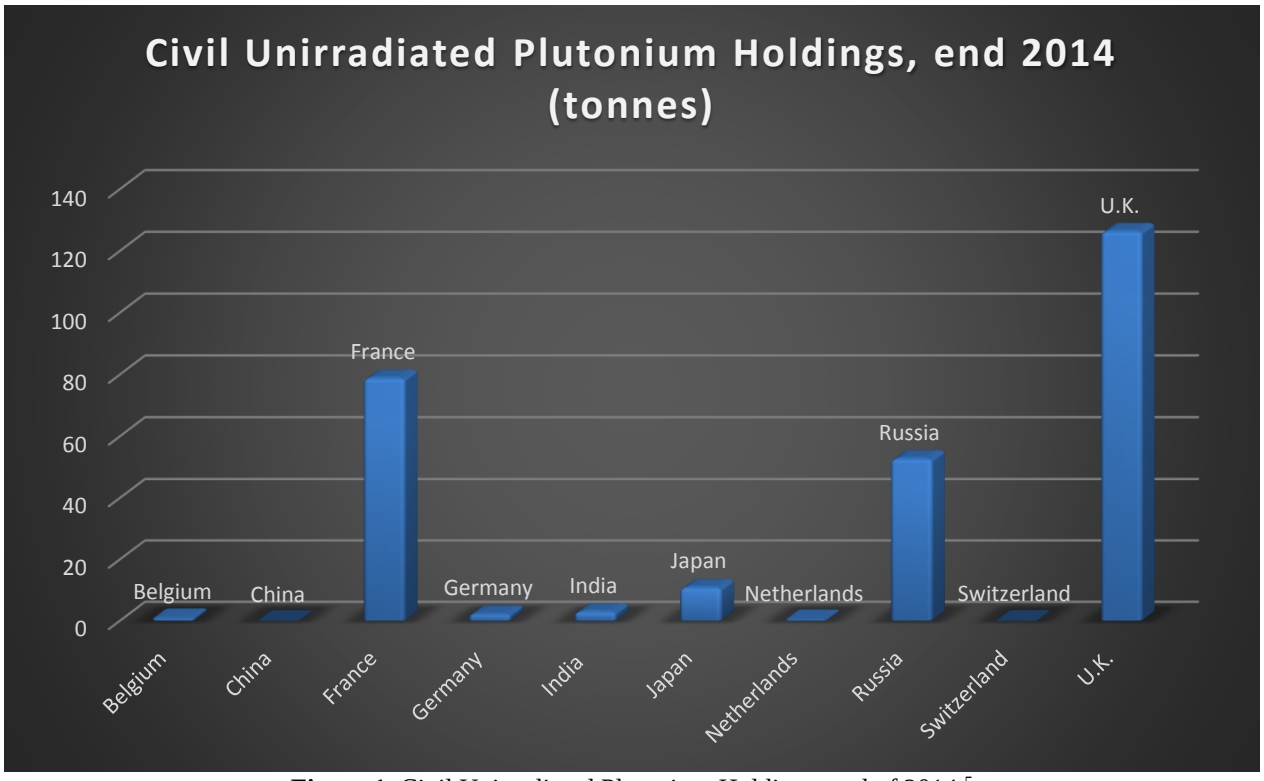

Figure 1. Civil Unirradiated Plutonium Holdings, end of 2014.[5]

[2] The metric unit of mass used here is the tonne, which equals 1,000 kilograms.
[3] See *Global Stocks of Explosive Nuclear Material*, ISIS Reports, January 1, 2005, http://isis-online.org/isis-reports/detail/global-stocks-of-nuclear-explosive-materials/17.
[4] India's separated plutonium is excluded from the figure, since its historical inventory is poorly understood. However, it also has a relatively small stock of separated plutonium that would not affect the graph visibly.
[5] The United States is excluded from this list since its unirradiated plutonium is classified under excess military plutonium.

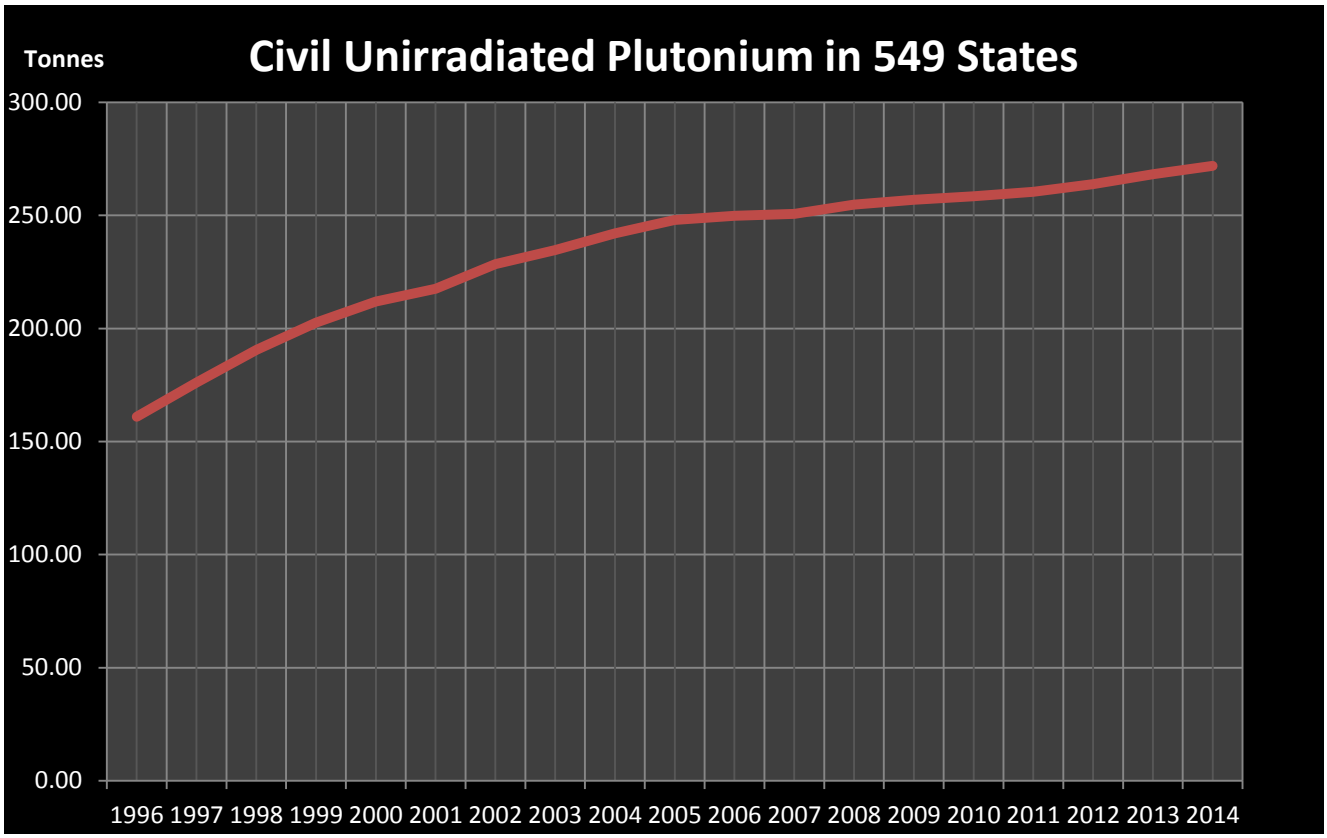

Figure 2. Civil Unirradiated Plutonium in the countries that submit INFCIRC/549 declarations to the International Atomic Energy Agency (IAEA).

Table 1 below shows irradiated and unirradiated plutonium holdings by country as of December 2014. A country's national plutonium holdings can include plutonium owned by other countries (see table 2).

