6. World nuclear forces

Overview

At the start of 2018 nine states—the United States, Russia, the United Kingdom, France, China, India, Pakistan, Israel and the Democratic People's Republic of Korea (DPRK, or North Korea)—possessed approximately 14 465 nuclear weapons, of which 3750 were deployed with operational forces (see table 6.1). Nearly 2000 of these are kept in a state of high operational alert.

Overall, inventories of nuclear warheads continue to decline. This is mainly due to the USA and Russia, which collectively account for approximately 92 per cent of global nuclear weapons, reducing their deployed nuclear forces in line with the 2010 Treaty on Measures for the Further Reduction and Limitation of Strategic Offensive Arms (New START). Despite making reductions in their arsenals, both the USA and Russia have extensive and expensive programmes under way to replace and modernize their nuclear warheads, missile and aircraft delivery systems, and nuclear weapon production facilities (see sections I and II in this chapter).

The nuclear arsenals of the other nuclear-armed states are considerably smaller (see sections III–IX), but all are either developing or deploying new weapon systems or have announced their intention to do so. China, India, North Korea and Pakistan are thought to be expanding the size of their nuclear arsenals.

The availability of reliable information on the status of the nuclear arsenals and capabilities of the nuclear-armed states varies considerably. The USA has disclosed important information about its stockpile and nuclear capabilities, and the UK and France have also declared some information. Russia refuses to disclose the detailed breakdown of its forces counted under New START even though it shares the information with the USA, and the US Government has stopped releasing detailed information about Russian and Chinese nuclear forces. The governments of India and Pakistan make statements about some of their missile tests but provide no information about the status or size of their arsenals. Israel has a policy of not commenting on its nuclear arsenal and North Korea provides no information about its nuclear capabilities.

North Korea continues to prioritize its military nuclear programme as a central element of its national security strategy, and conducted its sixth test explosion in 2017. The test took the total number of nuclear explosions recorded worldwide since 1945 to 2058 (see section XI).

The raw material for nuclear weapons is fissile material, either highly enriched uranium (HEU) or separated plutonium. China, France, Russia, the UK and the

Table 6.1. World nuclear forces, January 2018

All figures are approximate. The estimates presented here are based on public information and contain some uncertainties, as reflected in the notes to tables 6.1–6.10.

Country	Year of first nuclear test	Deployed warheads[a]	Stored warheads[b]	Other warheads	Total inventory
United States	1945	1 750[c]	2 050[d]	2 650[e]	6 450
Russia	1949	1 600[f]	2 750[g]	2 500[e]	6 850
United Kingdom	1952	120	95	–	215
France	1960	280	10	10	300
China	1964	–	280	–	280
India	1974	–	130–140	. .	130–140
Pakistan	1998	–	140–150	. .	140–150
Israel	. .	–	80	. .	80
North Korea	2006	–	. .	(10–20)	(10–20)[h]
Total[i]		**3 750**	**5 555**	**5 160**	**14 465**

. . = not applicable or not available; – = zero; ( ) = uncertain figure.

[a] These are warheads placed on missiles or located on bases with operational forces.

[b] These are warheads in central storage that would require some preparation (e.g. transport and loading on to launchers) before they could become fully operationally available.

[c] This figure includes approximately 1600 strategic warheads (about 1300 on ballistic missiles and nearly 300 on bomber bases), as well as *c.* 150 non-strategic (tactical) nuclear bombs deployed in Europe for delivery by US and other North Atlantic Treaty Organization combat aircraft.

[d] This figure includes *c.* 50 non-strategic nuclear bombs stored in the USA.

[e] This figure is for retired warheads awaiting dismantlement.

[f] This figure includes approximately 1400 strategic warheads on ballistic missiles and about 200 deployed on heavy bomber bases.

[g] This figure includes *c.* 920 warheads for strategic bombers and nuclear-powered ballistic missile submarines (SSBNs) in overhaul and *c.* 1830 non-strategic nuclear weapons for use by short-range naval, air force and air defence forces.

[h] There is no authoritative open-source evidence to confirm that North Korea has produced or deployed operational nuclear warheads.

