X. Global stocks and production of fissile materials, 2019

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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. This section gives details of military and civilian stocks, as of the beginning of 2019, of HEU (table 10.11) and separated plutonium (table 10.12), including in weapons, and details of the current capacity to produce these materials (tables 10.13 and 10.14, respectively). The information in the tables is based on estimates prepared for the International Panel on Fissile Materials (IPFM). The most recent annual declarations (INFCIRC/549 declarations) on civilian plutonium and HEU stocks to the International Atomic Energy Agency (IAEA) were released in 2019 and give data for 31 December 2018, and so are taken here to be applicable for the start of 2019.

The production of both HEU and plutonium starts with natural uranium. Natural uranium consists almost entirely of the non-chain-reacting isotope uranium-238 (U-238) and is only about 0.7 per cent uranium-235 (U-235). The concentration of U-235, however, 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—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 U-235. Plutonium is produced in nuclear reactors when U-238 is exposed to neutrons. The plutonium is subsequently chemically separated from spent fuel in a reprocessing operation. Plutonium comes in a variety of isotopic mixtures, most of which are weapon-usable. Weapon designers prefer to work with a mixture that predominantly consists of plutonium-239 (Pu-239) because of its relatively low rate of spontaneous emission of neutrons and gamma rays and the low level of heat generation from radioactive alpha 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.

All states with a civil nuclear industry have some capability to produce fissile materials that could be used for weapons.

Table 10.11. Global stocks of highly enriched uranium, 2019

State	National stockpile (tonnes)[a]	Production status	Comments
China	14 ± 3	Stopped 1987–89	
France[b]	30 ± 6	Stopped 1996	Includes 5.1 tonnes declared civilian[c]
India[d]	4.4 ± 1.6	Continuing	Includes HEU in naval reactor cores
Israel[e]	0.3	–	
Korea, North[f]	Uncertain	Uncertain	
Pakistan	3.7 ± 0.4	Continuing	
Russia[g]	679 ± 120	Stopped 1987–88	Includes about 6 tonnes in use in research applications
UK[h]	22.6	Stopped 1962	Includes 0.7 tonnes declared civilian[c]
USA[i]	565 (85 not available for military purposes)	Stopped 1992	Includes HEU in a naval reserve
Other states[j]	~15		
Total[k]	**~1 335**		

HEU = highly enriched uranium.

[a] Most of this material is 90–93% enriched uranium-235 (U-235), which is typically considered weapon-grade. The estimates are for the end of 2018 and treated as applicable for the start of 2019. Important exceptions are noted.

[b] The uncertainty in the estimate applies only to the military stockpile of about 25 tonnes and does not apply to the declared civilian stock. A 2014 analysis offers grounds for a significantly lower estimate of the stockpile of weapon-grade HEU (as high as 10 ± 2 tonnes or as low as 6 ± 2 tonnes), based on evidence that the Pierrelatte enrichment plant may have had both a much shorter effective period of operation and a smaller weapon-grade HEU production capacity than previously assumed.

[c] INFCIRC/549 declaration to the International Atomic Energy Agency (IAEA) for the end of 2018 and treated as applicable for the start of 2019.

[d] 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%.

[e] Israel may have acquired illicitly about 300 kg of weapon-grade HEU from the USA in or before 1965.

[f] North Korea is known to have a uranium enrichment plant at Yongbyon and possibly others elsewhere. Independent estimates of uranium enrichment capability and possible HEU production extrapolated to the end of 2018 suggest an accumulated HEU stockpile range of 180–850 kg.

[g] This estimate may understate the amount of HEU in Russia since it assumes that it ceased production of all HEU in 1988. However, Russia may have continued producing HEU for civilian and non-weapon military uses after that date. The material in discharged naval cores is not included in the current stock since the enrichment of uranium in these cores is believed to be less than 20% U-235.

[h] The estimate reflects a UK declaration of 21.9 tonnes of military HEU as of 31 Mar. 2002, the average enrichment of which was not given. As the UK continues to use HEU in naval reactors, the value contains an increasing fraction of spent naval fuel. In 2018 about 500 kg of HEU from the UK were transferred to the USA for downblending into low-enriched uranium.

