

Civil Plutonium Produced in Power Reactors

April 30, 2004, *Revised August 16, 2005*

Table 1 Estimated Inventory of Civil Plutonium, in tonnes

	End 2002	End 2003	End 2004
Total Plutonium from Civil Power Reactors(a)	1502	1565-1575	1635-1645
Plutonium in unirradiated forms (b)	230	238	242
Plutonium in irradiated fuel	1272	1327-1337	1393-1403
US and Russian Excess Plutonium(c)	102.5	102.5	102.5
Plutonium in unirradiated forms	95	95	95
Plutonium in irradiated fuel	7.5	7.5	7.5
Total Civil Plutonium (rounded)(d)	1605	1668-1678	1738-1748

- a) These values are estimates of the total amount of plutonium generated and remaining in civil power programs. These estimates depend on three primary sources: (1) INFCIRC/549 declarations by nine key states filed with the International Atomic Energy Agency about civil plutonium holdings; (2) information about plutonium discharges from civil power reactors; and (3) detailed, country-specific data about plutonium separation and use. The estimates in this table do not include the roughly 100-200 tonnes of plutonium remaining in the cores of nuclear power reactors at the end of each year. Estimates for the end of 2004 are extrapolations from the results for the end of 2003 supplemented by data about plutonium separation and use. These estimates assume an annual increase in total civil plutonium of about 70 tonnes. Supporting information and findings for the estimates of the amount of plutonium from civil power reactors are in tables 2-9 in this report and in the ISIS report “Separated Civil Plutonium Inventories: Current Status and Future Directions.”
- b) British military plutonium declared excess to military requirements is included in the estimates for civil plutonium in unirradiated forms. Britain’s relatively small amount of excess plutonium, which was not produced in civil power reactors, is not segregated from Britain’s much larger total stock of unirradiated plutonium produced in civil power reactors in its INFCIRC/549 declaration.
- c) The total amount of civil plutonium also includes plutonium declared excess to U.S. and Russian defense programs. More information about the U.S. and Russian stocks of excess plutonium can be found in “Separated Civil Plutonium Inventories: Current Status and Future Directions.”
- d) This number does not take into account plutonium 241 (Pu-241) that has decayed into americium 241 (Am-241). Almost 70 tonnes of civil Pu-241 are estimated to have decayed into Am-241 as of the end of 2003. Because very little Pu-241 exists in military plutonium, its decay has an insignificant effect on estimated inventories of military plutonium. For more information, see *Neptunium 237 and Americium: World Inventories and Proliferation Concerns*, by David Albright and Kimberly Kramer, June 10, 2005.

Table 2 Holdings of Plutonium in Civil Power Reactor Programs, end 2003 (in tonnes)(a)

Country	Total Plutonium Holdings (irradiated and unirradiated forms)
Argentina	11
Armenia	1.4
Belgium	24
Brazil	2.1
Bulgaria	8.5
Canada	135
China	5.1
Czech Republic	6.2
Finland	11
France	231(b)
Germany	93-96
Hungary	7.5
India	14
Italy	6.5
Japan	152-154
Kazakhstan	3.0
Lithuania	10
Mexico	2.4
Netherlands	3.5
Pakistan	0.8
Romania	2.4
Russia	126
Slovakia	8.4
Slovenia	2.7
South Africa	5.8
South Korea	44
Spain	27
Sweden	42
Switzerland	19
Taiwan	22
Ukraine	41
United Kingdom	93-99(b)
United States	403
Total (rounded)	1565-1575

- a) The estimates in this table are from tables 3, 6, and 7 in this report. They do not include the roughly 100-200 tonnes of plutonium remaining in the cores of nuclear power reactors at the end of 2003.
- b) The values for British and French holdings of irradiated plutonium holdings as of the end of 2002 were overestimated by roughly 8 and 15 tonnes, respectively. The declarations that these countries submitted to the IAEA included foreign-owned spent fuel which was not accounted for in the end of 2002 numbers. The British value also includes 4.4 tonnes of excess British military plutonium.