[i] Total figures assume the highest estimate when a range is given. Figures for North Korea are not included.

USA have produced both HEU and plutonium for use in their nuclear weapons; India and Israel have produced mainly plutonium; and Pakistan has produced mainly HEU, but is increasing its ability to produce plutonium. North Korea has produced plutonium for use in nuclear weapons but may have produced HEU as well. All states with a civilian nuclear industry are capable of producing fissile materials (see section X).

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I. US nuclear forces

HANS M. KRISTENSEN

As of January 2018, the United States maintained a military stockpile of about 3800 nuclear warheads, a reduction of nearly 200 warheads compared with the total in early 2017.[1] The stockpile included approximately 1750 deployed nuclear warheads, consisting of about 1600 strategic and 150 non-strategic warheads. In addition, about 2050 warheads were held in reserve and around 2650 retired warheads were awaiting dismantlement, giving a total inventory of approximately 6450 nuclear warheads (see table 6.2). The reduction in warheads was due to the USA's implementation of its warhead life-extension programmes and continuing implementation of the 2010 Treaty on Measures for the Further Reduction and Limitation of Strategic Offensive Arms (New START) during 2017.[2]

Nuclear modernization

The USA has initiated a large-scale nuclear modernization programme (known as the 'program of record'), which aims to replace or upgrade (*a*) US land-, sea- and air-based nuclear delivery systems; (*b*) the command and control systems at the US Department of Defense; and (*c*) the nuclear warheads and their supporting infrastructure at the US Department of Energy's National Nuclear Security Administration.[3] According to an estimate published in February 2017 by the US Congressional Budget Office (CBO), modernizing and operating the US nuclear arsenal and the facilities that support it will cost around $400 billion for the period 2017–26 (a 15 per cent increase on the CBO's estimate covering the period 2015–24).[4] The nuclear modernization (and maintenance) programme will continue well beyond 2026 and, based on the CBO's estimate, will cost $1.2 trillion for the period 2017–46. Notably, although the CBO estimate accounts for inflation, other estimates forecast that the total cost will be closer to $1.7 trillion.[5] The CBO estimates that the planned modernization would increase the total costs of US nuclear forces for 2017–46 by roughly 50 per cent when compared with

[1] Kristensen, H. M., 'Despite rhetoric, US stockpile continues to decline', FAS Strategic Security Blog, Federation of Atomic Scientists, 22 Mar. 2018.

[2] For a summary and other details of New START see annex A, section III, in this volume. On the implementation of New START see chapter 7, section II, in this volume.

[3] Kristensen, H. M., 'US nuclear forces', *SIPRI Yearbook 2017*, pp. 413–15.

[4] US Congressional Budget Office, 'Projected costs of US nuclear forces, 2017 to 2026', Feb. 2017, p. 1.

[5] See e.g. Reif, K., 'US nuclear modernization programs', Arms Control Association, Fact Sheet, Mar. 2018.

Table 6.2. US nuclear forces, January 2018

Type	Designation	No. of launchers	Year first deployed	Range (km)[a]	Warheads x yield	No. of warheads[b]
Strategic forces						**3 600**
Bombers		*60/107*[c]				*880*[d]
B-52H	Stratofortress	44/87	1961	16 000	20 x ALCM 5–150 kt[e]	528
B-2A	Spirit	16/20	1994	11 000	16 x B61-7, -11, B83-1 bombs[f]	282
ICBMs		*400*				*800*[g]
LGM-30G	Minuteman III					
	Mk-12A	200	1979	13 000	1-3 x W78 335 kt	600[h]
	Mk-21 SERV	200	2006	13 000	1 x W87 300 kt	200[i]
SSBNs/SLBMs		*240*[j]				*1 920*[k]
UGM-133A	Trident II (D5/D5LE)					
	Mk-4	. .	1992	>7 400	1-8 x W76-0 100 kt	216
	Mk-4A	. .	2008	>7 400	1-8 x W76-1 100 kt	1 320
	Mk-5	. .	1990	>7 400	1-8 x W88 455 kt	384
Non-strategic forces						**200**[l]
F-15E	Strike Eagle	. .	1988	3 840	5 x B61-3, -4[m]	70
F-16C/D	Falcon	. .	1987	3 200[n]	2 x B61-3, -4	70
F-16MLU	Falcon (NATO)	. .	1985	3 200	2 x B61-3, -4	30
PA-200	Tornado (NATO)	. .	1983	2 400	2 x B61-3, -4	30
Total stockpile						**3 800**[o]
Deployed warheads						1 750
Reserve warheads						2 050
Retired warheads awaiting dismantlement						**2 650**
Total inventory						**6 450**[p]

