



Plutonium Watch

Tracking Plutonium Inventories

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Plutonium is a key ingredient in nuclear weapons, making it one of the most dangerous materials in existence. At the end of 2003, there were about 1,830 tonnes (metric tons) of plutonium in the world in 35 countries. This is enough plutonium for more than 225,000 nuclear weapons.

Civil plutonium is in two basic forms--contained in spent (irradiated) fuel, or in separated (unirradiated) form. Unirradiated plutonium may be in pure form, in the process of being fabricated into mixed-oxide (MOX) fuel, or in fresh MOX fuel. Once it has been irradiated, however, the plutonium in MOX fuel, like the plutonium produced when uranium fuel is irradiated, is contained in spent fuel. The plutonium in spent fuel is considered more proliferation resistant because it is difficult to separate the plutonium from the other radioactive constituents of spent fuel.

Table 1 shows that, of the 1,830 tonnes of plutonium in the world at the end of 2003, about 1,675 tonnes were in civil stocks, and 155 tonnes were dedicated to nuclear weapons and other military stocks. Each year, the amount of civil plutonium grows at a rate of about 70 tonnes. The military stocks grow only slightly each year. For comparison, stocks of highly enriched uranium are included.

The 1,675 tonnes of civil plutonium were contained in both spent fuel and unirradiated forms. The amount of plutonium in both categories is increasing. Roughly 1,335-1,345 tonnes were in spent fuel. About 333 tonnes were in unirradiated forms. The plutonium was separated in civil reprocessing programs or was declared excess to military requirements by the United States, Russia, and Britain.

Plutonium Holdings by Country, end of 2003

Table 2 shows plutonium holdings by country at the end of 2003, the last year for which there is detailed information. About 1325-1340 tonnes of plutonium were in spent fuel in civil research and power reactor programs. Another 238 tonnes were in unirradiated

forms in civil power reactor programs at the end of 2003. The rest of the civil plutonium, 102.5 tonnes, was plutonium declared excess to U.S. and Russian defense programs and committed to peaceful uses. Of this amount, 7.5 tonnes were in spent fuel, and about 95 tonnes were in unirradiated forms.

At the end of 2003, military stocks comprised about 155 tonnes of plutonium. India, Israel, and North Korea had a combined total of about one tonne of plutonium dedicated to military purposes.

In a few cases, the figures in table 2 come from official public declarations. For countries that do not declare plutonium holdings, or produce incomplete declarations, ISIS estimates are used. ISIS judges that, without detailed knowledge of plutonium discharges at individual reactors, the country-by-country estimates presented here are uncertain by 10-25 percent. Uncertainty could not be lowered to less than five percent unless each country provided more information about the amount of plutonium discharged in spent fuel, or more information about spent fuel discharges and fuel burn-up.

Civil Separated Power Reactor Plutonium by Country, end of 2003

Table 3 shows the amounts of separated plutonium produced in civil power reactor programs held and owned by 14 key countries at the end of 2003, the last year for which detailed country-specific information is available. Most of the figures come from the official public declarations that nine countries make annually to the International Atomic Energy Agency (IAEA). Several of the entries in the table are estimates, however, because some declarations are incomplete or ambiguous. In addition, India, Italy, Netherlands, and Spain have not made declarations of their separated plutonium inventories to the IAEA or the public.

Most declarations for stocks at the end of 2004 are not yet available from the IAEA. However, based on an assessment of the amount of spent fuel reprocessed and the amount of plutonium used in MOX fuel, ISIS estimates that roughly 242 tonnes of power reactor plutonium were in unirradiated forms at the end of 2004.

Projected Civil Separated Plutonium Inventories

From the end of 1997 to the end of 2003, the world's stock of civil unirradiated plutonium in civil programs grew at an average rate of about 10 tonnes per year. During this period, about 20 tonnes of plutonium per year were separated worldwide from commercial spent fuel, and roughly 10 tonnes of plutonium per year were fabricated into MOX fuel for use almost exclusively in LWRs. During the next five years, the net amount of unirradiated plutonium is projected to grow at about half the earlier rate. This slowdown in the growth of the global stock reflects a decrease in the amount of plutonium being separated and an increase in the amount of plutonium fuel being fabricated and irradiated.