Table 1: Civil Power Reactor Plutonium Held by Country, end 2014 (a)

Country	Irradiated Plutonium in spent fuel (tonnes)	Unirradiated Plutonium (tonnes)
Argentina	17.6	
Armenia	2.1	
Belgium	40	0.9
Brazil	5.9	
Bulgaria	8.8	
Canada	213	
China	32.5	0.025
Czech Rep.	16.8	
Finland	17.6	
France	275.6	78.8
Germany	113	2.1
Hungary	10.8	
India	31.9	2.9
Italy	<0.4	
Japan	161	10.8
Kazakhstan	3	
Lithuania	12.3	
Mexico	5.2	
Netherlands	1.4	0-0.3
Pakistan	2.17	
Romania	10.4	
Russia (b)	146.5	About 52.7
S. Africa	9.46	
S. Korea	97.9	
Slovakia	14.3	
Slovenia	4.3	
Spain	44.4	
Sweden	54.4	
Switzerland	18.0	<50kg
Taiwan	32.4	
Ukraine	50.6	
U.K.	30.0	126.3
U.S.A (c)	629	(u)
Totals (rounded)	2113	275
Grand Total	**2,388 tonnes**	

Notes and Comments

(a) Plutonium holdings are quantities of plutonium in one country. Several countries declare their unirradiated and irradiated inventories of plutonium each year in their INFCIRC/549 declarations to the IAEA. For countries that do not provide INFCIRC/549 declarations, estimates are used (see tables A1, A2, and A3). A country may also own plutonium that is located in other countries. Table 2 lists ownership of unirradiated plutonium. With regards to irradiated plutonium, Japan had one tonne of plutonium in spent fuel in Britain. Italy and the Netherlands had about 0.11 and 0.2

tonnes, respectively, in spent fuel in France. (For Italy and the Netherlands, see table A2 endnotes; for Japan, Secretariat of the Atomic Energy Commission, Cabinet Office, "The Status of Plutonium Management in Japan," July 21, 2015)

(b) Russia's 2015 INFCIRC/549 declaration must contain a mistake. The most recent declaration states that Russia owns 5,200 kg of unirradiated separated plutonium, when the amount of this material was 50,300 the year before. Likely, Russia left off a zero. Given that it is unclear if the correct amount is 50,200 or 52,000 kg, the average was used for the purposes of this estimate.

(c) The United States includes plutonium excess to military requirements in its INFCIRC declaration. These values are not included in this table.

The sources for Table 1's values are described in three tables in the appendix, namely tables A1, A2, and A3. Table A1 is a duplicate of table 1 with endnotes describing sources. In several cases, the irradiated and unirradiated values in table 1 come from official public declarations that countries make annually to the International Atomic Energy Agency (IAEA). Table A2 and A3 provide additional information and outline the estimates for countries that do not officially declare their plutonium stocks. Nationally aggregated data on plutonium discharged from power reactors is from the Nuclear Assurance Corporation (NAC) and used with their permission.

Table 1 does not include plutonium declared excess to military nuclear programs. The governments of Britain, Russia, and the United States have declared approximately 110 tonnes of their nuclear weapons, or military, stocks excess to defense purposes. Most of this plutonium is in unirradiated forms. In its annual declaration to the IAEA, the United States provides information about its stock of excess plutonium. About 49 tonnes of this plutonium are in fresh form, 7.8 tonnes in spent fuel, and about 4.5 tonnes disposed as waste, for a total of 61.5 tonnes. The excess plutonium stocks of the United States and Russia are further discussed in another ISIS report.[6]

Military nuclear programs contain about 240 tonnes, almost equal to the amount of civilian separated unirradiated plutonium. About 238 tonnes of this military plutonium are in the five acknowledged nuclear weapon states, Britain, China, France, Russia, and the United States. Other states with nuclear weapons, namely India, Israel, Pakistan, and North Korea, possess about 1.5 tonnes of weapon-grade plutonium in their weapons programs.

Civil Unirradiated Power Reactor Plutonium by Country, end of 2014

Table 2 summarizes the amounts of unirradiated plutonium produced in civil power reactor programs held and owned by 12 key countries at the end of 2014.[7] This table identifies not only the countries that hold this plutonium but it also tabulates plutonium quantities by owners. Several countries, such as Italy, the Netherlands, and Spain, own plutonium but store much or all of it in France, Britain, or Belgium.

[6] See David Albright and Serena Kelleher-Vergantini, *Military Highly Enriched Uranium and Plutonium Stocks in Acknowledged Nuclear Weapon States*, ISIS Report, November 3, 2015, http://www.isis-online.org/uploads/isis-reports/documents/Military_HEU_and_Pu_Stocks_in_Acknowledged_NWS_November3_2015_Final.pdf.

[7] The United States is excluded from this list since its unirradiated plutonium is classified under excess military plutonium.

Table 2: Unirradiated Civil Power Reactor Plutonium, end 2014 (tonnes) (a)

Country	A: Holdings in-country	B: Holdings in other countries	C: Tonnes of A that are foreign-owned	D: Plutonium owned by a country (A+B-C)
Britain	126.3	0	23	103.5
France	78.8	less than 0.05	16.9	61.9
Belgium	0.95	0	0.9	<0.05
Germany	2.1	1-1.5(b)	0	3.1-3.6(b)
Japan	10.8	37	0	47.8
Switzerland	<0.05	0	0	<0.05
Russia	52.7	0	0	52.7
China	0.025	0	0	0.025
United States	(c)	0	0	(c)
India	2.9	0	0	2.9
Netherlands	0	0.62-1.12	0	0.62-1.12
Italy	0	0.45-0.68	0	0.45-0.68
Sweden	0	0	0	0
Spain	0	0.55-0.6	0	0.55-0.6
Total (rounded)	**274.6**	**39.6-41**	**40.8**	**273.5-274.9**

Notes and Comments

(a)For the first eight countries in the table, the main sources of information are the IAEA's INFCIRC/549 declarations. The estimates for the last five countries depend on a variety of sources of information found in the appendix. The totals of Columns A and D and Columns B and C do not match exactly because the declarations are incomplete and several estimates are required to complete the table. Further clarification is needed of Germany's overseas plutonium inventories (see (b)) and Italy's and the Netherlands' unirradiated plutonium inventories).
(b) Germany does not declare its overseas stocks of plutonium. It is roughly estimated as about 1-1.5 tonnes.
(c) Excess military plutonium is not included in this table.

The largest stocks of unirradiated plutonium are in Britain, France, Japan, and Russia. All four remain committed to reprocessing and plutonium recycle, albeit with differing abilities to implement these activities.

China's inventory of unirradiated plutonium is small. However, it is aiming to greatly enlarge its domestic separation and use of plutonium.

Several countries, such as Belgium, Germany, and Switzerland, were previously heavily committed to plutonium separation and MOX recycling but have now reversed their course. Their more recent challenge has been to reduce their accumulated stocks of unirradiated plutonium via the use of MOX fuel in power reactors. By the end of 2014, Belgium and Switzerland have used almost all of their stocks, and Germany is not far behind. At the end of 2014, Germany had residual stocks of unirradiated plutonium totaling 2.1 tonnes in country and some small stocks overseas, although the amounts abroad could not be precisely determined and are estimated. Industry data show that

German reactors have no plans to load much more MOX fuel after 2014. Although some of this residual stock could be slated for irradiation as MOX fuel, a fraction of it may need to be stored in the long term or sold to overseas buyers.

An important development for countries wanting to work down their separated plutonium is that Britain and France are willing to take ownership of stocks of plutonium for countries that lack the resources or political ability to recycle their separated plutonium. This has allowed Sweden to sell its separated plutonium to Britain. In addition, a German research institute and a small Dutch utility were able to transfer ownership of their stocks, 140 and 350 kilograms respectively.[8]

Although Belgium has only minimal stocks of unirradiated plutonium and no plans to separate or use more, it still stores 0.9 tonnes of unirradiated plutonium from unidentified foreign owners, presumably at a closed MOX fuel fabrication plant.