. . = not available or not applicable; ALCM = air-launched cruise missile; ICBM = intercontinental ballistic missile; kt = kiloton; NATO = North Atlantic Treaty Organization; SERV = security-enhanced re-entry vehicle; SLBM = submarine-launched ballistic missile; SSBN = nuclear-powered ballistic missile submarine.

Note: The figures in the USA's New START Treaty declaration do not necessarily correspond to those contained in the table because of the treaty's counting rules.

[a] Maximum unrefuelled range. All nuclear-equipped aircraft can be refuelled in the air. Actual mission range will vary according to flight profile and weapon loading.

[b] The number shows the total number of warheads assigned to nuclear-capable delivery systems. Only some of these warheads are deployed on missiles and aircraft bases.

[c] Bombers have 2 numbers: the first is the number assigned to the nuclear mission; the second is the total inventory. The US Air Force has 66 nuclear-capable bombers (20 B-2As and 46 B-52Hs) of which no more than 60 will be deployed at any given time.

[d] Of the bomber weapons, *c.* 300 (200 ALCMs and 100 bombs) are deployed at the bomber bases; all the rest are in central storage. The total bomb inventory is listed as higher than in *SIPRI Yearbook 2017* to compensate for a recount of the ICBM warhead estimate, but many of the gravity bombs are no longer fully active and are slated for retirement after the B61-12 is fielded in 2020.

[e] The B-52H is no longer configured to carry nuclear gravity bombs.

[f] Strategic gravity bombs are only assigned to B-2A bombers. The maximum yields of strategic bombs are: B61-7 (360 kt), B61-11 (400 kt), B83-1 (1200 kt). However, they also have lower yields. Many B83-1s have been moved to the inactive stockpile. The administration of President Barack Obama decided that the B83-1 would be retired once the B61-12 was deployed, but

the administration of President Donald J. Trump has indicated that it might retain the B83-1 for a longer period.

[g] Of these ICBM warheads, only 400 are deployed on the missiles. The remaining warheads are in central storage.

[h] Only 200 of these W78 warheads are deployed. The rest are in central storage.

[i] Another 340 W87s are possibly in long-term storage outside the stockpile for planned use in future so-called interoperable warheads.

[j] Of the 14 SSBNs, 2 are normally undergoing refuelling overhaul at any given time. They are not assigned weapons. Another 2 or more submarines may be undergoing maintenance at any given time and may not be carrying missiles. The number of deployable missiles has been reduced to 240 to meet the New START limit on deployed strategic missile launchers.

[k] Of these warheads, only about 900 are deployed on submarines; all the rest are in central storage. Although each D5 missile was counted under the 1991 Strategic Arms Reduction Treaty as carrying 8 warheads and was initially flight tested with 14, the US Navy has downloaded each missile to an average of 4–5 warheads. All deployed W76 warheads are of the new W76-1 type. Once production of the W76-1 is finished in 2019, all remaining W76-0s will be retired.

[l] Approximately 150 of the tactical bombs are deployed in Europe. The remaining bombs are in central storage in the USA. Once the B61-12 is deployed, all other B61 versions will be retired.

[m] The maximum yields of tactical bombs are as follows: B61-3 (170 kt) and B61-4 (50 kt). All have selective lower yields. The B61-10 was retired in 2016.

[n] Most sources list 2400 km unrefuelled ferry range but Lockheed Martin, which produces the F-16, lists 3200 km.