There are several reasons that the current estimate projects higher global plutonium inventories during the next decade. The British MOX fabrication plant, or Sellafield MOX plant (SMP), was unable to commence commercial operation as originally scheduled around 2000, and many now doubt that it will ever reach its full capacity of 120 tonnes of MOX fuel per year. In addition, the lack of Japanese orders to make MOX fuel in Europe led to the unexpected growth of Japanese separated plutonium stocks. Japanese utilities have been unable so far to start loading MOX fuel into their light water reactors due to intense local opposition to their plans, causing the utilities to delay their European MOX contracts. Continuing controversies in Britain and Japan could cause further delays in MOX fabrication and use during the next decade.

Given these uncertainties, projections inevitably vary depending on assumptions regarding the fate of the MOX fabrication plants, the amount of plutonium separated, and the number of reactors using MOX fuel. The projections presented here are rather broad ranges that attempt to capture most of the possible futures for plutonium separation and use during the next 15 years. Table 4 summarizes these results both for countries with plans to use MOX fuel and those without firm plans to use MOX fuel. A sobering conclusion is that under a wide variety of reasonable assumptions, total civil separated power reactor plutonium stocks are not expected to decrease significantly in this period. A positive result is that Belgium, Sweden, Switzerland, and likely Germany will reduce their inventories to zero or near zero. However, most countries listed in the table will have to store their plutonium either domestically or overseas for the foreseeable future, absent major initiatives to reduce inventories of separated plutonium.

Military Plutonium

The world's militaries have significantly less plutonium than civil owners do--some 155 tonnes, not including 107 tonnes declared excess to military needs by Britain, Russia and the United States. For the purposes of this study, excess plutonium is considered part of civil inventories. The amount of dedicated military plutonium is less than 10 percent of the amount in civil inventories. But more than 90 percent of military plutonium is in separated form, and thus more readily usable in weapons. Table 5 lists the inventories of military and excess plutonium in the five acknowledged nuclear weapon states. In the coming years, more military plutonium could be declared excess.

Excess Plutonium Disposition

Table 6 estimates the disposition of US and Russian excess plutonium stocks through their conversion and use as MOX fuel in power reactors. The United States and Russia have each agreed to dispose of 34 tonnes of excess plutonium as MOX fuel.

However, plutonium disposition has gone more slowly than expected. All 68 tonnes of plutonium should be irradiated in power reactors by 2030, although delays could postpone this date further.

Unirradiated Civil Plutonium Projections

The total projected stock of unirradiated plutonium is shown in table 7. By 2020, the total stock is projected to be 315 tonnes, with a range of 255 to 340 tonnes. Compared to a total stock of 333 tonnes at the end of 2003, this result shows that the projected inventory of unirradiated plutonium will be relatively fixed during the next 15 to 20 years.

Table 1 Global Plutonium and Highly Enriched Uranium (HEU), Assigned to Civil or Military Stocks, end 2003 (in tonnes)(a)

Category	Plutonium	HEU	Total
Civil Stocks	1,675(b)	175	1850
Power and Research Reactor Programs(c)	1570	50	
Russian and U.S. Military Excess(d)	102.5	125 (US only)	
Military Stocks	155	1725	1880
Primary	155	1250	
Naval and Other	--	175	
Russian HEU Declared Excess	--	300(e)	
Total	1830	1900	3730

(a) These aggregate numbers are based on an attempt to realistically assign plutonium and HEU to civil or military stocks based on a combination of factors, principally current use and future intended use. The bulk of the plutonium and HEU in military stocks is material in nuclear weapons, reserves, naval and production reactor programs, and in storage from dismantled weapons.

(b) Rounded.

(c) British excess military plutonium is included with civil power reactor values because Britain includes this plutonium in the category of civil, unirradiated plutonium in its INFCIRC/549 declarations to the International Atomic Energy Agency.

(d) Britain and the United States declared that their excess plutonium would be used only for peaceful purposes. The United States made a similar commitment for its excess HEU; Britain did not declare any excess HEU. Russia has made a similar commitment for its excess plutonium, but not for its excess HEU (see below).

(e) Russia has committed to blend down 500 tonnes of HEU to LEU. By the end of 2003, it had blended down 200 tonnes. The remaining 300 tonnes remain in its military stock, probably in nuclear weapons. As a result, this stock is assigned to the military stock. As HEU from this category is blended down to LEU, it is removed from this total.