Spain was originally committed to reprocessing spent fuel but is no longer pursuing that path. It retains ownership of a small stock of plutonium, which is currently stored in Britain. Its fate is unknown, although it may transfer ownership to Britain.

Italy and the Netherlands remain committed to reprocessing as a way to avoid storing irradiated fuel from power reactors. Italy has decided to remove its spent fuel from its defunct nuclear reactor sites and selected the most direct manner to do so, namely contracting to have all this power reactor spent fuel reprocessed in France and selling the separated plutonium. It is in the midst of carrying out this policy. The Dutch utility EPZ has contracted with France's AREVA to reprocess its spent fuel and fabricate it into MOX fuel for use in its Borssele nuclear power reactor. EPZ wants to ensure that it will not retain any spent fuel when its Borssele nuclear reactor ends operation in a few decades. As a result, it is shipping its spent fuel to AREVA's La Hague reprocessing plant and having the separated plutonium made into MOX fuel at the AREVA MELOX plant. The MOX fuel is then shipped to the Borssele reactor. When the reactor shuts down, the last core load of fuel is planned to be sent to AREVA under a special arrangement, which will take ownership of the plutonium.

The Taiwanese nuclear utility, Taipower, is also seeking to reprocess its spent fuel overseas, likely by AREVA, as a method to reduce its spent fuel inventories at reactor sites. To avoid exceeding on-site spent fuel storage legal limits at two nuclear power plants, Taipower has recently proposed sending spent fuel to France for reprocessing. Taipower has stipulated that it would not bring back the separated plutonium but instead transfer its ownership to other states for reuse in civilian reactors. The initial reprocessing contract would involve a total of 1,200 irradiated fuel assemblies, 480 from the Chinshan nuclear power reactors and 720 from the Kuosheng reactors. This number of fuel assemblies corresponds to about 200 tonnes of spent fuel. The plutonium content of the spent fuel from these reactors varies, but this amount of spent fuel should contain about one or two tonnes of plutonium. However, this proposal has generated domestic controversy. As of late October 2015, Taipower's proposal had not been approved by Taiwan's parliament, which must approve the budget to carry out the reprocessing plan. If approved, Taipower has plans to send considerable more spent fuel for reprocessing.

[8] "UK government increases control of civil plutonium," World Nuclear News, July 3, 2014.

Legacy U.S. Exports of Unirradiated Plutonium

Starting in the 1950s, the United States exported unirradiated plutonium for use in civilian research programs. Most of the exports occurred in the 1960s and 1970s. There were also exports of excess weapons plutonium to France in the early 2000s to make four MOX assemblies for testing in a U.S. power reactor. Other countries may have also exported unirradiated plutonium for civilian research programs during this earlier period but not as widely as the United States.

Under Department of Energy (DOE) programs aimed mainly at repatriating U.S.-supplied highly enriched uranium (HEU) from overseas locations, the DOE has also brought back small amounts of separated plutonium. In 2014, Belgium returned an unspecified amount of plutonium from two research institutes. Italy returned fresh plutonium in 2014 that may have amounted to several kilograms. The United States is seeking to bring over 300 kilograms of unirradiated or lightly irradiated plutonium from Japan's Fast Critical Assembly. Much of this plutonium was likely exported originally by the United States.

To better understand the scale of U.S.-supplied plutonium abroad and the number of countries that received U.S. plutonium, table 3 shows U.S. exports of unirradiated plutonium as of 1982. These data are from the DOE Nuclear Materials Management and Safeguards System (NMMSS) and were given to one of the authors in the mid-1980s by Congressional offices, who had received the data from the DOE and sought analysis of the export data.

In total, through 1982, 40 countries received 1,224 kilograms (1.224 tonnes) of unirradiated plutonium for their civil programs. Most of the exports are small, involving grams of plutonium. The plutonium on average contained 87 percent plutonium 239, representing a high grade of plutonium.

West Germany received the most, namely 754 kilograms. Japan received the second largest amount, or 159 kilograms.

The export data do not provide an inventory of U.S.-supplied unirradiated plutonium in a country. The plutonium may have stayed in a particular country, for example, for use in research or, in the case of Germany and Japan, a criticality facility, or have been re-exported to another country. If this re-export happened in the European Union, the United States would not have been informed that it occurred. The data also do not show any returns to the United States. Thus, the listing for a particular country does not represent the inventory of U.S.-supplied plutonium in that country, and there could have been U.S. exports after 1982. Nonetheless, the data provide a measure of the amount and dispersion of U.S. exported plutonium through the period when the bulk of the high-grade plutonium exports occurred.

The yearly plutonium export data were also provided. Most of this plutonium was exported from the mid-1960s through the mid-1970s. There is a dramatic decrease in exports after 1974-1975, reflecting India's 1974 underground nuclear explosion and growing U.S. opposition to exporting both plutonium and HEU.

Table 3. Total U.S. Exports of Plutonium Through 1982

Country	Plutonium (g)	Plutonium (kg)	% Pu-239 (Average)
Argentina	9	0.009	100
Austria	162	0.162	93
Australia	6577	6.577	92
Belgium	57644	57.644	81
Brazil	84	0.084	93
Canada	5017	5.017	87
Columbia	80	0.08	93
Czechoslovakia	29	0.029	86
Denmark	81	0.081	93
Finland	3	0.003	67
France	41507	41.507	92
W. Germany	754072	754.072	89
Greece	192	0.192	93
IAEA	387	0.387	91
Ireland	16	0.016	94
India	82	0.082	91
Israel	606	0.606	93
Iran	112	0.112	92
Iraq	16	0.016	94
Italy	129103	129.103	79
Japan	159145	159.145	88
Rep. of Korea	8	0.008	88
Mexico	164	0.164	91
Netherlands	835	0.835	90
Norway	1083	1.083	86
New Zealand	80	0.08	93
Pakistan	117	0.117	93
Philippines	32	0.032	94
Portugal	1	0.001	100
South Africa	159	0.159	93
Spain	6	0.006	83
Sweden	9702	9.702	91
Switzerland	1502	1.502	93
Taiwan	708	0.708	87
Thailand	80	0.08	80
Turkey	368	0.368	92
United Kingdom	54378	54.378	84
Uruguay	80	0.08	93
Venezuela	10	0.01	90
Re. of Vietnam	80	0.08	93
Total	1224317	1224.317	87%

Source: Department of Energy, Nuclear Materials Management and Safeguards System

APPENDIX

Table A1: Civil Power Reactor Plutonium Held by Country, end 2014 (a)

Country	Irradiated Plutonium in spent fuel (tonnes)	Unirradiated Plutonium (tonnes)
Argentina	17.6	
Armenia (b)	2.1	
Belgium (c)	40	0.9
Brazil	5.9	
Bulgaria (d)	8.8	
Canada	213	
China	32.5	0.025
Czech Rep.	16.8	
Finland (e)	17.6	
France (f)	275.6	78.8
Germany (g)	113	2.1
Hungary (h)	10.8	
India (i)	31.9	2.9
Italy (j)	<0.4	
Japan (k)	161	10.8
Kazakhstan (l)	3.0	
Lithuania	12.3	
Mexico	5.2	
Netherlands (m)	1.4	0-0.3
Pakistan	2.17	
Romania	10.4	
Russia (n)	146.5	About 52.7
S. Africa	9.46	
S. Korea	97.9	
Slovakia (o)	14.3	
Slovenia	4.3	
Spain (p)	44.4	
Sweden (q)	54.4	
Switzerland (r)	18.0	<50kg
Taiwan	32.4	
Ukraine (s)	50.6	
U.K.(t)	30.0	126.3
U.S.A (u)	629	(u)
Totals (rounded)	2112.73	275
Grand Total	2,388	

Notes for Table A1:

(a) Plutonium holdings are quantities of plutonium in one country. However, a country, or utility, may also own plutonium located in other countries. This plutonium is included in the inventory of the country storing the plutonium. Several countries, namely Belgium, France, Germany, Japan, Russia, Switzerland, the United Kingdom, and the United States declare their unirradiated and irradiated inventories of plutonium each year in what are commonly called INFCIRC/549 declarations, for the IAEA designation of the original document about the declarations. China declares the amount of unirradiated plutonium but so far not the amount of irradatiated plutonium. For countries that do not provide INFCIRC/549 declarations, estimates are used. The declarations of unirradiated plutonium by the INFCIRC/549 countries may or may not account for the decay of plutonium 241 into americium 241; the other values in the table do not. Plutonium 241 has a half-life of about 14.4 years. For light water reactor spent fuel with a burn-up of 30,000 MWth-d/tonne, about 10-15 percent of the plutonium in spent fuel is plutonium 241. The total amount of plutonium 241 decayed could be on order of 100 tonnes. The values in this table do not include the roughly 100 tonnes of plutonium remaining in the cores of nuclear power reactors at the end of each year.

