X. Global stocks and production of fissile materials, 2020

MORITZ KÜTT, ZIA MIAN AND PAVEL PODVIG
INTERNATIONAL PANEL ON FISSILE MATERIALS

Materials that can sustain an explosive fission chain reaction are essential for all types of nuclear explosive, 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 2020, of HEU (table 10.11) and separated plutonium (table 10.12), including in weapons. It also provides 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) give data for 31 December 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 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 that have a civil nuclear industry (i.e. that operate a nuclear reactor or a uranium enrichment plant) have some capability to produce fissile materials that could be used for weapons.

Table 10.11. Global stocks of highly enriched uranium, 2020

State	National stockpile (tonnes)[a]	Production status	Comments
China	14 ± 3	Stopped 1987–89	
France[b]	30 ± 6	Stopped 1996	Includes 5.4 tonnes declared civilian[c]
India[d]	5.2 ± 1.8	Continuing	Includes HEU in naval reactor cores
Israel[e]	0.3	Unknown	
Korea, North[f]	Uncertain	Uncertain	
Pakistan[g]	3.9 ± 0.4	Continuing	
Russia[h]	678 ± 120	Continuing[i]	Includes *c.* 6 tonnes in use in research applications
UK[j]	22.6	Stopped 1962	Includes HEU in naval reactor cores and 0.7 tonnes declared civilian
USA[k]	562 (83 not available for military purposes)	Stopped 1992	Includes HEU in a naval reserve
Other states[l]	~15		
Total[m]	**~1 330**		

HEU = highly enriched uranium.

[a] Most of this material is enriched uranium that contains 90–93% uranium-235 (U-235), which is typically considered weapon-grade. The estimates are for the start of 2020. Important exceptions are noted.

[b] The uncertainty in the estimate for France applies only to the military stockpile of *c.* 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] This figure is from France's INFCIRC/549 declaration to the International Atomic Energy Agency (IAEA) for the start of 2020.

[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 *c.* 300 kg of weapon-grade HEU from the USA in or before 1965. Some of this material may have been consumed in the process of producing tritium.

[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 2019 suggest that an accumulated HEU stockpile could be in the range of 230–1180 kg.

[g] This estimate for Pakistan assumes total HEU production of 4 tonnes, of which *c.* 100 kg was used in nuclear weapon tests.

[h] This estimate is for the amount of 90% enriched uranium that would contain all U-235 in HEU. The actual amount of HEU might be different. It assumes that the Soviet Union stopped all HEU production in 1988. It may therefore understate the amount of HEU in Russia (see also note i). 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.

[i] The Soviet Union stopped production of HEU for weapons in 1988 but kept producing HEU for civilian and non-weapon military uses. Russia continues this practice.

[j] The estimate for the UK reflects a 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 the UK transferred *c.* 500 kg of HEU to the USA for downblending into low-enriched uranium.

[k] 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 2019, another 19 tonnes had been downblended or shipped for blending down. The amount available for use had been reduced to *c.* 480 tonnes, mostly by consumption in naval reactors. The 83 tonnes declared excess includes *c.* 67 tonnes remaining for downblending as well as 16 tonnes remaining for HEU fuel for research reactors.

[l] The IAEA's 2019 annual report lists 156 significant quantities of HEU under comprehensive safeguards in non-nuclear weapon states as of the end of 2019. 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 2 countries have reported under this scheme. At the end of 2018 (time of last declaration), Norway held less than 4 kg of HEU for civilian purposes. As of 30 June 2019, Australia held 2.7 kg of HEU for civilian purposes.

[m] 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, 2015). *China*: Zhang, H., *China's Fissile Material Production and Stockpile* (IPFM: Princeton, NJ, 2017). *France*: International Atomic Energy Agency (IAEA), 'Communication received from France concerning its policies regarding the management of plutonium', INFCIRC/549/Add.5/24, 28 Aug. 2020; 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, 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.8/23, 11 Jan. 2021. *USA*: US Department of Energy (DOE), National Nuclear Security Administration, *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, Jan. 2001); White House, 'Transparency in the US highly enriched uranium inventory', Fact sheet, 31 Mar. 2016; US Department of Energy (DOE), *FY 2021 Congressional Budget Request*, vol. 1, *National Nuclear Security Administration* (DOE: Washington, DC, Feb. 2020), p. 593; and US Department of Energy (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 2019* (IAEA: Vienna, 2019), Annex, Table A4, p. 113; IAEA, 'Communication Dated 19 July 2019 received From the Permanent Mission of Norway concerning a joint statement on minimising and eliminating the use of highly enriched uranium in civilian applications', INFCIRC/912/Add.3, 15 Aug. 2019; and IAEA, 'Communication dated 23 January 2020 received from the Permanent Mission of Australia concerning the joint statement on minimising and eliminating the use of highly enriched uranium in civilian applications', INFCIRC/912/Add.4, 5 Mar. 2020.

