Appendix 7A. Global stocks and production of fissile materials, 2010

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Materials that can sustain an explosive fission chain reaction are essential for all types of nuclear explosives, from first-generation fission weapons to advanced thermonuclear weapons. The most common of these fissile materials are highly enriched uranium (HEU) and plutonium of almost any isotopic composition. This appendix gives details of current stocks of HEU (table 7A.1) and separated plutonium (table 7A.2), including in weapons, and details of the current capacity to produce these materials (tables 7A.3 and 7A.4, respectively). The information in the tables is based on new estimates prepared for the *Global Fissile Material Report 2010* of the International Panel on Fissile Materials.[1]

The production of HEU and plutonium both start with natural uranium.[2] Natural uranium consists almost entirely of the non-chain-reacting isotope U-238, with about 0.7 per cent U-235, but the concentration of U-235 can be increased through enrichment—typically using gas centrifuges. Uranium that has been enriched to less than 20 per cent U-235 (typically, 3–5 per cent)—known as low-enriched uranium (LEU)—is suitable for use in power reactors. Uranium that has been enriched to contain at least 20 per cent U-235—known as HEU—is generally taken to be the lowest concentration practicable for use in weapons. However, in order to minimize the mass of the nuclear explosive, weapon-grade uranium is usually enriched to over 90 per cent in U-235.

Plutonium is produced in nuclear reactors through the exposure of U-238 to neutrons and is subsequently chemically separated from spent fuel in a reprocessing operation. Plutonium comes in a variety of isotopic mixtures, and most such mixtures are weapon-usable. Weapon designers prefer to work with a mixture that is predominantly Pu-239 because of its relatively low rate of spontaneous emission of neutrons and gamma rays and the low generation of heat through this radioactive decay. Weapon-grade plutonium typically contains more than 90 per cent of the isotope Pu-239. The plutonium in typical spent fuel from power reactors (reactor-grade plutonium) contains 50–60 per cent Pu-239 but is weapon-usable, even in a first-generation weapon design.

The five nuclear weapon states party to the 1968 Non-Proliferation Treaty—China, France, Russia, the United Kingdom and the United States—have produced both HEU and plutonium. India, Israel and North Korea have produced mainly plutonium, and Pakistan mainly HEU for weapons. All states with a civilian nuclear industry have some capability to produce fissile materials.

[1] International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2010: Balancing the Books—Production and Stocks* (IPFM: Princeton, NJ, 2010).

[2] For full details see International Panel on Fissile Materials (note 1), appendix B.

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Table 7A.1. Global stocks of highly enriched uranium (HEU), 2010

State	National stockpile (tonnes)[a]	Production status	Comments
China	16 ± 4	Stopped 1987–89	
France[b]	31 ± 6	Stopped 1996	Includes 4.9 tonnes declared civilian
India[c]	1.3 ± 0.3	Continuing	
Israel[d]	0.3	–	
Pakistan	2.6 ± 0.4	Continuing	
Russia[e]	670 ± 120	Stopped 1987–88	Includes 50 tonnes assumed to be reserved for naval and research reactor fuel; does not include 104 tonnes to be blended down
UK[f]	21.2 (declared)	Stopped 1962	Includes 1.4 tonnes declared civilian
USA[g]	510 (declared)	Stopped 1992	Includes 130 tonnes reserved for naval reactor fuel and 20 tonnes for other HEU reactor fuel; does not include 104 tonnes to be blended down or for disposition as waste
Non-nuclear weapon states[h]	~20		
Total	**~1270**[i]		**Does not include 208 tonnes to be blended down**

[a] Most of this material is 90–93% enriched in uranium-235, which is typically considered as weapon-grade. Important exceptions are noted where required. Blending down (i.e. reducing the concentration of U-235) of excess Russian and US weapon-grade HEU up to late 2010 and early 2010, respectively, has been taken into account.

[b] France declared 4.9 tonnes of civilian HEU to the International Atomic Energy Agency (IAEA) as of the end of 2009; it is assumed here to be weapon-grade, 93% enriched HEU, even though some of the material is in irradiated form. The uncertainty in the estimate applies only to the military stockpile of 26 tonnes and does not apply to the declared stock of 4.9 tonnes.

[c] It is believed that India is producing HEU (enriched to 30–45%) for use as naval reactor fuel. The estimate is for HEU enriched to 30%.