(b) Armenia has shipped spent fuel to Russia. The plutonium has not been returned but is part of Russia's stock of unirradiated plutonium. See Table A3.

(c) *Communication Received from Belgium Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.3/14, June 26, 2015.

(d) Bulgaria has shipped spent fuel to Russia. The plutonium has not been returned but is counted as part of Russia's stock of unirradiated plutonium. See Table A3.

(e) Finland has shipped spent fuel to Russia. The plutonium has not been returned but is counted as part of Russia's stock of unirradiated plutonium. See Table A3.

(f) *Communication Received from France Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.5/19, August 28, 2015.

(g) *Communication Received from Germany Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.2/18, August 28, 2015. Germany does not declare the amount of its unirradiated plutonium held in other countries, and it does not delineate the amount of other countries' plutonium stored in Germany. The latter is included in the total plutonium held in Germany. It is unknown how much German unirradiated plutonium is in Belgium, France, and Britain but this amount is likely less than a tonne.

(h) Hungary has shipped spent fuel to Russia. The plutonium has not been returned but is part of Russia's stock of unirradiated plutonium. See Table A3.

(i) David Albright and Serena Kelleher-Vergantini , *India's Stocks of Civil and Military Plutonium and Highly Enriched Uranium,* ISIS Report, November 2, 2015, http://isis-online.org/uploads/isis-reports/documents/India_Fissile_Material_Stock_November2_2015-Final.pdf.

(j) See Table A2.

(k) *Communication Received from Japan Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.1/18, August 28, 2015. The INFCIR/549 value for plutonium held overseas is an aggregate total. However, Japan provides more detail publicly about its stocks of overseas unirradiated plutonium held in Britain and France. At the end of 2014, Japan had 20.7 tonnes of unirradiated plutonium in the United Kingdom and 16.3 tonnes in France, for a total uniradiated overseas plutonium inventory of 37 tonnes. (Secretariat of the Atomic Energy Commission, Cabinet Office, "The Status of Plutonium Management in Japan," July 21, 2015)

(l) Weapon-grade plutonium from the BN-350 reactor is being permanently stored in the irradiated blanket material in Kazakhstan. See NNSA, "NNSA Secures 775 Nuclear Weapons Worth of Weapons-Grade Nuclear Material from BN-350 Fast Reactor in Kazakhstan," Press Release, Nov 18, 2010, http://nnsa.energy.gov/mediaroom/pressreleases/bn35011.18.10. See also Table A2.

(m) See Table A2.

(n) *Communication Received from the Russian Federation Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.9/17, September 25, 2015, and an estimate of unirradiated plutonium holdings. It is important to note that Russia's 2015 INFCIRC/549 declaration must contain a mistake. The documents states that Russia owns 5,200 kg of unirradiated separated plutonium, when the amount of this material was 50,300 the year before. Likely, Russia left off a zero. Given that it is unclear if the correct amount is 50,200 or 52,000 kg, the average was used for the purposes of this estimate. Russia has received a considerable amount of spent fuel from countries with Russian-supplied VVER reactors. See Table A3.

(o) Slovakia has shipped spent fuel to Russia. The plutonium has not been returned but is counted as part of Russia's stock of unirradiated plutonium. See Table A3.

(p) See Table A2.

(q) See table A2

(r) *Communication Received from Switzerland Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.4/19, August 28, 2015. Switzerland may not have any unirradiated plutonium overseas at the end of 2014. It does not have any spent power reactor fuel awaiting reprocessing, according to this declaration.

(s) Ukraine has shipped spent fuel to Russia. The plutonium has not been returned but is part of Russia's stock of unirradiated plutonium. See Table A3.

(t) *Communication Received from the United Kingdom Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.8/18, October 8, 2015.

(u) *Communication Received from the United States Concerning its Policies Regarding the Management of Plutonium*, INFCIRC/549/Add.6/18, October 30, 2015. The declared amount of irradiated plutonium contains 7.7 tonnes of plutonium declared excess to military needs and is subtracted from the declared amount in this table, which focuses on nuclear power reactor

plutonium. Unirradiated plutonium is also excess military plutonium and is not included in this table.

Table A2: Estimated Civil Plutonium Holdings in Several Countries, end 2014 (tonnes) (a)

Country	Estimated Pu discharged in power reactor spent fuel	Adjustments to total amount of Pu discharged	Estimated Pu holdings, end of 2014(b)	Total Unirradiated Pu holdings from civil power reactors	Total amount of Pu in spent fuel from power reactors, held domestically(c)	Pu in spent fuel, stored overseas
India	34.8			2.9(d)	31.9	
Italy(e)	5.6	-(4.45 to 4.68)	0.92 -1.15	0.45-0.676	0.35	0.11
Kazakhstan	3(f)				3(f)	
Netherlands(g)	4.6	- 2.1 to 2.6	2.0-2.5	0.62-1.12	1.4	0.2
Spain(h)	50.6	-5.6	45	0.55-0.60	44.4	
Sweden(i)	55.25	-0.83	54.4	0	54.4	

Notes for Table A2

(a) The countries in this table are or were involved in separating plutonium, recycling plutonium, or operating breeder reactors but do not submit INFCIRC/549 declarations to the IAEA.

(b) The values in this column estimate the total plutonium holdings of a country, which includes both irradiated plutonium and unirradiated plutonium. Each value is determined by taking the estimated amount of plutonium discharged in power reactor spent fuel, column 2, and applying adjustments in column 3. The estimate does not include reductions due to the consumption of plutonium in irradiated MOX fuel. Such reductions are relatively small in these countries since they have not recycled plutonium in any significant manner as of the end of 2014.

(c) The total amount of plutonium in irradiated fuel, column 6, is derived by taking the value in column 4, plutonium holdings, and subtracting the estimate for unirradiated plutonium in column 5. Column 7, plutonium in irradiated fuel stored overseas, contains estimates of the amount of plutonium in irradiated fuel held overseas.

(d) David Albright and Serena Kelleher-Vergantini, *India's Stocks of Civil and Military Plutonium and Highly Enriched Uranium*, ISIS Report, November 2, 2015, http://isis-online.org/uploads/isis-reports/documents/India_Fissile_Material_Stock_November2_2015-Final.pdf.

(e) Italy has generated a considerable amount of separated plutonium that was produced in its nuclear power reactors, all of which shut down years ago. In addition to legacy stocks of separated plutonium, Italy has decided in the last decade to separate plutonium from its remaining LWR spent fuel as part of a national nuclear waste disposal strategy. To that end, Italy's nuclear liquidator, SOGIN, signed a reprocessing contract in 2007 with the French company AREVA to reprocess its

LWR spent fuel. Because Italy cannot recycle separated plutonium, SOGIN has sought buyers for this plutonium being produced in this more recent reprocessing contract, as it has also done for its legacy unirradiated plutonium stocks. To that end, Italy's liquidator, SOGIN, signed a service contract with AREVA in 2008 aimed at selling its separated plutonium, "allowing AREVA NC to carry out these services." (AREVA, *2008 Reference Document*, p. 377 (English translation)).