Table 3 Holdings of Plutonium in Civil Power Reactor Programs in Countries Involved in Plutonium Separation or Recycling, end 2003 (in tonnes)

Country	Irradiated Plutonium	Unirradiated Plutonium	Total(rounded)
Belgium	23.1	0.4-1.4	24
China	5.1	0	5.1
France	183	48.1	231
Germany	67-70	26	93-96
India	12.5-13	1-1.5	14
Italy	4.0	2.5	6.5
Japan	111-113	40.6	152-154
Netherlands	1-1.4	2-2.5	3.5
Russia	88	38.2	126
Spain	26.6	0.3	27
Sweden	41	0.83	42
Switzerland	16-17	1.5-3.0	19
United Kingdom	18.5-24.6	74.6	93-99
United States	403	0	403
Total (rounded)	1000-1013	236-240	1240-1250

Table 4 Total Holdings of Plutonium from Civil Power Reactors, INFCIRC/549 Countries, end 2003, in tonnes

Country	A: Unirradiated Plutonium holdings from civil power reactors, INFCIRC/549 declaration (end 2003)	B: Unirradiated plutonium holdings from civil power reactors, estimated since not declared (end 2003)(a)	C: Plutonium in spent fuel, INFCIRC/549 declaration (end 2003)	D: Estimated plutonium in spent fuel, stored overseas and not in INFCIRC/549 declarations (end 2003)(b)	E: Estimated amount of foreign-owned plutonium in spent fuel, held at reprocessing plants or other sites (end 2003)(b)	F: Plutonium in spent fuel from civil power reactors, (end 2003)(c) (C + D – E)	Total Plutonium holdings, ISIS estimate (end 2003)(d) ([A or B] + F)
Belgium	n.i.(e)	0.4-1.4	23	0.1		23.1	24
China	0	n.a.(e)	5.1(f) no declaration	0		5.1	5.1
France	48.1	n.a.	191	0	8-8.4	183	231
Germany	n.i.	26	56	11-14		67-70	93-96
Japan	40.6	n.a.	105	6-8		111-113	152-154
Russia	38.2	n.a.	88	0		88	126
Switzerland	n.i.	1.5-3.0	15	1-2		16-17	19
United Kingdom	74.6(g)	n.a.	37	0	12.4-18.5	18.5-24.6	93-99
United States	n.i.	0	403(h)	0		403	403

Comments and Notes for Table 4

- a) These values are from table 2 in the ISIS report “Separated Civil Plutonium Inventories: Current Status and Future Directions,” by David Albright and Kimberly Kramer, June 2004, *Revised May 13, 2005*.
- b) These values are from tables 8 and 9 in this report.
- c) The values for plutonium in irradiated fuel, column 7, are the sum of the values in columns 4 and 5 minus the value in column 6.
- d) Figures rounded. Values in column 8, total plutonium holdings, are the sum of the unirradiated and irradiated plutonium holdings. Thus, a value in column eight is a sum of the values in column 2 or 3 and column 7.
- e) Abbreviations used in the table: n.i. is not included in the declaration and n.a. is not applicable.
- f) The value for China is an ISIS estimate of total plutonium discharged from Chinese power reactors, assuming no plutonium from this spent fuel has been reprocessed.
- g) This value includes a relatively small quantity of plutonium declared excess to military requirements. This plutonium is from non-civil reactors.
- h) This value does not include 7.5 tonnes declared as excess to national security needs.