[i] The amount of US HEU is given in actual tonnes, not 93%-enriched equivalent. In 2016 the USA declared that, as of 30 Sep. 2013, its HEU inventory was 585.6 tonnes, of which 499.4 tonnes was declared to be for 'national security or non-national security programs including nuclear

weapons, naval propulsion, nuclear energy, and science'. The remaining 86.2 tonnes was composed of 41.6 tonnes 'available for potential down-blend to low enriched uranium or, if not possible, disposal as low-level waste', and 44.6 tonnes in spent reactor fuel. As of the end of Sep. 2018, another 17 tonnes had been downblended or shipped for blending down. The amount available for use had been reduced to about 480 tonnes, mostly by consumption in naval reactors. The 85 tonnes declared excess includes the remaining about 69 tonnes as well as 16 tonnes of the 20 tonnes originally reserved for HEU fuel for research reactors.

[j] The 2018 IAEA Annual Report lists 160 significant quantities of HEU under comprehensive safeguards in non-nuclear weapon states as of the end of 2018. In order to reflect the uncertainty in the enrichment levels of this material, mostly in research reactor fuel, a total of 15 tonnes of HEU is assumed. About 10 tonnes of this is in Kazakhstan and has been irradiated; it was initially slightly higher than 20%-enriched fuel. It is possible that this material is no longer HEU.

In INFCIRC/912 (from 2017) more than 20 states committed to reducing civilian HEU stocks and providing regular reports. So far, only Norway has reported under this scheme. At the end of 2018, it held less than 4 kg of HEU for civilian purposes.

[k] Totals are rounded to the nearest 5 tonnes.

Sources: International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2015: Nuclear Weapon and Fissile Material Stockpiles and Production* (IPFM: Princeton, NJ, Dec. 2015). China: Zhang, H., *China's Fissile Material Production and Stockpile* (IPFM: Princeton, NJ, Dec. 2017). France: International Atomic Energy Agency (IAEA), Communication Received from France Concerning its Policies Regarding the Management of Plutonium, INFCIRC/549/Add.5-21, 29 Sep. 2017; and Philippe, S. and Glaser, A., 'Nuclear archaeology for gaseous diffusion enrichment plants', *Science & Global Security*, vol. 22, no. 1 (2014), pp. 27–49. Israel: Myers, H., 'The real source of Israel's first fissile material', *Arms Control Today*, vol. 37, no. 8 (Oct. 2007), p. 56; and Gilinsky, V. and Mattson, R. J., 'Revisiting the NUMEC affair', *Bulletin of the Atomic Scientists*, vol. 66, no. 2 (Mar./Apr. 2010). North Korea: Hecker, S. S., Braun, C. and Lawrence, C., 'North Korea's stockpiles of fissile material', *Korea Observer*, vol 47, no. 4 (winter 2016), pp. 721–49. Russia: Podvig, P. (ed.), *The Use of Highly-Enriched Uranium as Fuel in Russia* (IPFM: Washington, DC, Sep. 2017). UK: British Ministry of Defence, 'Historical accounting for UK defence highly enriched uranium', Mar. 2006; and IAEA, Communications Received from the United Kingdom of Great Britain and Northern Ireland Concerning its Policies Regarding the Management of Plutonium, INFCIRC/549/Add.8-22, 23 Oct. 2019. 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); Personal communication, US DOE, Office of Fissile Material Disposition, National Nuclear Security Administration; White House, Office of the Press Secretary, 'Fact sheet: Transparency in the US highly enriched uranium inventory', 31 Mar. 2016; US DOE, *FY 2019 Congressional Budget Request* (DOE: Washington, DC, Mar. 2018), p. 474; and US DOE, *Tritium and Enriched Uranium Management Plan through 2060*, Report to Congress (DOE: Washington, DC, Oct. 2015). Non-nuclear weapon states: IAEA, *IAEA Annual Report 2018* (IAEA: Vienna, 2018), Annex, Table A4, p. 129.