SOGIN's 2007 reprocessing contract with AREVA involves 235 tonnes of LWR spent fuel that will be reprocessed at La Hague and represents essentially all of its remaining spent LWR fuel from Italian nuclear power reactors. The contract is for 190 tonnes of BWR fuel from the Caorso nuclear plant and about 30 tonnes of PWR fuel from the Trino Vercellese plant, for a total of 220 tonnes of LWR spent fuel. It also includes about 13 tonnes of MOX spent fuel from the Garigliano reactor and 2.5 tonnes of spent MOX fuel from the Trino reactor. ("Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management: First Italian National Report," April 2006, www.isprambiente.gov.it/files/temi/italianreport.pdf). The shipments of the first 190 tonnes of spent fuel were completed in 2010. ("Italian used fuel arrives in France," World Nuclear News, http://www.world-nuclear-news.org/IT-Italian_used_fuel_arrives_in_France-1005117.html). As of March 2013, 207 tonnes had been delivered and 190 tonnes reprocessed. (AREVA, "21st Arrival of Used Nuclear Fuel from Italy for Recycling," Press Release, March 19, 2013). This amount increased to 215 tonnes in June 2015 and 222 tonnes in September 2015. (AREVA Press Releases, "Arrival of 22nd Transport," June 26, 2015 and "Arrival of 23rd Transport," September 29, 2015). These more recent press releases state that more than 190 tonnes have been reprocessed.

However, it is important to note that as of October 2015, much of Italy's MOX fuel had not been sent to France pending the appropriate French authorizations to reprocess this special type of fuel (see *Commissione Parlamentare d'Inchiesta sulle Attivita' Illecite Connesse al Ciclo dei Rifiuti e su Illeciti Ambientali as Esse Correlati,"* Commissione d'Inchiesta, 1 Ottobre, 2015, http://documenti.camera.it/leg17/resoconti/commissioni/bollettini/pdf/2015/10/01/leg.17.bol0514.data20151001.com39.pdf.) Thus, it appears that no Italian MOX spent fuel has yet been reprocessed under the 2007 contract.

Based on spent fuel data on these LWRs, the spent fuel is estimated to contain about 1,600-1,700 kilograms of plutonium (1,220 kilograms from Caorso spent fuel, 200 kg from Trino spent fuel, and roughly 200-300 kilograms in the spent MOX fuel). The relatively low plutonium values reflect that this irradiated fuel achieved relatively low burnups, and some of it was from the last core loads of these reactors. In the case of the 15 tonnes of MOX fuel, it is estimated to have originally contained a low percentage of plutonium, reflecting the period of time when this MOX fuel was originally manufactured. The ownership of the plutonium separated by SOGIN is discussed below.

About 190 tonnes of this spent fuel were reprocessed through 2014. Since it is assumed that no MOX fuel was reprocessed, this spent fuel contained an estimated 1,420 kilograms of plutonium. Using a simple ratio (190/220), then the amount separated through 2014 is about 1,226 kilograms of separated plutonium. As of the end of 2014, out of a total of 207 tonnes of spent fuel that had been delivered to La Hague (see above), about 17 tonnes of spent fuel remained unreprocessed. This spent fuel is estimated to contain 110 kilograms of plutonium.

Legacy Stocks (pre-2007 reprocessing contract)

Decades ago, Italy decided to separate plutonium in Belgium and Britain, resulting in about 4.1-4.2 tonnes of separated plutonium (ISIS information based on information about original reprocessing contracts in Britain, Belgium, and France, including 3.1 tonnes from the Latino gas-graphite reactor). A small fraction of Italian spent fuel may still be awaiting reprocessing in the Thorp plant in Britain.

Italy bought about 347 kilograms of plutonium from Belgium and the Netherlands in the 1980s, respectively 190 and 157 kilograms (ISIS information from Italian nuclear officials, March 30, 1984 and see Dutch Parliamentary information below under Netherlands). This value is rounded to 350 kilograms and is a positive adjustment in column 3. With these sales, Italy accumulated about 4.45-4.55 tonnes of separated plutonium under its old reprocessing and purchase contracts.

An amount of this legacy plutonium was irradiated. An estimated 200-300 kilograms were used as MOX fuel in various reactors several decades ago. Another estimated 3.8 tonnes of separated plutonium were allocated to the Superphenix reactor, of which Italy owned 33 percent (Albright, "French Military Plans for Superphenix," *Bulletin of Atomic Scientists*, November 1984). About 1.9 tonnes of Italy's Superphenix plutonium are estimated to have been irradiated and the spent fuel stored in France; the rest was stored in unirradiated fuel in France.

Subtracting out the amount of separated plutonium subsequently irradiated, namely 2.1-2.3 tonnes, Italy then owned in the 1990s about 2.35 tonnes of unirradiated plutonium, almost all located in Britain and France. It also retained ownership of about 1.9 tonnes of plutonium in spent Superphenix fuel. This inventory of fresh and irradiated plutonium represents a legacy plutonium stock inherited by SOGIN in the mid-2000s.

Italy also imported 129 kilograms of plutonium from the United States, of which 125 kilograms were imported in 1975 (see table 3). However, this plutonium is not included in this analysis because it is unknown how much of it remained in Italy or was re-exported to other European nations.

Selling Stocks of Plutonium

As discussed above, Italy decided about a decade ago to sell its separated plutonium as part of dealing with its residual nuclear waste. This strategy included the remaining LWR spent fuel discussed above, but it also included getting rid of the plutonium in fresh and spent Superphenix fuel. With regard to Italian plutonium in Superphenix spent fuel, France required Italy to take this spent fuel back to Italy for storage or opt for what is called "virtual reprocessing." ("Nucleare: Sogin firma con EDF e areva accordi gestione plutonio Superphenix," *adnkronos*, February 5, 2008.) In this type of arrangement, Italy would receive an equivalent amount of unirradiated plutonium and nuclear waste, unless it pays more for France to take the "entire quantity" (assumed to include the plutonium). According to SOGIN, AREVA took possession, for a fee, of all Italy's Superphenix plutonium, both fresh and unirradiated, which in this estimate amounts to 3.8 tonnes (personal communication, January 2015). (This value is a negative adjustment in column 3.)

Subtracting out the fresh Superphenix plutonium, which is 1.9 tonnes, leaves 0.45 tonnes of this legacy unirradiated plutonium. This plutonium is almost all in Britain.

Of the estimated 1.226 tonnes (1,226 kg) of plutonium in the 190 tonnes of spent fuel reprocessed since 2007 in France, Italy has sold 0.783 tonnes of fissile plutonium in May 2011. (*La Gestione del Combustibile Irraggiato e delle Materie Nucleari*, Relazione al Parlamento, XVII Legistatura, DOC.XV, N.171, http://www.camera.it/_dati/leg17/lavori/documentiparlamentari/indiceetesti/015/171_RS/00000009.pdf). Fissile plutonium is composed of the two principal isotopes of interest for MOX use, namely plutonium 239 and plutonium 241. However, the plutonium also contains other isotopes, namely plutonium 240. In the case of the 190 tonnes of spent fuel reprocessed by the end of 2014, this plutonium was about 75-80 percent fissile, based on reactor operating records. In this case, 0.783 tonnes of fissile plutonium corresponds to 0.98-1.04 tonnes of plutonium, rounded to 1.0 tonne. Italy's policy is to try to sell the rest of the plutonium recovered from the reprocessing of this spent fuel. However, if buyers are not found by December 31, 2021, Italy will have to take back the remaining quantities of plutonium by the end of 2025. It is unknown if Italy managed to sell any other quantities of this plutonium. AREVA has expressed openness to the purchase. So, likely most of this plutonium has been or will be sold. Nonetheless, absent new information of additional plutonium sales, Italy may still own about 0.226 tonnes of unirradaited plutonium resulting from its 2007 reprocessing contract as of the end of 2014. However, to account for possible additional sales, a range of 0 to 0.226 tonnes is assigned as the amount of this post 2007 separated plutonium still owned by Italy. As reprocessing continues at La Hague, additional plutonium will need to be sold.