[d] Israel may have acquired *c.* 300 kg of weapon-grade HEU covertly in or before 1965 from the USA.

[e] As of Sep. 2010, 400 tonnes of Russia's weapon-grade HEU had been blended down. The estimate shown for the Russian reserve for naval reactors is the authors' estimate based on the size of the Russian fleet.

[f] This figure includes 21.9 tonnes of HEU as of 31 Mar. 2002, the average enrichment of which was not given. The UK declared a stock of 1.4 tonnes of civilian HEU to the IAEA as of the end of 2008.

[g] The amount of US HEU is given in actual tonnes, not 93% enriched equivalent. As of 30 Sep. 1996 the USA had an inventory of 741 tonnes of HEU containing 620 tonnes of U-235. To date, the USA has earmarked 233 tonnes of HEU for blending down. As of mid-2010 it had blended down 131 tonnes of this; however, little if any of this HEU was weapon-grade. At least 100 tonnes is in the form of irradiated naval fuel.

[h] The 2009 IAEA Annual Report lists 246.5 significant quantities of HEU under comprehensive safeguards. This corresponds to 6.15 tonnes of U-235 in uranium. To reflect the uncertainty in the enrichment levels of this material, mostly in research reactor fuel, a total of 20 tonnes of HEU is assumed. About half of this is in Kazakhstan and is about 20% enriched.

[i] This total is rounded to the nearest 5 tonnes.

Table 7A.2. Global stocks of separated plutonium, 2010

State	Military stocks as of 2010 (tonnes)	Military production status	Civilian stocks as of 2010, unless indicated (tonnes)
China	1.8 ± 0.8	Stopped in 1991	0
France	6 ± 1.0	Stopped in 1992	55.9 (does not include 28.3 foreign owned)
Germany	0	–	9.5 (in France, Germany and the UK)
India[a]	0.5 ± 0.14	Continuing	3.7 (includes 3.5 outside safeguards)
Israel[b]	0.8 ± 0.13	Continuing	0
Japan	0	–	46.1 (including a total of 36.1 in France and the UK)
North Korea[c]	0.034	Resumed in 2009	0
Pakistan[d]	0.1 ± 0.02	Continuing	0
Russia[e]	128 ± 8 (34 declared excess)	Effectively stopped in 1997	47.7
UK[f]	7.6 (4.4 declared excess)	Stopped in 1995	85.3 (includes 0.9 abroad but not 27.7 foreign owned)
USA[g]	92 (53.9 declared excess)	Stopped in 1988	0
Totals	**~237 (92 declared excess)**		**~248**

[a] India produced weapon-grade plutonium from the CIRUS and Dhruva reactors until CIRUS closed at the end of 2010. As part of the 2005 Indian–US Civil Nuclear Cooperation Initiative, India has included in the military sector much of the plutonium separated from its spent power-reactor fuel. While it is labelled civilian here since it is intended for breeder reactor fuel, this plutonium was not placed under safeguards in the 'India-specific' safeguards agreement signed by the Indian Government and the IAEA on 2 Feb. 2009.

[b] Israel is believed to still be operating the Dimona plutonium production reactor but may be using it primarily for tritium production.

[c] North Korea is reported to have declared plutonium production of 31 kg in June 2008 and to have carried out nuclear tests in 2006 and 2009, and resumed production in 2009, adding 8–10 kg.

[d] Pakistan is estimated to be producing *c.* 10 kg a year of weapon-grade plutonium from its Khushab-1 reactor. Three additional plutonium production reactors are under construction at the same site.

[e] Russia does not include its plutonium declared as excess in its IAEA INFCIRC/549 statement.

[f] The UK declared 85.3 tonnes of civilian plutonium (not including 27.7 tonnes of foreign-owned plutonium in the UK). This apparently includes 4.4 tonnes of military plutonium declared excess. However, since this 4.4 tonnes is not designated for IAEA safeguarding, in this estimate it continues to be assigned to the military stocks and is not included in the civilian stocks. The UK declared in 1995 that it had stopped fissile material production for weapons; this was the last year in which the UK's Atomic Weapons Establishment at Aldermaston received plutonium from the Sellafield reprocessing plant.