Table 10.12. Global stocks of separated plutonium, 2019

State	Military stocks (tonnes)	Military production status	Civilian stocks (tonnes)[a]
China	2.9 ± 0.6	Stopped in 1991	0.04[b]
France	6 ± 1.0	Stopped in 1992	67.7 (excludes foreign owned)
India[c]	0.6 ± 0.15	Continuing	6.9 ± 3.7 (includes 0.4 under safeguards)
Israel[d]	0.96 ± 0.13	Continuing	–
Japan	–	–	45.7 (includes 36.7 in France and UK)
Korea, North[e]	0.04	Continuing	–
Pakistan[f]	0.37 ± 0.1	Continuing	–
Russia[g]	128 ± 8 (40 not available for weapons)	Stopped in 2010	61.3
UK	3.2	Stopped in 1995	115.8 (excludes 23.1 foreign owned)[b]
USA[h]	79.7 (41.3 not available for weapons)	Stopped in 1988	8[i]
Other states[j]	–	–	1.9
Totals[k]	**~220 (81 not available for weapons)**		**~300**

– = nil or negligible figure.

[a] The data for France, Japan, Russia, the UK and the USA is for the end of 2018, reflecting their most recent INFCIRC/549 declaration. Some countries with civilian plutonium stocks do not submit an INFCIRC/549 declaration to the International Atomic Energy Agency (IAEA). Of these countries, Italy, the Netherlands, Spain and Sweden store their plutonium abroad.

[b] As of Mar. 2020, China had not submitted IAEA INFCIRC/549 declarations for the end of 2017, nor for the end of 2018. The number is based on the 2016 declaration.

[c] 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. India does not submit an IAEA INFCIRC/549 declaration.

[d] Israel is believed to still be operating the Dimona plutonium production reactor but may be using it primarily for tritium production. The estimate is for the end of 2018.

[e] North Korea reportedly declared a plutonium stock of 37 kg in June 2008. It resumed plutonium production in 2009 but has probably expended some material in the nuclear tests that were conducted since then. It is believed to have separated up to 8 kg of plutonium in 2016. An additional 10–14 kg of plutonium may be in irradiated fuel unloaded in Dec. 2018 and is not included here.

[f] As of the end of 2018, Pakistan was operating 4 plutonium production reactors at its Khushab site. This estimate assumes that Pakistan is separating plutonium from the cooled spent fuel from all 4 reactors.

[g] The 40 tonnes of plutonium not available for weapons comprises 25 tonnes of weapon-origin plutonium stored at the Mayak Fissile Material Storage Facility and about 15 tonnes of weapon-grade plutonium produced between 1 Jan. 1995 and 15 Apr. 2010, when the last plutonium production reactor was shut down. The post-1994 plutonium, which is currently stored at Zheleznogorsk, cannot be used for weapon purposes under the terms of the US–Russian agreement on plutonium production reactors signed in 1997. Russia made a commitment to eliminate 34 tonnes of that material (including all 25 tonnes of plutonium stored at Mayak) as part of the US–Russian Plutonium Management and Disposition Agreement concluded in 2000.

Russia does not include the plutonium that is not available for weapons in its INFCIRC/549 declaration; nor does it make the plutonium it reports as civilian available to IAEA safeguards.

[h] In 2012 the USA declared a government-owned plutonium inventory of 95.4 tonnes as of 30 Sep. 2009. In its 2019 IAEA INFCIRC/549 declaration, the most recent submitted, the USA declared 49.3 tonnes of unirradiated plutonium (both separated and in mixed oxide, MOX) as part of the stock that was identified as excess for military purposes. Since most of this material is stored in classified form, it is considered military stock. The USA considers a total of 61.5 tonnes of plutonium as declared excess to national security needs.

[i] The USA placed about 3 tonnes of its excess plutonium, stored at the K-Area Material Storage facility at the Savannah River Plant, under IAEA safeguards. In addition, it reported that 4.6 tonnes of plutonium was contained in unirradiated MOX fuel, and also declared 0.4 tonnes of plutonium that was brought to the USA in 2016 from Japan, Germany and Switzerland (331 kg, 30 kg and 18 kg, respectively). All this material is considered civilian.

[j] This is estimated by reconciling the amounts of plutonium declared as 'held in locations in other countries' and 'belonging to foreign bodies' in the INFCIRC/549 declarations.

[k] Totals are rounded to the nearest 5 tonnes.