Likewise, SOGIN is expected to sell its holdings of plutonium in the United Kingdom under old reprocessing contracts. The status of that effort is not known. Here, it is assumed not to be sold yet.

Taking Stock

The adjustments in column 3 represent known quantities and a range. Known amounts are 350 kg of unirradiated plutonium purchased and 3.8 tonnes of Superphenix plutonium sold, giving a net subtraction of -3.45 tonnes. In addition, 1.0 to 1.226 tonnes were sold more recently. Thus, the total subtraction in column 3 is a range of 4.45 to 4.676 tonnes, rounded to 4.45 to 4.68 tonnes.

The amount of unirradiated plutonium represents a range of 0 to 0.226 tonnes plus the leftover legacy plutonium of about 0.45 tonnes, for a total of 0.45 to 0.676 tonnes.

Because the values in the columns are ranges, adding them is complicated. The total amount of plutonium discharged in spent fuel through 2014 is estimated as 5.6 tonnes, of which no more than about 0.46 tonnes remained in spent fuel. Another 4.45-4.68 tonnes have been sold, and the remaining stock of unirradiated plutonium is about 0.45-0.676 tonnes.

Misc. Amounts

In the late 2000s, SOGIN took responsibility for about 6 kilograms of unirradiated plutonium stored domestically that was left over from earlier, now defunct, nuclear endeavors. In 2013 or 2014, Italy sent to the United States both plutonium and highly enriched uranium. Based on an inventory of this material, up to 6 kilograms of unirradiated plutonium and 4.8 kilograms of irradiated plutonium

could have gone to the United States from SOGIN's stock. (See Pavel Podvig, "HEU and plutonium removed from Italy," *IPFM Blog*, March 24, 2014.) SOGIN also has a stock of 3.2 kilograms of unirradiated plutonium in Canada at the AECL.

(f) Kazakhstan's value represents the plutonium that was produced in the breeder blanket of the BN-350 reactor that was shut down. The BN-350 was fueled with HEU, which led to minimal plutonium production in the fuel. The breeder blanket material is being stored permanently and its plutonium, which is weapon-grade, will not be separated. See NNSA, "NNSA Secures 775 Nuclear Weapons Worth of Weapons-Grade Nuclear Material from BN-350 Fast Reactor in Kazakhstan," Press Release, Nov 18, 2010, http://nnsa.energy.gov/mediaroom/pressreleases/bn35011.18.10.

(g) The Dutch utilities have contracted to have a considerable amount of spent fuel from their power reactors reprocessed in France and Britain. However, the Netherlands does not participate in the INFCIRC/549 declaration process. As a result, available information, including information provided by Dutch utilities, is used to estimate unirradiated plutonium stocks as of the end of 2014. A table at the end of the endnote summarizes the following information.

Plutonium Separation from Borssele Reactor Spent Fuel

The Dutch utility, EPZ, has been involved in a long-term, on-going contract with AREVA (formerly Cogema) to separate and recycle plutonium from the Borssele power reactor fuel. As of March 2013, 293 tonnes of PWR fuel from the Borssele reactor had been received at the French UP3 reprocessing plant at La Hague, of which 275 tonnes had been reprocessed. (AREVA Press Release, "Arrival of Used Nuclear Fuel from the Netherlands for Recycling," March 20, 2013). By June 2015, with the arrival of a shipment of 6.7 tonnes of EPZ spent fuel at AREVA's La Hague reprocessing plant, AREVA had received a cumulative total of 319 tonnes of spent fuel out of the contracted amount of 350 tonnes. (AREVA Press Release, "Arrival of the 12th Transport of Used Nuclear Fuel from the Netherlands to AREVA La Hague Plant for Recycling," June 17, 2015). This press release also said that about 295 tonnes of this spent fuel had already been reprocessed at the UP3 plant. This spent fuel is estimated to have contained about 8.5 kilograms of plutonium per tonne of fuel, or about 2.5 tonnes of plutonium. EPZ's predecessor, PZEM, had earlier contracted with Cogema to reprocess spent fuel at the UP2 plant at La Hague. This contract involved about 80 tonnes of spent fuel, containing about 7.5 kilograms of plutonium per tonne, or about 620 kilograms, or 0.62 tonnes. Combined, through about the end of 2014, EPZ had had about 3.12 tonnes of plutonium separated at the UP2 and UP3 plants. (The amounts of plutonium in the spent fuel reprocessed in UP2 and UP3 plants and information about the UP2 and UP3 contracts are from a document provided to the Dutch Parliament by the Ministry of Economic Affairs, and published in the *Tweede Kamer*, vergaderjaar 1996-1997, 25 422, nr. 1).

The reprocessing of Dutch spent fuel is expected to continue as EPZ plans on reprocessing Borssele spent fuel until the reactor closes in about 2034. (European Nuclear Society, "First MOX Loading in Borssele," *e-news*, Issue 45, Summer 2014, http://www.euronuclear.org/e-news/e-news-45/borssele.htm). The last reactor core is also expected to be reprocessed in France although this plutonium cannot be recycled into the Borssele reactor. To ensure that EPZ does not end up with separated plutonium it cannot recycle, or for that matter any spent fuel, France has loaned EPZ an equivalent amount of plutonium for recycling prior to the reactor's shutdown. EPZ will use the plutonium in the final core to repay France for this loan. (See "First MOX Loading in Borssele," op.

cit.) This plutonium in the last core, taken as 0.35 tonnes in later calculations, effectively represents an increase in the EPZ plutonium stock as of the end of 2014.

In 2014, the Borssele reactor first loaded MOX fuel, which was made at the French AREVA MELOX facility. It had arrived in the Netherlands in December 2013. The initial loading was 8 fuel assemblies, with plans to increase that number to 12 fuel assemblies per year. (AREVA Press Release, "AREVA begins production of the first MOX fuel for the Netherlands," November 4, 2013; and AREVA Press Release, "Netherlands: First Electricity Generated with MOX Fuel," June 30, 2014). The plutonium loading in the fresh MOX fuel is about eight percent, or about 25 kilograms per fuel assembly. However, the first fuel assemblies may have had less plutonium in them. Nonetheless, here the loading is assumed to be eight percent, so eight fuel assemblies would contain 200 kilograms of plutonium and 12 assemblies would contain 300 kilograms of unirradiated plutonium, based on Borssele reactor data. Because the MOX inserted in the Borssele reactor in 2014 is now irradiated, it is subtracted from the accumulated stock of unirradiated plutonium.

In addition, fresh MOX may have been shipped to the reactor in 2014 in anticipation of fuel loading in 2015. As a result, the Netherlands is listed as having 0-0.3 tonnes of fresh plutonium at the end of 2014.

Dodewaard Reactor Plutonium and Its Disposition

The EPZ plutonium is not all of the plutonium separated by the Netherlands. Earlier, the Dutch utility GKN, which owned the now closed Dodewaard reactor, separated about 9 tonnes of spent fuel in Belgium and another 57 tonnes in Britain; the former resulted in an estimated 50 kilograms of plutonium and the latter resulted in about 350 kilograms, or a total of 400 kilograms. The 66 tonnes of spent fuel represented almost all the spent fuel generated by this reactor which closed in 1997 (*Tweede Kamer*, vergaderjaar 1996-1997, op. cit.). In 2014, Britain agreed to take ownership of 350 kilograms of plutonium separated from the 57 tonnes of fuel at the THORP plant, as GKN had no means to recycle this plutonium. ("Statement by Michael Fallon: Management of Overseas Owned Plutonium in the UK," Written Statement to Parliament, April 23, 2013).