[g] In its IAEA INFCIRC/549 statement, the USA declared 53.9 tonnes of plutonium as excess for military purposes.

Sources for table 7A.1: International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2010: Balancing the Books—Production and Stocks* (IPFM: Princeton, NJ, 2010), figure 1.2, p. 12; *Israel*: Myers, H., 'The real source of Israel's first fissile material', *Arms Control Today*, vol. 37, no. 8 (Oct. 2007), p. 56; see also Gilinsky, V. and Mattson, R. J., 'Revisiting the NUMEC affair', *Bulletin of the Atomic Scientists*, vol. 66, no. 2 (Mar./Apr. 2010); *Russia*: United States Enrichment Corporation, 'Megaton to megawatts', <http://www.usec.com/>; *UK*: British Ministry of Defence, 'Historical accounting for UK defence highly enriched uranium', Mar. 2006, <http://www.mod.uk/DefenceInternet/AboutDefence/CorporatePublications/HealthandSafetyPublications/DepletedUranium/>; International Atomic Energy Agency (IAEA), Communication received from the United Kingdom of Great Britain and Northern Ireland concerning its policies regarding the management of plutonium, INFCIRC/549/Add.8/12, 15 Sep. 2009; *USA*: US Department of Energy (DOE), *Highly Enriched Uranium, Striking a Balance: A Historical Report on the United States Highly Enriched Uranium Production, Acquisition, and Utilization Activities from 1945 through September 30, 1996* (DOE: Washington, DC, 2001); George, R. and Tousley, D., DOE, 'US highly enriched uranium disposition', Presentation to the Nuclear Energy Institute Nuclear Fuel Supply Forum, Washington, DC, 24 Jan. 2006; George, R., 'U.S. HEU disposition program', Institute of Nuclear Materials Management 50th Annual Meeting, Tucson, AZ, 13–19 July 2009; and Person, G. A., 'HEU commercial down-blending: a non-proliferation winner!', Institute of Nuclear Materials Management 51st Annual Meeting, Baltimore, MD, 13 July 2010; *Non-nuclear weapon states*: IAEA, *Annual Report 2008* (IAEA: Vienna, 2009), table A4.

Sources for table 7A.2: International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2010: Balancing the Books—Production and Stocks* (IPFM: Princeton, NJ, 2010), figure 1.6, p. 19; US Department of Energy (DOE), 'U.S. removes nine metric tons of plutonium from nuclear weapons stockpile', Press release, 17 Sep. 2007, <http://www.energy.gov/nationalsecurity/5500.htm>; *Civilian stocks (except for India)*: declarations by country to the International Atomic Energy Agency (IAEA) under INFCIRC/549, <http://www.iaea.org/Publications/Documents/>; *North Korea*: Kessler, G., 'Message to U.S. preceded nuclear declaration by North Korea', *Washington Post*, 2 July 2008; *Russia*: Russian–US Agreement concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation (Russian–US Plutonium Management and Disposition Agreement), signed on 29 Aug. and 1 Sep. 2000, <http://www.state.gov/t/isn/trty/>.

Table 7A.3. Significant uranium enrichment facilities and capacity worldwide, as of December 2010

State	Facility name or location	Type	Status	Enrichment process[a]	Capacity (thousands SWU/yr)[b]
Argentina	Pilcaniyeu	Civilian	Resuming operation	GD	20–3 000
Brazil	Resende Enrichment	Civilian	Under construction	GC	120
China	Lanzhou 2	Civilian	Operational	GC	500
	Lanzhou (new)	Civilian	Operational	GC	500
	Shaanxi	Civilian	Operational	GC	500–1 000
France	Eurodif	Civilian	Operational	GD	10 800
	Georges Besse II	Civilian	Under construction	GC	7 500–11 000
Germany	Urenco Gronau[c]	Civilian	Operational	GC	2 200–4 500
India	Rattehalli	Military	Operational	GC	15–30
Iran	Natanz	Civilian	Under construction	GC	120
	Qom	Civilian	Under construction	GC	5–10
Japan	Rokkasho[d]	Civilian	Shut down	GC	<1 050
Netherlands	Urenco Almelo	Civilian	Operational	GC	3 800
North Korea	Yongbyon	?	?	GC	?[e]
Pakistan	Gadwal	Military	Operational	GC	?
	Kahuta	Military	Operational	GC	20–30
Russia	Angarsk	Civilian	Operational	GC	2 200–5 000
	Novouralsk	Civilian	Operational	GC	13 300
	Seversk	Civilian	Operational	GC	3 800
	Zelenogorsk	Civilian	Operational	GC	7 900
UK	Capenhurst	Civilian	Operational	GC	5 000
USA	Areva Eagle Rock	Civilian	Planned	GC	3 300–6 600
	Paducah	Civilian	To be shutdown	GD	11 300
	Piketon, Ohio	Civilian	Under construction	GC	3 800
	Urenco Eunice	Civilian	Operating	GC	5 900