Sources: International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2015: Nuclear Weapon and Fissile Material Stockpiles and Production* (IPFM: Princeton, NJ, Dec. 2015). Civilian stocks (except for India): declarations by countries to the International Atomic Energy Agency (IAEA) under INFCIRC/549. China: Zhang, H., *China's Fissile Material Production and Stockpile* (IPFM: Princeton, NJ, Dec. 2017). North Korea: Kessler, G., 'Message to US preceded nuclear declaration by North Korea', *Washington Post*, 2 July 2008; Hecker, S. S., Braun, C. and Lawrence, C., 'North Korea's stockpiles of fissile material', *Korea Observer*, vol 47, no. 4 (winter 2016), pp. 721–49; and IAEA, Board of Governors, General Conference, 'Application of safeguards in the Democratic People's Republic of Korea', Report by the Acting Director General, GOV/2019/33-GC(63)/20, 19 Aug. 2019. Russia: 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 29 Aug. and 1 Sep. 2000, amended Apr. 2010, entered into force July 2011. USA: National Nuclear Security Administration (NNSA), *The United States Plutonium Balance, 1944–2009* (NNSA: Washington, DC, June 2012); and Gunter, A., 'US DOE, Office of Environmental Management, K-Area Overview/Update', 28 July 2015.

Table 10.13. Significant uranium enrichment facilities and capacity worldwide, 2019

State	Facility name or location	Type	Status	Enrichment process[a]	Capacity (thousands SWU/yr)[b]
Argentina[c]	Pilcaniyeu	Civilian	Uncertain	GD	20
Brazil	Resende Enrichment	Civilian	Expanding capacity	GC	35
China[d]	Lanzhou	Civilian	Operational	GC	2 600
	Hanzhong (Shaanxi)	Civilian	Operational	GC	2 000
	Emeishan	Civilian	Operational	GC	1 050
	Heping	Dual-use	Operational	GD	230
France	Georges Besse II	Civilian	Operational	GC	7 500
Germany	Urenco Gronau	Civilian	Operational	GC	3 900
India	Rattehalli	Military	Operational	GC	15–30
Iran[e]	Natanz	Civilian	Limited operation	GC	3.5–5
	Qom (Fordow)	Civilian	Limited operation	GC	. .
Japan	Rokkasho[f]	Civilian	Resuming operation	GC	75
Korea, North	Yongbyon[g]	Uncertain	Operational	GC	8
Netherlands	Urenco Almelo	Civilian	Operational	GC	5 200
Pakistan	Gadwal	Military	Operational	GC	. .
	Kahuta	Military	Operational	GC	15–45
Russia	Angarsk	Civilian	Operational	GC	4 000
	Novouralsk	Civilian	Operational	GC	13 300
	Seversk	Civilian	Operational	GC	3 800
	Zelenogorsk[h]	Civilian	Operational	GC	7 900
UK	Capenhurst	Civilian	Operational	GC	4 600
USA	Urenco Eunice	Civilian	Operational	GC	4 900

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

[b] SWU/yr = Separative work units per year, a measure of the effort required in an enrichment facility to separate uranium of a given content of U-235 into two components, one with a higher and one with a lower percentage of U-235. Where a range of capacities is shown, the capacity is uncertain or the facility is expanding its capacity.

[c] In Dec. 2015 Argentina announced resumption of production at its Pilcaniyeu GD uranium enrichment plant, which was shut down in the 1990s. There is no evidence of actual production.

[d] Assessments of China's enrichment capacity in 2015 and 2017 identified new enrichment sites and suggested a much larger total capacity than had previously been estimated.

[e] In July 2015 Iran agreed a Joint Comprehensive Plan of Action (JCPOA) that ended uranium enrichment at Fordow but kept centrifuges operating, and limited the enrichment capacity at Natanz to 5060 IR-1 centrifuges (equivalent to 3500–5000 SWU/yr) for 10 years. In Nov. 2019, following the USA's withdrawal from the JCPOA, Iran announced a limited restart of enrichment at Natanz and Fordow.

[f] The Rokkasho centrifuge plant has been in the process of being refitted with new centrifuge technology since 2011. Production since the start of retrofitting has been negligible.

[g] North Korea revealed its Yongbyon enrichment facility in 2010. It appears to be operational as of 2019. It is believed that North Korea is operating at least one other enrichment facility located elsewhere.