Disposition of EPZ Separated Plutonium

The Netherlands has sold a significant amount of its unirradiated plutonium for use in European breeder reactors, used some of it to fulfill its own contract with these breeder reactors, transferred ownership of large amounts of unirradiated plutonium to France and other European utilities for use as MOX fuel, and perhaps applied some to MOX research and development.

According to 1996/97 Dutch Parliamentary information (Tweed Kamer, vergaderjaar 1996-1997, op. cit), up to a total of 615 kilograms of Dutch separated plutonium, recovered in France between 1979 and 1985, were sold to an Italian utility for use in the Superphenix breeder reactor, used as the Dutch utilities' contribution to Superphenix, and used to fulfill Netherland's contribution to the Kalkar breeder reactor. The Italian utility bought 157 kilograms. ("Dutch Foreign Ministry answers to Dutch parliamentary members' questions about Dutch participation in the Superphenix reactor," June 24, 1983). Most of the remaining 458 kilograms of separated plutonium were used in the Superphenix and Kalkar cores. It is estimated based on the fraction of Dutch ownership of these two reactors that about 170 kilograms went to Kalkar and 275 kilograms went to Superphenix for

use in the first two cores. The remaining 13 kilograms could have ended up in these reactors as well or in MOX research and development programs. The Kalkar reactor never operated, so the plutonium remained in unirradiated form. In 2005, France allowed the unirradiated fuel from Kalkar to be processed at its La Hague UP2-800 reprocessing plant. (See Journal Officiel, no. 87, 2005, page 6679, Text no. 33 (in French)). It is likely the Kalkar plutonium was recovered and the Netherlands' fraction was stored in the form of plutonium oxide powder in France, awaiting use. About half of the Dutch plutonium contribution to Superphenix was likely irradiated in the reactor and subsequently stored as spent fuel. As discussed above in the case of Italy (footnote (e)), the Netherlands would have had to take back its plutonium in the Superphenix spent fuel or agree to "virtually reprocess" it and then decide on the fate of an amount of fresh plutonium equivalent to that in the spent Superphenix fuel. How it decided is unknown. The other half of Superphenix plutonium, which was unirradiated, could have been recovered, although no record could be found stating that this plutonium was recovered from the unirradiated second core. But given that the Kalkar fuel was processed at La Hague, it is possible that the second core of Superphenix was also processed and the plutonium recovered for reuse. So, of this up to 615 kilograms, up to about 445 kilograms were left over from the breeder programs. Based on information from EPZ, all of this plutonium was transferred to France or another MOX user. As a result, the 445 kilograms is deducted from the Netherlands' unirradiated plutonium inventory as of the end of 2014.

EPZ has also transferred ownership, or loaned, a considerable amount of plutonium separated under its UP3 reprocessing contract. These arrangements are described in a summary of the AREVA, EPZ UP3 reprocessing contract, which was made public in 2006 as a result of a Greenpeace lawsuit. (Summary document at http://www.areva.com/activities/liblocal/docs/BG%20aval/Recyclage/La%20hague/LIRE_EPZ.pdf) Under a 2004 amendment to the contract, AREVA committed to provide plutonium MOX recycling solutions for EPZ's plutonium, via the manufacture of MOX fuel on behalf of AREVA's European customers. This amendment applied to both plutonium separated before and after the date of the amendment. Under this amendment, AREVA also took ownership of some of the Dutch plutonium for use as feedstock for starting the MELOX MOX fuel fabrication plant.

The contract stipulates that the EPZ plutonium was loaned and a corresponding amount of plutonium in due time would be returned in due course. It is unclear what this condition means in practice. In a 2006 Dutch national report on spent fuel management, the government stated that "EPZ has contracted the management and recycling of its plutonium as MOX fuel, in foreign reactors. None of this plutonium is being returned to the Netherlands." (National Report of the Kingdom of the Netherlands, Second review conference (May 2006), Supplement Answers to questions received from other parties, The Hague, April 11, 2006; see also Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, National Report of the Kingdom of the Netherlands, Fourth review conference (May 2012), Ministry of Economic Affairs, Agriculture and Innovation, Ministry of Foreign Affairs, the Hague, September 2011).

According to this information, EPZ has likely sold most of its plutonium separated until recently. In 2011, it received a license to recycle its plutonium in the Borssele reactor, so after that date, it likely kept its separated plutonium for its own use. In sum, about 1.5-2.0 tonnes of this plutonium are estimated as transferred to non-Dutch entities or utilities, as of the end of 2014.

The following table summarizes the Netherlands accumulation and disposition of unirradiated plutonium through 2014. As shown below, its stock of unirradiated plutonium is estimated as about 0.62 to 1.12 tonnes.

Table Unirradiated Plutonium, Separation, Use, and Sale (tonnes), end of 2014

Plutonium Separated		
EPZ		+3.12
GKN		+0.4
	Subtotal	3.52
Borrowed from AREVA		+0.35
	Subtotal	**3.87**
Reductions		
Transfer to UK and Italy		- 0.507
Superphenix and Kalkar sale		- 0.445
MOX Irradiated in Borssele reactor		- .0.3
Otherwise transferred by EPZ		-1.5-2.0
	Subtotal	-2.75 to 3.25
Total Unirradiated Plutonium:		**0.62 to 1.12**

It should be noted that the adjustment in column 3 resulted from Dutch utilities selling about 350 kilograms to Britain in 2012 and 157 kilograms of plutonium to Italy in the 1980s. In addition, EPZ sold an estimated 1.5 to 2.0 tonnes under its 7th amendment to its AREVA UP3 contract, and the Dutch utilities also sold France or other countries its leftover fresh plutonium from the Superphenix and Kalkar reactors, or 0.445 tonnes. Finally, EPZ is estimated to have borrowed 0.35 tonnes. In total, the adjustment in column 3 is a net subtraction of 2.10 to 2.60 tonnes.

In addition, there is Dutch plutonium in spent fuel awaiting reprocessing in France as of the end of 2014. As stated at the beginning of this footnote, as of June 2015, about 24 tonnes (319-295 tonnes) of spent fuel awaited reprocessing. This spent fuel would contain about 220 kilograms of plutonium. This amount of spent fuel corresponds to about one or two years' worth of Borselle older spent fuel and is a reasonable amount to be at La Hague awaiting reprocessing at the end of 2014. Additional shipments are expected.

(h) Spain's Vandellos gas-graphite reactor was supplied by France, which also took ownership of the plutonium from this reactor. The irradiated fuel, containing approximately 5.12 tonnes of plutonium, was reprocessed in France. Spain also contracted to have 154 tonnes of spent fuel reprocessed at the Thorp reprocessing plant (57 tonnes from the Zorita PWR reactor and 97 tonnes from the BWR Garona reactor). As of the end of 2003, 106 tonnes of this spent fuel had been reprocessed, all 57 tonnes of spent fuel from the Zorita reactor and 49 tonnes from the Garona reactor. Spain sold the roughly 500 kg of separated plutonium from the reprocessed Zorita fuel to BNFL in recent years. The remaining 48 tonnes of spent fuel from the Garona reactor were expected to be reprocessed by the end of 2005. The 97 tonnes of Garona fuel are estimated to contain about 550-600 kilograms of plutonium. In sum, Spain is known to have sold 5.6 tonnes of plutonium in separated form and owns 550-600 kilograms in separated form, where it is assumed

that all its fuel in Britain has already been reprocessed. The separated plutonium remains in the United Kingdom.