Table 10.12. Global stocks of separated plutonium, 2020

State	Military stocks (tonnes)[a]	Military production status	Civilian stocks (tonnes)[b]
China	2.9 ± 0.6	Stopped in 1991	0.04[c]
France	6 ± 1.0	Stopped in 1992	74.7 (excludes foreign owned)
India[d]	0.62 ± 0.14	Continuing	8.2 ± 4.3 (includes 0.4 under safeguards)
Israel[e]	0.98 ± 0.13	Continuing	–
Japan	–	–	45.5 (includes 36.6 in France and UK)
Korea, North[f]	0.04	Continuing	–
Pakistan[g]	0.41 ± 0.1	Continuing	–
Russia[h]	128 ± 8 (40 not available for weapons)	Stopped in 2010	63
UK	3.2	Stopped in 1995	115.8 (excludes 24.1 foreign owned)
USA[i]	79.7 (41.3 not available for weapons)	Stopped in 1988	8[j]
Other states[k]	–	–	3.0
Total[l]	**~220 (81 not available for weapons)**		**~320**

– = nil or a negligible value.

[a] The estimates are for the start of 2020. Important exceptions are noted.

[b] The data for France, Japan, Russia and the UK is for the end of 2019, reflecting their most recent INFCIRC/549 declaration to the International Atomic Energy Agency (IAEA). Some countries with civilian plutonium stocks do not submit an INFCIRC/549 declaration. Of these countries, Italy, the Netherlands, Spain and Sweden store their plutonium abroad.

[c] These numbers are based on China's INFCIRC/549 declaration to the IAEA for the end of 2016. As of Mar. 2021, this is the most recent declaration.

[d] 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 INFCIRC/549 declaration to the IAEA.

[e] Israel is still operating the Dimona plutonium production reactor but may be using it primarily for tritium production. The estimate is for the end of 2019.

[f] North Korea reportedly declared a plutonium stock of 37 kg in June 2008. It is believed that it subsequently unloaded its 5-MWe reactor 3 additional times, in 2009, 2016 and 2018. The stockpile estimate has been reduced to account for the 6 nuclear tests conducted by the country.

[g] As of the end of 2019, 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.

[h] The 40 tonnes of plutonium not available to Russia for weapons comprises 25 tonnes of weapon-origin plutonium stored at the Mayak Fissile Material Storage Facility and *c.* 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 a 1997 Russian–US agreement on plutonium production reactors. Russia made a commitment to eliminate 34 tonnes of that material (including all 25 tonnes of plutonium stored at Mayak) as part of the 2000 Russian–US Plutonium Management and Disposition Agreement. 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.

[i] In 2012 the USA declared a government-owned plutonium inventory of 95.4 tonnes as of 30 Sep. 2009. In its 2019 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 (declaration for 31 Dec. 2018). 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 to be declared excess to national security needs.

[j] The USA has placed *c.* 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.

[k] 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.

[l] 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, 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, 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 and 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*: Russian–US Agreement Concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation (Plutonium Management and Disposition Agreement), signed 29 Aug. and 1 Sep. 2000, amendment signed 5 Sep. 2006, entered into force 13 July 2011. *USA*: National Nuclear Security Administration (NNSA), *The United States Plutonium Balance, 1944–2009* (NNSA: Washington, DC, June 2012); and Gunter, A., 'K-Area overview/update', US Department of Energy, Savanah River Site, 28 July 2015.

Table 10.13. Significant uranium enrichment facilities and capacity worldwide, 2020

State	Facility name or location	Type	Status	Enrichment process[a]	Capacity (thousands SWU/yr)[b]
Argentina[c]	Pilcaniyeu	Civilian	Uncertain	GD	20
Brazil	Resende	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] Separative work units per year (SWU/yr) is 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 the reopening of 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 the Joint Comprehensive Plan of Action (JCPOA), which 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 (IANS), '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* (IPFM: Princeton, NJ, 2017); Hecker, S. S., Carlin, R. L. and Serbin, E. A., 'A comprehensive history of North Korea's nuclear program', Stanford University, Center for International Security and Cooperation (CISAC), 2018 update; 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, 'Global operations', [n.d.]; and International Panel on Fissile Materials (IPFM), *Global Fissile Material Report 2015: Nuclear Weapon and Fissile Material Stockpiles and Production* (IPFM: Princeton, NJ, 2015).

Table 10.14. Significant reprocessing facilities worldwide, 2020

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 2022	800
Korea, North	Yongbyon (GCR fuel)	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	250
UK	Sellafield B205 (Magnox fuel)	Civilian	To be shut down in 2021	1 500
	Sellafield Thorp	Civilian	Shut down in 2018	(was 1 200)
USA	H-canyon, Savannah River Site	Civilian	Operational	15

HWR = heavy water reactor; GCR = gas cooled 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 *c.* 1% plutonium, and heavy water- and graphite-moderated reactor fuels contain *c.* 0.4% plutonium.

[b] China is building a pilot reprocessing facility near Jinta, 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] Russia continues to construct a 250 tHM/yr pilot experimental centre at Zheleznogorsk. A pilot reprocessing line with a capacity of 5 tHM/yr was launched in June 2018. The centre is scheduled to begin operations in 2021.

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], 29 May 2018 (in Russian). Data on design capacity is based on International Atomic Energy Agency, 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, 2015).