Table 2 Holdings of Civil Power and Military Plutonium by Country, end 2003 (in tonnes)(a)

<u>Country</u>	<u>Civil</u>			<u>Military</u>	<u>Total</u>
	<u>Power Reactor Programs</u>		<u>Military Excess</u>		
	<u>Irradiated</u>	<u>Unirradiated</u>			
Argentina	11				11
Armenia	1.4				1.4
Belgium	23.1	0.4-1.4			23.5-24.5
Brazil	2.1				2.1
Bulgaria	8.5				8.5
Canada	135				135
China	5.1			4	9.1
Czech Republic	6.2				6.2
Finland	11				11
France	183	48.1		5	236.1
Germany	67-70	26			93-96
Hungary	7.5				7.5
India	12.5-13	1-1.5		0.43	13.9-14.9
Israel	0			0.56	0.56
Italy	4.0	2.5			6.5
Japan	111-113	40.6			151.6-153.6
Kazakhstan	3.0				3.0
Lithuania	10				10
Mexico	2.4				2.4
Netherlands	1-1.4	2-2.5			3-3.9
North Korea	0			0.035-0.045(b)	0.035-0.045
Pakistan	0.8			0.04	0.84
Romania	2.4				2.4
Russia	88	38.2	50	95	271.2
Slovakia	8.4				8.4
Slovenia	2.7				2.7
South Africa	5.8				5.8
South Korea	44				44
Spain	26.6	0.3			26.9
Sweden	41	0.83			41.8
Switzerland	16-17	1.5-3.0			17.5-20
Taiwan	22				22
Ukraine	41				41
United Kingdom	18.5-24.6	74.6(c)		3.2	96.3-102.4
United States	403		52.5	47	502.5
Total (rounded)	1325-1340	238	102.5	155	1820-1835

(a) The figures in this table are central estimates, except for North Korea. Values are rounded.

(b) At the end of 2003, most of North Korea's plutonium was unirradiated.

(c) Contains 4.4 tonnes of British excess plutonium.

Table 3 Unirradiated Civil Plutonium Produced in Power Reactor Programs, end 2003 (in tonnes)

	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	96.2	0.9	22.5	74.6(a)
France	78.6	less than 0.05	30.5	48.1
Belgium	3.5	0.4	2.5-3.5	0.4-1.4
Germany	12.5	~13.5	0	26
Japan	5.4	35.2	0	40.6
Switzerland	0.5-1.0	1-2	0	1.5-3.0
Russia	38.2	0.0006	0	38.2
China	0	0	0	0
United States	(b)	0	0	(b)
India	~1-1.5	0	0	1-1.5
Netherlands	0	2-2.5	0	2-2.5
Italy	0?	2.5	0	2.5
Sweden	0	0.83	0	0.83
Spain	0	0.3	0	0.3
TOTAL(c)	236-237			236-240

- (a) Of this value, 4.4 tonnes are British excess military plutonium produced in military reactors. Because this amount of plutonium is included in Britain's INFCIRC/549 declaration, it is included here.
- (b) US declared values in INFCIRC/549 are the amounts of unirradiated military plutonium that the United States has declared excess to military requirements and is included in tabulations of such excess plutonium. In total, the United States has declared 52.5 tonnes of plutonium excess. Of this 52.5 tonnes, the United States has declared in its INFCIRC/549 that 45 tonnes are in unirradiated or separated forms. Earlier versions of this report included a fraction of this declared amount, namely an estimate of the amount of unirradiated plutonium originally produced in civil reactors. This estimate was 4 to 5 tonnes, the bulk of which was produced in British civil reactors and exported to the United States several decades ago.
- (c) Totals rounded.

Source: For the first nine 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. The totals of Columns A and D do not match exactly because the declarations are incomplete and several estimates are required to complete the table. For more detailed sourcing, see Table 1, *Separated Civil Plutonium Inventories: Current Status and Future Directions*, by David Albright and Kimberly Kramer, July 8, 2005.