(i) Sweden separated 833 kg of plutonium in Britain. The United Kingdom has taken ownership of this plutonium. David Lowry and Johan Swahn, "Sweden wants to transfer ownership of 834 kg of separated plutonium to the United Kingdom," March 18, 2014, http://fissilematerials.org/blog/2014/03/sweden_wants_to_transfer_.html; Michael Fallon, "Written statement to Parliament: Management of overseas owned plutonium in the UK." July 3, 2014, https://www.gov.uk/government/speeches/management-of-overseas-owned-plutonium-in-the-uk

Table A3: Countries that Shipped Irradiated Civil Power Reactor Fuel to Russia, through the end of 2014 (tonnes) (a)

Country	Estimated Pu discharged from power reactors (b)	Estimated VVER-440 spent fuel and Pu sent to Mayak for reprocessing		Estimated VVER-1000 spent fuel and Pu sent for storage in Russia		Pu in spent fuel from power reactors held in country, estimate
	Pu	Fuel	Pu(b)	Fuel	Pu	
Armenia(c)	4.0	240	1.9	0		2.1
Bulgaria(d)	20.0	848	7.6	403	3.6	8.8
Finland(c)	21.1	340	2.9	0		18.2
GDR (c)	6.3	293	2.0	0		4.3(e)
Hungary	13.3	280	2.5(f)	0		10.8
Slovakia	15.1	84(g)	0.85(g)	0		14.3
Ukraine(h)	82.1	500	4.5	3,000	27.0	50.6
Total	161.9	2,585	22.25	3,403	30.6	109.1

Notes for Table A3:

(a) Russia has taken back a sizeable amount of spent fuel from VVER-440 and VVER-1000 reactors that it sold to the countries in this table. The VVER-440 spent fuel is reprocessed at the RT-1 facility at Mayak. Russia has assumed ownership of much of the plutonium contained in this spent fuel. Currently, there are no plans to ship back the separated plutonium. These plutonium quantities are contained in Russia's INFCIRC/549 declaration. The VVER-1000 spent fuel is being stored at the Mining Chemical Complex at Zheleznogorsk, near Krasnoyarsk in Siberia. The original intention was to reprocess the VVER-1000 spent fuel in the RT-2 facility at the Complex, but the construction of this facility was cancelled in 1989. However, a large spent fuel storage facility was completed. As a result, countries have continued to send spent VVER-1000 fuel there for long-term storage. This spent fuel is expected to remain in Russia for decades; it may be eventually reprocessed. The amounts of plutonium in the spent fuel transported to Russia are subtracted from the total plutonium discharge values for each country in the table to arrive at the

plutonium holdings of each of these countries. Most of the VVER-440 spent fuel is believed to have been separated at the RT-1 facility by the end of 2014.

(b) The second column of this table lists the total amount of plutonium in spent fuel discharged from commercial reactors in these countries through 2014.

(c) In the cases of Armenia, Finland, and the former German Democratic Republic (GDR), spent fuel was shipped many years ago. As a result, the amount of plutonium in the shipped spent fuel is derived from older estimates of the average amount of plutonium in spent fuel, in units of kg of plutonium per tonnes of heavy metal in the fuel. These values can be found in Table 6 in the ISIS study, "Civil Plutonium Produced in Power Reactors, April 30, 2004 (Revised June 7, 2005), http://isis-online.org/uploads/isis-reports/documents/civil_pu.pdf.

(d) Through 2009, Bulgaria shipped 4,906 spent VVER-440 fuel assemblies and 959 spent VVER-1000 fuel assemblies to Russia. See Diana Dacheva, Chief Inspector, Division Nuclear Materials and Physical Protection, Nuclear Regulatory Agency, Bulgaria, "Bulgarian Vision and Experiences of Fuel Cycle Options," Technical Meeting on Nuclear Fuel Cycle Information System, IAEA, Vienna, December 15-17, 2010.
http://www.iaea.org/OurWork/ST/NE/NEFW/documents/INFCIS/TM-NFCIS-2010/13.pdf.

From 2009 through 2014, no VVER-1000 spent fuel assemblies were transported and a total of 2,160 VVER-440 spent fuel assemblies were sent to Mayak for reprocessing. See 2010-2014 Annual Reports of the Bulgarian Nuclear Regulatory Agency. In total, 7,066 VVER-440 spent fuel assemblies and 959 VVER-1000 spent fuel assemblies were sent to Russia. A VVER-440 fresh spent assembly contains about 0.12 tonnes of heavy metal and a VVER-1000 spent fuel assembly contains about 0.42 tonnes of heavy metal. Using the fresh uranium mass, about 848 tonnes of VVER-440 spent fuel and 403 tonnes of VVER-1000 spent fuel were shipped to Russia. A value of 9 kg plutonium per tonne of uranium is used.

(e) The plutonium in the German Democratic Republic (GDR) was inherited by Germany after the fall of the Berlin wall. Plutonium in irradiated GDR power reactor fuel that remained after the collapse of the GDR is included in the German INFCIRC/549 declaration. Thus, the GDR plutonium value in the last column of this table is not used in other tables in this report.

(f) A value of 9 kg plutonium per tonne of uranium is used.

(g) The 84 tonnes represents the amount of VVER-440 spent fuel that Slovakia sent to Russia. It is assumed to have about 8 kg plutonium per tonne of fuel. Slovakia also sent all the spent fuel from the A1 reactor, a heavy-water, gas-cooled reactor, but the amount of A1 spent fuel is not included above in either spent fuel listing for Slovakia. This spent fuel contained no more than 200 kilograms of plutonium. However, this amount is included in the value in the column listing the amount of plutonium sent to Mayak.

(h) Ukraine has sent a considerable amount of its spent VVER-440 and VVER-1000 spent fuel to Russia. The VVER-440 spent fuel has gone to Mayak for reprocessing in the RT-1 facility and Russia has kept the plutonium, which is included in Russia's INFCIRC/549 declaration. The total amount of VVER-440 spent fuel sent to Mayak for reprocessing through 2014 is an estimate.

Since 1985, Ukraine has sent VVER-1000 spent fuel to a storage site at Zheleznogorsk, near Krasnoyarsk. See K.G. Kudinov, "Creating an Infrastructure for Managing Spent Nuclear Fuel," in *An International Spent Fuel Repository*, Glenn E. Shweitzer and A. Chelsea Sharber, eds (Washington, D.C.: National Academies Press, 2005), p. 146. Originally intended to be reprocessed at the Mining Chemical Complex, called RT-2, the spent fuel is instead stored there after the construction of the RT-2 plant was halted in 1989. As of January 1, 2003, the storage site had received about 1,500 tonnes of spent VVER-1000 fuel. (Ibid., p. 148). The amount of VVER-1000 spent fuel sent from the end of 2003 through 2014 is estimated. In the early 2000s, Ukraine was expected to send about 220 tonnes per year of VVER-1000 spent fuel to this site. (Ibid., p. 146). Since 2005, the amount shipped to the Zheleznogorsk site was reportedly down to about 150 tonnes per year, after the Zaporozhskaya nuclear power station decided to save costs and store its fuel itself at the reactor complex in dry casks. A crude estimate is that during 2004 and 2005, Ukraine sent an average of 200 tonnes per year, for a total of 400 tonnes. From 2005 through 2014, Ukraine is estimated to have sent an average of about 100-150 tonnes per year, for a total of 900-1,350 tonnes. In total, the shipments from 2003 through 2014 are estimated as 1,300-1,750 tonnes of spent VVER-1000 fuel.

The total amount of VVER-1000 spent fuel shipped to Zheleznogorsk through 2014 is estimated as 2,800-3,250 tonnes. Because of the uncertainties in this estimate, a central estimate of 3,000 tonnes is used in the table. Each tonne of spent fuel is assumed to contain 9 kilograms of plutonium.