[o] Of these weapons, approximately 1750 are deployed on ballistic missiles, at bomber bases, and in Europe; all the rest are in central storage.

[p] In addition to these intact warheads, there are more than 20 000 plutonium pits stored at the Pantex Plant, Texas, and perhaps 4000 uranium secondaries stored at the Y-12 facility at Oak Ridge, Tennessee.

Sources: US Department of Defense, various budget reports, press releases and documents obtained under the Freedom of Information Act; US Department of Energy, various budget reports and plans; US Air Force, US Navy and US Department of Energy, personal communications; 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

the costs of operating and sustaining only the forces that are already fielded.[6] It remains to be seen to what extent the US Congress will agree to fund these expensive projects (instead of building cheaper life-extended versions of existing designs) or whether it will decide to delay some of them.

Bombers

The US Air Force currently operates a fleet of 169 heavy bombers: 62 B-1Bs, 20 B-2As, and 87 B-52Hs. Of these, 66 (20 B-2As and 46 B-52Hs) were declared to be nuclear-capable as of 1 September 2017, although only 60 (18 B-2As and 42 B-52Hs) are thought to be assigned nuclear delivery

[6] US Congressional Budget Office (CBO), *Approaches for Managing the Costs of US Nuclear Forces, 2017 to 2046* (CBO: Washington, DC, Oct 2017), p. 1.

roles.[7] The bombers are being equipped with new command and control systems to improve interconnectivity with other forces and the US National Command Authority.[8]

The development of the next-generation long-range strike bomber, known as the B-21 Raider, is well under way. The B-21 is scheduled to enter service in the mid-2020s.[9]

To arm its bombers, the Air Force is developing a controversial new nuclear air-launched cruise missile, known as the LRSO (Long-Range Standoff missile), for deployment from 2030.[10] The Air Force plans to acquire 1000 missiles, of which about half will be nuclear-armed and the rest used for test launches. The weapon is intended for integration on the B-2A, the B-52H and the new B-21.[11]

Land-based ballistic missiles

As part of its implementation of New START, in 2017 the USA completed the reduction of its intercontinental ballistic missile (ICBM) force from 450 to 400 deployed Minuteman III missiles, which are deployed in silos across three missile wings. Following the reduction, each of the three ICBM bases has 133–34 deployed missiles. The 50 emptied silos are being kept in a state of readiness and can be reloaded with stored missiles if necessary.

Each Minuteman III ICBM is armed with one warhead: either a 335-kiloton W78/Mk12A or a 300-kt W87/Mk21. Missiles carrying the W78 can be uploaded with up to two more warheads for a maximum of three multiple independently targetable re-entry vehicles (MIRVs). The entire Minuteman III force completed a decade-long upgrade in 2015 to extend its life through the 2020s. Moreover, an upgrade is under way of the W87/Mk21 re-entry vehicle to a new fuze (arming, fuzing and firing unit).[12]

[7] US Department of State, 'New START Treaty aggregate numbers of strategic offensive arms', Fact Sheet, 12 Jan. 2018.

[8] US Air Force, Presentation to the US House of Representatives Armed Services Committee, Strategic Forces Subcommittee, Subject: FY19 Posture for Department of Defense Nuclear Forces, Statement of Rand, R. (Gen.), Commander Air Force Global Strike Command, 22 Mar. 2018.

[9] Gertler, J., *Air Force B-21 Raider Long-Range Strike Bomber*, Congressional Research Service (CRS) Report for Congress R44463 (US Congress, CRS: Washington, DC, 7 June 2017).

[10] For background and context on the LRSO see e.g. Kristensen, H. M., 'LRSO: the nuclear cruise missile mission', FAS Strategic Security Blog, Federation of American Scientists, 20 Oct. 2015; Kristensen, H. M., 'Forget LRSO: JASSM-ER can do the job', FAS Strategic Security Blog, Federation of American Scientists, 16 Dec. 2015; and Reif, K., 'Examining the flawed rationale for a new nuclear air-launched cruise missile', *Arms Control Today*, vol. 8, no. 2 (12 June 2016).