Table 5 Estimated Civil Plutonium Holdings in Several Countries, end 2003, in tonnes(a)

Country	Estimated Pu discharged in power reactor spent fuel, ISIS estimate (through 2003)	Adjustments to total amount of plutonium discharged	Estimated Plutonium holdings, (end 2003)(b)	Total Unirradiated plutonium holdings from civil power reactors, ISIS estimate (end 2003) (c)	Total amount of plutonium in spent fuel from power reactors, held domestically and overseas, ISIS estimate (end 2003)(d)	Plutonium in spent fuel, stored overseas (end 2003)	Estimated plutonium holdings, (end 2003)(b)
India	14		14	1-1.5	12.5-13	0	14
Italy(e)	6.1	+0.35	6.45	2.5	4.0	2.4	6.5
Kazakhstan	3(f)		3	0?	3	0	3
Netherlands(g)	3.7	-0.2	3.5	2.1-2.5	1-1.4	0.3-0.8	3.5
Spain(h)	34	-7.1(h)	26.9	0.3	26.6	0.3	26.9
Sweden	42		42	0.83	41	0	42

Comments and Notes for Table 5

- 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. As a result, the values are more uncertain than those found in table 4, which lists countries that have submitted INFCIRC/549 declarations.
- 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 amount of plutonium discharged in power reactor spent fuel, column 2, and using 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. This column is repeated as column 8, where the values are rounded.
- c) These values are from table 1 in the ISIS report “Separated Civil Plutonium Inventories: Current Status and Future Directions,” by David Albright and Kimberly Kramer, June 2004, *Revised May 3 2005*. The amounts held domestically and overseas are listed in table 1 in this reference.
- d) 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.
- e) The adjustment in column 3 resulted from Italy buying about 350 kilograms of plutonium from Belgium and the Netherlands. Through 2003, Italy separated about 4.35 tonnes of plutonium overseas, giving it a total supply of about 4.7 tonnes of separated plutonium. About 200-300 kilograms were used as MOX fuel in Italian reactors. Another 3.8 tonnes were allocated to the Superphenix reactor, of which Italy owned 33 percent. About 1.9 tonnes of the Superphenix plutonium are in irradiated form; the rest is stored as unirradiated fuel in France. Italy is believed to have retained ownership of all 3.8 tonnes of this plutonium. At the end of 2003, Italy had about 2.5 tonnes of unirradiated plutonium stored overseas in France and Britain. Italy also has some unprocessed irradiated fuel in Britain at Thorp, containing an estimated 500 kilograms of plutonium, bringing to 2.4 tonnes its total of irradiated plutonium held overseas.
- f) The value for Kazakhstan is the plutonium that was produced in the breeder blanket of the BN-350 reactor that was shut down. The BN-350 was fueled by HEU, which led to minimal plutonium production in the fuel and this plutonium is ignored in this table.
- g) The adjustment in column 3 resulted from Dutch utilities selling about 200 kilograms of plutonium in the 1980s to Italy and perhaps France for use in the Superphenix reactor. Under its original reprocessing contracts, the Netherlands contracted to have about 3.6 tonnes of plutonium separated in Britain and France. In 2004, the Dutch contracted for additional reprocessing in France. As of the end of 2003, Dutch utilities still had about 0.8-1.2 tonnes of plutonium yet to be separated under the original reprocessing contracts. In total, the Netherlands had about 2.1-2.5 tonnes of separated plutonium at the end of 2003. In addition, about 300 kilograms of Dutch plutonium was in irradiated forms in France. Almost half is believed to be in

irradiated fuel from Superphenix, which was partially owned by the Netherlands. The rest was at La Hague awaiting reprocessing. Up to 500 kg of plutonium in spent fuel are stored at the Thorp reprocessing plant in Britain.

- h) Spain's Vandellós gas-graphite reactor was supplied by France, which also bought the plutonium from this reactor. The irradiated fuel 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 reactor and 97 tonnes from the 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, expected to be reprocessed by the end of 2005, contain about 300 kg of plutonium.