[h] Zelenogorsk operates a cascade for highly enriched uranium production for fast reactor and research reactor fuel.

Sources: Indo-Asian News Service, 'Argentina president inaugurates enriched uranium plant', *Business Standard*, 1 Dec. 2015; Zhang, H., 'China's uranium enrichment complex', *Science & Global Security*, vol. 23, no. 3 (2015), pp. 171–90; Zhang, H., *China's Fissile Material Production and Stockpile* (International Panel on Fissile Materials, IPFM: Princeton, NJ, Dec. 2017); Hecker, S. S., Carlin, R. L. and Serbin, E. A., 'A comprehensive history of North Korea's nuclear program', Center for International Security and Cooperation, accessed Feb. 2019; Pabian, F. V., Liu, J. and Town, J., 'North Korea's Yongbyon Nuclear Center: Continuing activity at the Uranium Enrichment Plant', 38 North, 5 June 2019; and Wolgelenter, M. and Sanger, D. E., 'Iran steps further from nuclear deal with move on centrifuges', *New York Times*, 5 Nov. 2019. Enrichment capacity data is based on International Atomic Energy Agency, Integrated Nuclear Fuel Cycle Information Systems (INFCIS); Urenco, *Annual Report and Accounts 2018* (Urenco: Stoke Poges, 2018); and IPFM, *Global Fissile Material Report 2015: Nuclear Weapons and Fissile Material Stockpile and Production* (IPFM: Princeton, NJ, Dec. 2015).

Table 10.14. Significant reprocessing facilities worldwide, as of 2019

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

State	Facility name or location	Type	Status	Design capacity (tHM/yr)[a]
China[b]	Jiuquan pilot plant	Civilian	Operational	50
France	La Hague UP2	Civilian	Operational	1 000
	La Hague UP3	Civilian	Operational	1 000
India[c]	Kalpakkam (HWR fuel)	Dual-use	Operational	100
	Tarapur (HWR fuel)	Dual-use	Operational	100
	Tarapur-II (HWR fuel)	Dual-use	Operational	100
	Trombay (HWR fuel)	Military	Operational	50
Israel	Dimona (HWR fuel)	Military	Operational	40–100
Japan	JNC Tokai	Civilian	Reprocessing shut down[d]	(was 200)
	Rokkasho	Civilian	Start planned for 2021	800
Korea, North	Yongbyon	Military	Operational	100–150
Pakistan	Chashma (HWR fuel)	Military	Starting up	50–100
	Nilore (HWR fuel)	Military	Operational	20–40
Russia[e]	Mayak RT-1, Ozersk	Civilian	Operational	400
	EDC, Zheleznogorsk	Civilian	Starting up	5
UK	BNFL B205 (Magnox fuel)	Civilian	To be shut down 2020	1 500
	BNFL Thorp, Sellafield	Civilian	Shut down in 2018	(was 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. LWR spent fuel contains about 1% plutonium, and heavy water- and graphite-moderated reactor fuel about 0.4%.

[b] China is building a pilot reprocessing facility near Jinta in Gansu province with a capacity of 200 tHM/yr, to be commissioned in 2025.

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

[d] In 2014 the Japan Atomic Energy Agency announced the planned closure of the head-end of its Tokai reprocessing plant, effectively ending further plutonium separation activity. In 2018 the Japanese Nuclear Regulation Authority approved a plan to decommission the plant.

[e] A 250 tHM/yr Pilot Experimental Centre is under construction in Zheleznogorsk. A pilot reprocessing line with the capacity of 5 tHM/yr was launched in June 2018. A second pilot line is expected to be completed in 2020.

Sources: Kyodo News, 'Japan approves 70-year plan to scrap nuclear reprocessing plant', 13 June 2018; and RIA Novosti, [Rosatom is ready to start 'green' processing of spent nuclear fuel], Rosatom, 29 May 2018 (in Russian). Data on design capacity is based on International Atomic Energy Agency (IAEA), Integrated Nuclear Fuel Cycle Information Systems (INFCIS); and International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2015: Nuclear Weapon and Fissile Material Stockpiles and Production* (IPFM: Princeton, NJ, Dec. 2015).