[11] US Air Force, 'USAF awards contracts for new nuclear missile to Lockheed, Raytheon', 23 Aug. 2017; Stone, M., 'US Air Force picks Raytheon, Lockheed for next-gen cruise missile', Reuters, 24 Aug. 2017; and Majumdar, D., 'B-52, B-2 and B-21 bombers are getting nuclear-tipped cruise missiles', *National Interest*, 24 Aug. 2017.

[12] Woolf, A. F., *US Strategic Nuclear Forces: Background, Developments, and Issues*, Congressional Research Service (CRS) Report for Congress RL33640 (US Congress, CRS: Washington, DC, 6 Mar. 2018), pp. 24–26.

The Air Force has begun development of a next-generation ICBM, known as the Ground Based Strategic Deterrent (GBSD), which is scheduled to begin replacing the Minuteman III in 2028. It plans to buy 642 missiles, of which 400 would be deployed, 50 stored and the rest used for test launches and as spares.[13] The expected cost of developing and producing the GBSD is increasing, and in 2017 it was projected to be around $100 billion, up from an initial projection of $62.3 billion in 2015.[14]

The Air Force conducted four test launches of the Minuteman III in 2017. The tests took place on 8 February, 26 April, 3 May and 2 August.[15] All four missiles were launched from Vandenberg Air Force Base (AFB) in California with re-entry vehicle impact some 6760 kilometres away at the Ronald Reagan Ballistic Missile Defense Test Site in the Kwajalein Atoll in the Marshall Islands. Several simulated ICBM launches were also conducted in 2017, including one at F. E. Warren AFB in Wyoming that involved six missiles.[16]

Ballistic missile submarines

In 2017 the US Navy completed the reduction of missile launch tubes (from 24 to 20) on each of its Ohio class nuclear-powered ballistic missile submarines (SSBNs). The reduction was necessary to meet the New START Treaty limit of no more than 700 deployed strategic launchers. Following the reductions, the navy's SSBN fleet can deploy up to 240 strategic missiles.[17]

All of the 14 Ohio class SSBNs, 8 of which are based in the Pacific and 6 in the Atlantic, carry Trident II (D5) submarine-launched ballistic missiles (SLBMs). Of the 14 SSBNs, 12 are normally considered to be operational and 2 are typically undergoing refuelling overhaul at any given time. Around 8 to 10 SSBNs are normally at sea, of which 4 or 5 are on alert in their designated patrol areas and ready to fire their missiles within 15 minutes of receiving the launch order.

In 2017 the navy started replacing the Trident II (D5) SLBMs with an enhanced version known as the D5LE. The D5LE is equipped with the new Mk-6 guidance system, designed to improve the D5LE's effectiveness. The D5LE will arm Ohio class submarines for the remainder of their service lives (up to 2042), and will also be deployed on British Trident submarines (see

[13] Reif, K., 'Air Force drafts plan for follow-on ICBM', *Arms Control Today*, 8 July 2015.

[14] Reif, K., 'New ICBM replacement cost revealed', *Arms Control Today*, Mar. 2017.

[15] US Air Force, Vandenberg Air Force Base, 30th Space Wing Public Affairs, 'Minuteman III launches from Vandenberg', 9 Feb. 2017; US Air Force, Global Strike Command, 'F. E. Warren tests Minuteman III missile with launch from Vandenberg', 26 Apr. 2017; US Air Force, Global Strike Command, 'Malmstrom tests Minuteman III missile with launch from Vandenberg', 3 May 2017; and US Air Force, Global Strike Command, 'F.E. Warren tests Minuteman III missile with launch from Vandenberg', 2 Aug. 2017.

[16] US Air Force, '90th MW provides unwavering nuclear deterrence', 13 Apr. 2017.