[a] The gas centrifuge (GC) is the main isotope-separation technology now used to increase the fraction of U-235 in uranium, but a few facilities continue to use gaseous diffusion (GD).

[b] SWU/yr = Separative work units per year: a SWU is a measure of the effort required in an enrichment facility to separate uranium of a given content of uranium-235 into 2 components, 1 with a higher and 1 with a lower percentage of uranium-235.

[c] Expansion is under way.

[d] The Rokkasho centrifuge plant was shut down in Dec. 2010; there are plans to reopen it with new centrifuge technology.

[e] On North Korea's Yongbyon facility see chapter 7, section X.

Sources: Enrichment capacity data is based on International Atomic Energy Agency (IAEA), Integrated Nuclear Fuel Cycle Information Systems (INFCIS), <http://www-nfcis.iaea.org/>; International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2010: Balancing the Books—Production and Stocks* (IPFM: Princeton, NJ, 2010); and Citizens' Nuclear Information Center (CNIC), 'Uranium enrichment plant turns into a big waste dump', *Nuke Info Tokyo*, no. 140 (Jan./Feb. 2011), pp. 3–4.

Table 7A.4. Significant reprocessing facilities worldwide, as of December 2010

All facilities process light water reactor (LWR) fuel, except where indicated.

State	Facility name or location	Type	Status	Design capacity (tHM/yr)[a]
China	Lanzhou pilot plant	Civilian	Starting up	50–100
France	La Hague UP2	Civilian	Operational	1 000
	La Hague UP3	Civilian	Operational	1 000
India[b]	Kalpakkam (HWR fuel)	Dual-use	Operational	100
	Tarapur (HWR fuel)	Dual-use	Operational	100
	Trombay (HWR fuel)	Military	Operational	50
Israel	Dimona (HWR fuel)	Military	Operational	40–100
Japan	JNC Tokai	Civilian	Temporarily shut down	200
	Rokkasho	Civilian	Starting up	800
Pakistan	Chashma	Military	Under construction	50–100
	Nilore (HWR fuel)	Military	Operational	20–40
Russia	Mayak RT-1, Ozersk (formerly Chelyabinsk-65)	Civilian	Operational	200–400
	Seversk (formerly Tomsk 7)	Military	To be shut down	6 000
	Zheleznogorsk (formerly Krasnoyarsk-26)	Military	To be shut down	3 500
UK	BNFL B205 Magnox	Civilian	To be shut down	1 500
	BNFL Thorp, Sellafield	Civilian	Temporarily shut down	1 200
USA	H-canyon, Savannah River Site	Civilian	Operational	15

HWR = Heavy water reactor.

[a] Design capacity refers to the highest amount of spent fuel the plant is designed to process and is measured in tonnes of heavy metal per year (tHM/yr), tHM being a measure of the amount of heavy metal—uranium in these cases—that is in the spent fuel. Actual throughput is often a small fraction of the design capacity. E.g. Russia's RT-1 plant has never reprocessed more than 130 tHM/yr and France, because of the non-renewal of its foreign contracts, will soon only reprocess 850 tHM/yr. LWR spent fuel contains about 1% plutonium, and heavy-water- and graphite-moderated reactor fuel about 0.4%.

[b] As part of the 2005 Indian–US Civil Nuclear Cooperation Initiative, India has decided that none of its reprocessing plants will be opened for IAEA safeguards inspections.

Sources: Data on design capacity is based on International Atomic Energy Agency (IAEA), Integrated Nuclear Fuel Cycle Information Systems (INFCIS), <http://www-nfcis.iaea.org/>; and International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2010: Balancing the Books—Production and Stocks* (IPFM: Princeton, NJ, 2010).