Table 6 Countries that Shipped Irradiated Civil Power Reactor Fuel to Russia, through the end of 2003, in tonnes(a)

Country	Estimated power reactor spent fuel and plutonium discharged, ISIS estimate (through 2003)		Estimated VVER-440 spent fuel and plutonium discharged sent to Mayak for reprocessing, ISIS estimate (through 2003)		Estimated VVER-1000 spent fuel and plutonium discharged, sent for storage in Russia, ISIS estimate (through 2003)		Plutonium in spent fuel from power reactors held in country, ISIS estimate (end 2002)
	Fuel	Pu	Fuel	Pu(b)	Fuel	Pu (b)	
<i>Armenia</i>	422	3.3	250	1.9	0		1.4
<i>Bulgaria</i>	1652	15	670-690	6.0-6.2(c)	40-60	0.4-0.5(c)	8.3-8.6
<i>Czech Republic</i>	809	7.5	140	1.3	0		6.2
<i>Finland</i>	1615	14	340	3.0(d)	0		11
<i>Germany (GDR)</i>	905	6.3	293	2.0	0		4.3(e)
<i>Hungary</i>	892	8.4	100	0.9	0		7.5
<i>Slovakia</i>	1026	9.6	84(f)	1.2(f)	0		8.4
<i>Ukraine</i>	6940	54	400-420	3.6-3.8(c)	1040-1080	9.4-9.7(c)	40.5-41.0
Total (rounded)	14,261	118	2277-2317	19.9-20.3	1080-1140	9.8-10.2	88

Comments and Notes for Table 6

- a) Russia has taken ownership of all or, at least, the vast majority of the plutonium contained in the VVER-440 and VVER-1000 spent fuel imported from the countries in this table. Thus, these amounts are subtracted from the total plutonium values for each country in the table to arrive at the plutonium holdings of each country. In total, this VVER-440 spent fuel contains about 19 tonnes of plutonium, almost all of which is believed to have been separated at the RT-1 facility at Mayak by the end of 2003. In total, Mayak separated almost 39 tonnes of plutonium by the end of 2003. The VVER-1000 spent fuel is stored in Zheleznogorsk, Krasnoyarsk region. Russia is believed to have taken over ownership of the Bulgarian and Ukrainian VVER-1000 spent fuel. This fuel may be eventually reprocessed.
- b) Except for Bulgaria, Slovakia, and the Ukraine, the values in this column are derived by multiplying the amount of spent fuel sent to Russia by the average amount of plutonium per tonne of fuel derived from the estimates in the column that gives total estimated spent fuel and plutonium discharged through 2003.
- c) The value of 9 kg plutonium per tonne of uranium is used.
- d) Adjusted to account for round-off in column three.
- e) The plutonium in the 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) The 84 tonnes represents the amount of VVER-440 spent fuel that Slovakia sent to Russia. It 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 about 400 kilograms of plutonium. This amount is included in the value in the column listing the amount of plutonium sent to Mayak.

Table 7 Cumulative Plutonium Discharges from Civilian Power Reactors, in tonnes

Country	End of 2003
Argentina	11
Armenia	3.3
Belgium	27
Brazil	2.1
Bulgaria	15
Canada	135
China	5.1
Czech Republic	7.5
Finland	14
France	231
Germany	102
Hungary	8.4
India	13
Italy	6.1
Japan	162
Kazakhstan	3.0
Lithuania	10
Mexico	2.4
Netherlands	3.7
Pakistan	0.8
Romania	2.4
Russia	104
Slovakia	9.6
Slovenia	2.7
South Africa	5.8
South Korea	44
Spain	34
Sweden	42
Switzerland	18
Taiwan	22
Ukraine	54
United Kingdom	117
United States	403*
TOTAL	1621

* This value does not include 7.5 tonnes declared as excess to national security needs.