[17] Woolf (note 12).

section III). The D5LE will initially also arm the new Columbia class SSBN, the first of which is scheduled to start patrols in 2031, but will eventually be replaced with a new SLBM in the early 2040s.[18]

The Trident SLBMs carry two basic warhead types: either the 455-kt W88 or the 100-kt W76. The navy has almost completed deployment of a life-extended version of the W76, known as W76-1. The W76-1 is equipped with a new fuze that improves its targeting effectiveness. Each SLBM can carry up to eight warheads but normally carries fewer. The navy does not disclose how many warheads it carries on each submarine but, in practice, each missile carries an average of four to five warheads, depending on mission requirements. The New START data indicates that the SSBN fleet carried a total of 945 warheads as of September 2017.[19]

The navy test launched four Trident II (D5) SLBMs from one SSBN in 2017. As part of Follow-on Commander Evaluation Test number 53, the missiles were launched in the Pacific from the *USS Kentucky* (SSBN-737) over the course of three days.[20] The event marked the final test launch of the original Trident II (D5). All future Trident II test launches will be for the D5LE.

Non-strategic nuclear weapons

The USA has one type of non-strategic weapon in its stockpile—the B61 gravity bomb. The weapon exists in two modifications: the B61-3 and B61-4. A third modification (B61-10) was retired in late 2016. There are an estimated 200 tactical B61 bombs in the US stockpile. Approximately 150 of these are deployed at six North Atlantic Treaty Organization (NATO) airbases in five European countries: Aviano and Ghedi, Italy; Büchel, Germany; Incirlik, Turkey; Kleine Brogel, Belgium; and Volkel, the Netherlands. The Belgian, Dutch and possibly Turkish air forces (using F-16 combat aircraft) and German and Italian air forces (using PA-200 Tornado combat aircraft) are assigned nuclear strike missions with the US B61 bombs. In peacetime, however, they are kept under the custodial control of US Air Force personnel.

Concerns were raised about the security of the nuclear weapons at the Incirlik base during the failed coup attempt in Turkey in July 2016, and reports emerged in late 2017 suggesting that the weapons might have been 'quietly withdrawn'.[21] These reports have not been confirmed, and Incirlik is still included in scheduled nuclear storage base upgrades for 2019.[22]

[18] Woolf (note 12).

[19] US Department of State (note 7).

[20] Daniels, J. M., US Navy, Strategic Systems Programs Public Affairs, 'FCET success: SSBN launches fleet ballistic missile', NNS170216-21, 16 Feb. 2017.

[21] Hammond, J., 'The future of Incirlik Air Base', Real Clear Defense, 30 Nov. 2017.

[22] For background and context see Nuclear Threat Initiative (NTI), *Building a Safe, Secure, and Credible NATO Nuclear Posture* (NTI: Washington, DC, Jan. 2018).

The remaining 50 B61 bombs are stored in the (continental) USA for potential use by US fighter-bombers in support of allies outside Europe, including in East Asia and the Middle East.

NATO has approved a modernization of its nuclear posture in Europe through deployment, beginning in 2022–24, of the US B61-12 guided nuclear gravity bomb.[23] The B61-12 will use the nuclear explosive package of the B61-4, which has a maximum yield of approximately 50 kt, but will be equipped with a new tail kit to increase its accuracy and standoff capability. The B61-12 will be able to destroy hardened targets that could not be destroyed by the B61-3 or B61-4. It will also enable strike planners to select lower yields for existing targets, which would reduce collateral damage.[24]

Integration flight tests have begun of the B61-12 bombs on F-15E, F-16 and Tornado combat aircraft. The B61-12 will also be integrated on the US-built F-35A combat aircraft, which is expected to be nuclear certified in 2024–26.[25] Italy and the Netherlands have received the first of their F-35A combat aircraft, some of which will later be designated for a nuclear delivery role.[26] Belgium is considering whether to buy the F-35A. Although in early 2018 the US State Department approved a possible sale of 34 F-35A aircraft, Belgium has not yet officially announced a decision to buy the F-35A.[27] Germany does not currently have a plan to replace the PA-200 Tornado in its nuclear role and is expected to extend its service life into the 2020s, despite the German Air Force's apparent preference for the F-35A.[28]

[23] US Government Accountability Office (GAO), *Nuclear Weapons: DOD and NNSA Need to Better Manage Scope of Future Refurbishments and Risks to Maintaining US Commitments to NATO*, Report to Congressional Requesters, GAO-11-387 (GAO: Washington, DC, May 2011), p. 13.