Table 4 Separated Civil Power Reactor Plutonium Inventories and Projected Inventories (in tonnes)

	Separated Civil Plutonium Owned by a Country, end of 2003	Separated Civil Plutonium Owned by a Country, 2010 Central estimate or median, (uncertainty range)	Separated Civil Plutonium Owned by a Country, 2015 Central estimate or median, (uncertainty range)	Separated Civil Plutonium Owned by a Country, 2020 Central estimate or median, (uncertainty range)
Countries with firm plans to use civil MOX				
Belgium	0.4-1.4	0	0	0
France	48.1	48 (44-53)	46 (38-54)	43 (32-55)
Germany	26	27 (22-31)	15 (7-22)	3 (0-13)
India	~1-1.5	~2	~1	~1
Japan	40.6	62 (51-64)	58 (24-91)	50 (15-86)
Sweden	0.83	0?	0	0
Switzerland	1.5-3.0	0?	0	0
China	0	0?	?	?
Countries without firm plans to use civil MOX through 2020				
Britain (includes excess military plutonium)	74.6	90	92	92
Italy	2.5	3	3?	3?
Netherlands	2-2.5	3	3.5	4
Spain	0.3	0.6?	0.6?	0.6?
Russia	38.2	50	58	66
Countries with plans to dispose of excess military plutonium (U.S. and Russia), see tables 6 and 7				
Total (rounded)	238 (236-240)	286 (266-297)	277 (227-325)	263 (214-321)

Source: Table 2, *Separated Civil Plutonium Inventories: Current Status and Future Directions*, by David Albright and Kimberly Kramer, July 8, 2005.

Table 5 Military and Excess Stocks of Plutonium in the Acknowledged Nuclear Weapon States, end of 2003 (in tonnes)

Official State Declaration of Stocks

	Total(a)	Military Stock(b)	Declared Excess	Under Safeguards
U.K.	7.6 ($\pm 2\%$?)	3.2	4.4	4.4
U.S.	99.5 ($\pm 2\%$)	47	52.5	2

ISIS Estimates of Stocks

	Total(a)	Military Stock(b)	Declared Excess(b)	Under Safeguards
China(c)	4.1 (2.1-6.6)	4.1	0	0
France	5 (3.6-6.4)	5	0	0
Russia(d)	145 (120-170)	95	50	0
Total	261 (231-292) (e)	155 (e)	107(e)	6.4

Notes and Comments

- (a) The values in the parentheses are the percentage uncertainty or the range of the total estimated stock.
- (b) Only the central estimates are used in this column.
- (c) China's military plutonium stock remains highly uncertain. It reportedly continued to produce plutonium in at least one military reactor after plutonium production for weapons ceased in about 1991. The estimate for the amount of weapon-grade plutonium produced prior to this cutoff is 2.3-3.2 tonnes. For more information, see *Chinese Military Plutonium and Highly Enriched Uranium Inventories*, by David Albright and Corey Hinderstein, June 22, 2005.
- (d) Russia continues to produce about 1.4 tonnes/year of plutonium in its three remaining plutonium production reactors. Plutonium produced after late 1994, or almost 13 tonnes, is legally banned from use in nuclear weapons. However, this plutonium is not believed to be included in Russia's INFCIRC/549 declaration, and thus it is treated as part of Russia's military stock. Prior to 1994, Russia is estimated to have produced about 130 tonnes of plutonium.
- (e) Rounded.

Table 6 Current and Projected US and Russian Stocks of Excess Unirradiated Plutonium Subject to MOX Disposition (in tonnes)*

Country	2010	2015	2020	2025	2030
Russia	34	26 (23-28)	16 (11-20)	6 (0-12)	0 (0-5)
United States	34	25 (20-29)	13 (4-22)	1 (0-16)	0 (0-9)

* The values in parentheses are the range in the estimates. The lower values for 2025 and 2030 are arbitrarily set at zero. Similarly, the central estimates for 2030 are set at zero. In practical terms, the zero values for the central estimates for 2030 mean that all the plutonium will likely have been disposed of by this time.

Source: Table 4, *Separated Civil Plutonium Inventories: Current Status and Future Directions*, by David Albright and Kimberly Kramer, July 8, 2005.

Table 7 Civil Unirradiated Plutonium, from Civil Reactors and Declared Military Excess, in tonnes (a)

Origin	2003	2010	2015	2020
Civil(b)	238	286 (266-297)	277 (227-325)	263 (214-271)
US and Russian Excess(c)	95	95	78 (70-84)	53 (42-69)
Total (rounded)	333	380 (360-390)	355 (295-410)	315 (255-340)

- (a) The values in parentheses are the lower and upper bounds of each estimate, derived from the bounds in tables 4 and 6.
- (b) This quantity includes British excess military plutonium.
- (c) About 7 tonnes of US excess plutonium are in spent fuel and not included here.

Source: Table 6, *Separated Civil Plutonium Inventories: Current Status and Future Directions*, by David Albright and Kimberly Kramer, July 8, 2005.