Table 8 Estimated Amount of Plutonium Held in Spent Fuel at Overseas Reprocessing Plants, end 2003, in tonnes

<u>Country</u>	<u>Plutonium</u>
Belgium	
Superphenix ^a	0.1
Germany	
Thorp ^b	5-8
La Hague ^c	5.2-5.6
Superphenix ^d	0.6
Subtotal	10.8-14.2
Italy	
Thorp ^e	0.5
Superphenix ^f	1.9
Subtotal	2.4
Japan	
Thorp ^g	6-8
Netherlands	
Thorp ^h	0-0.5
Superphenix, La Hague ⁱ	0.3
Subtotal	0.3-0.8
Spain	
Thorp ^j	0.3
Switzerland	
Thorp ^k	0.6-1.2
La Hague ^l	0.5
Subtotal	1.1-1.7
Total	21-27.5

^a Belgium was a part owner of the closed Superphenix breeder reactor located in France. About 100 kg of Belgian plutonium in irradiated fuel are estimated to have been discharged from this reactor. Belgium is believed to still own this plutonium.

^b The estimate in this table is derived from information about Germany's spent fuel contracted for reprocessing at the Thorp plant, its deliveries of spent fuel to Thorp, and the expected reprocessing schedule of this fuel.

^c Based on spent fuel data provided by Cogema. At the end of 2003, La Hague had 482 tonnes of German LWR spent fuel and 52 tonnes of MOX spent fuel in storage. The estimated plutonium content of this fuel, presented in the table above, assumes an average of 9 kg Pu per tonne of LWR spent fuel and 3.5-5% plutonium content for MOX spent fuel.

^d Germany was a part owner of the Superphenix reactor, and roughly 600 kilograms of German-origin plutonium are estimated to be contained in irradiated Superphenix spent fuel. This plutonium is assumed to remain under German ownership.

^e Italy has some unprocessed irradiated fuel in Britain at Thorp, containing an estimated 500 kilograms of plutonium.

^f About 3.8 tonnes of Italian plutonium were allocated to the Superphenix reactor, of which Italy owned 33 percent. About 1.9 tonnes of Italy's Superphenix plutonium is in irradiated form; the rest is stored as unirradiated fuel in France. Italy is believed to have retained ownership of all 3.8 tonnes of this plutonium.

^g Japan does not declare the amount of spent fuel stored in Britain awaiting reprocessing. The estimate in this table is derived from information about Japan's spent fuel contracted for reprocessing at the Thorp plant, its declared inventory of separated plutonium at Thorp, and the expected reprocessing schedule of this fuel.

^h The estimate in this table is derived from information about Netherlands' spent fuel contracted for reprocessing at the Thorp plant and the expected reprocessing schedule of this fuel.

ⁱ At the end of 2003, about 300 kilograms of Dutch plutonium were in irradiated forms in France. Almost half is believed to be in irradiated fuel from Superphenix, which was partially owned by the Netherlands. The rest was at La Hague awaiting reprocessing.

^j Spain contracted to have 154 tonnes of spent fuel reprocessed at the Thorp reprocessing plant (57 tonnes from the Zorita reactor and 97 tonnes from the 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. The remaining 48 tonnes of spent fuel from the Garona reactor, expected to be reprocessed by the end of 2005, contain about 300 kg of plutonium.

^k The estimate in this table is derived from information about Switzerland's spent fuel contracted for reprocessing at the Thorp plant and the expected reprocessing schedule of this fuel.

^l Based on spent fuel data provided by Cogema. At the end of 2003, La Hague had 56 tonnes of Swiss LWR spent fuel in storage. The estimated plutonium content of this fuel, presented in the table above, assumes an average of 9 kg Pu per tonne of LWR spent fuel.

Table 9 Estimated Amount of Foreign-Owned Plutonium Contained in Spent Fuel Held at Reprocessing Plants or Other Sites, end 2003, in tonnes

<u>Country</u>	<u>Plutonium</u>
France	
Belgium	0.1
Germany	5.8-6.2
Italy	1.9
Japan	0
Netherlands	0.3
Spain	0
Switzerland	0.5
Subtotal	8.6-9.0
Britain	
Belgium	0
Germany	5-8
Italy	0.5
Japan	6-8
Netherlands	0-0.5
Spain	0.3
Switzerland	0.6-1.2
Subtotal	12.4-18.5
Total	21-27.5