[24] For a description of the B61-12 and its implications see Kristensen, H. M., 'B61 LEP: increasing NATO nuclear capability and precision low-yield strikes', FAS Strategic Security Blog, Federation of American Scientists, 15 June 2011.

[25] Kristensen, H. M. and Norris, R. S., 'The B61 family of nuclear bombs', *Bulletin of the Atomic Scientists*, vol. 70, no. 3 (2014).

[26] Seligman, L., 'Dutch F-35s land in the Netherlands', *Defense News*, 23 May 2016; and Peruzzi, L., 'Italy receives first Cameri-assembled F-35A', Flight Global, 8 Dec. 2015.

[27] Defense Security Cooperation Agency, 'Belgium: F-35 Joint Strike Fighter Aircraft', News Release 17-80, 18 Jan. 2018.

[28] Reuters, '"F-35" für die Bundeswehr? Luftwaffe benennt Anforderungen an "Tornado": Nachfolger' ['F-35' for the Bundeswehr? Air Force calls requirements on 'Tornado' successor], *Der Spiegel*, 8 Nov. 2017.

II. Russian nuclear forces

HANS M. KRISTENSEN

As of January 2018, Russia maintained an arsenal of approximately 4350 nuclear warheads. About 2520 of these are strategic warheads, of which nearly 1600 are deployed on land- and sea-based ballistic missiles and at bomber bases. Russia also possessed approximately 1830 non-strategic (tactical) nuclear warheads, all of which are in central storage sites.[1] An estimated additional 2500 warheads were retired or awaiting dismantlement, giving a total inventory of approximately 6850 warheads (see table 6.3). The reduction in Russia's deployed strategic warheads from the estimated total of 1950 in early 2017 was due to its continuing implementation of the 2010 Treaty on Measures for the Further Reduction and Limitation of Strategic Offensive Arms (New START) during 2017.[2]

Strategic bombers

Russia's Long-range Aviation Command operates a fleet of approximately 13 Tu-160 (Blackjack), 30 Tu-95MS16 (Bear-H16) and 25 Tu-95MS6 (Bear-H6) bombers. Some of these may not be fully operational and others are undergoing various upgrades. The maximum loading on the operational bombers is more than 600 nuclear weapons, of which approximately 200 might be stored at the two strategic bomber bases. Modernization of the bombers is well under way. Nearly all of the Tu-160s and some of the Tu-95s will be upgraded to maintain a bomber force of 50–60 aircraft. The upgraded bombers are capable of carrying the new Kh-102 (AS-23B) nuclear air-launched cruise missile.[3] The Russian Government has also announced plans to resume production of the Tu-160 to produce up to 50 modified aircraft known as Tu-160M2, with serial production starting in 2023.[4] The additional bombers would probably replace many of the old Tu-95 (MS16 and MS6) aircraft and provide a bridge to the future next-generation bomber, known as PAK-DA, which is scheduled to begin fielding in the late 2020s.[5]

[1] For a recent overview of Russia's nuclear weapon storage facilities see Podvig, P. and Serrat, J., 'Lock them up: zero-deployed non-strategic nuclear weapons in Europe', United Nations Institute for Disarmament Research, 2017.

[2] For a summary and other details of New START see annex A, section III, in this volume. On the implementation of New START see chapter 7, section II, in this volume.

[3] Roblin, S., 'The Tu-95 Bear: the 60-year-old Russian bomber America still chases all over the world', *National Interest*, 11 June 2017.

[4] TASS, 'Russia's upgraded Tu-160M2 bomber to remain state-of-the-art for four more decades', 1 Nov. 2017.

[5] TASS, 'Russia to develop first prototype of next-generation strategic bomber by early 2020s', 13 Apr. 2017.

Land-based ballistic missiles

As of January 2018, Russia's Strategic Rocket Forces—the branch of the armed forces that controls land-based intercontinental ballistic missiles (ICBMs)—consisted of 12 missile divisions grouped into 3 armies and deploying an estimated 318 ICBMs of 7 different types and variations. These ICBMs can carry a total of 1138 warheads but SIPRI estimates that they have been downloaded to carry just under 800 warheads, nearly 50 per cent of Russia's deployed strategic warheads. In contrast to the frequent claims in recent years about a Russian nuclear 'build-up', the US Air Force's National Intelligence and Space Center (NASIC) estimates that 'the number of missiles in the Russian ICBM force will continue to decrease because of arms control agreements, aging missiles, and resource constraints'.[6]

Russia's ICBM force is in the middle of a significant modernization programme to replace all Soviet-era missiles with new types, albeit not on a one-for-one basis. The replacement programme, which started in 1997, appears to be progressing more slowly than planned. About 60 per cent of the force had been upgraded by the end of 2017. All the remaining Soviet-era ICBMs are scheduled to be withdrawn by 2024, three years later than previously announced. In addition to the procurement of new missiles, the modernization involves substantial reconstruction of silos, launch control centres, garrisons and support facilities.[7]

Russia's current ICBM modernization is focused on the multiple-warhead version of the RS-12, known as RS-24 Yars (SS-27 Mod 2). Three mobile divisions have already been completed, with two more in progress, and two more to begin upgrade by 2020. The first silo-based RS-24 regiment with 10 missiles is operational at Kozelsk and a second regiment is in the early stages of construction.[8] Russia is developing a third modification of the RS-12M, known as the RS-26 Yars-M (SS-X-28), which will be lighter than the RS-24. However, final development and deployment of the RS-26 has been delayed.[9] In addition, Russia is developing a new 'heavy' liquid-fuelled, silo-based ICBM, known as the RS-28 Sarmat (SS-X-29), as a replacement for the RS-20V (SS-18). According to Russia's Deputy Defence Minister, Yuriy Borisov, the RS-28 will carry 'new types of warheads', including

[6] US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat* (NASIC: Wright-Patterson Air Force Base, OH, July 2017), p. 27. On the alleged Russian nuclear 'build-up' see e.g. Gertz, B., 'Russia sharply expanding nuclear arsenal, upgrading underground facilities', Washington Free Beacon, 13 Dec. 2017.

[7] Azanov, R., 'Russia's Strategic Missile Forces as its decisive defense', TASS, 19 Dec. 2017.

[8] Azanov (note 7); and Andreyev, D. and Zotov, I., [The nuclear shield is reliable], *Krasnaya Zvezda*, 14 Dec. 2017 (in Russian).

[9] Kristensen, H. M., 'Review of NASIC Report 2017: nuclear force developments', FAS Strategic Security Blog, Federation of American Scientists, 30 June 2017.

Table 6.3. Russian nuclear forces, January 2018

All estimated figures are approximate. Figures may not add up to stated totals due to the conventions of rounding.

Type/ Russian designation (NATO designation)	No. of launchers	Year first deployed	Range (km)[a]	Warhead loading	No. of warheads[b]
Strategic offensive forces					**2 520**[c]
Bombers	*50/68*[d]				*616*[e]
Tu-95MS6 (Bear-H6)	14/25	1981	6 500–10 500	6 x AS-15A or AS-23B ALCMs, bombs	84
Tu-95MS16 (Bear-H16)	25/30	1981	6 500–10 500	16 x AS-15A or AS-23B ALCMs, bombs	400
Tu-160 (Blackjack)	11/13	1987	10 500–13 200	12 x AS-15B or AS-23B ALCM, bombs	132
ICBMs	*318*				*1 138*[f]
RS-20V (SS-18 Satan)	46	1992	11 000–15 000	10 x 500–800 kt	460
RS-18 (SS-19 Stiletto)	20	1980	10 000	6 x 400 kt	120
RS-12M Topol (SS-25 Sickle)	72[g]	1985	10 500	1 x 800 kt	72
RS-12M2 Topol-M (SS-27 Mod 1/silo)	60	1997	10 500	1 x 800 kt	60
RS-12M1 Topol-M (SS-27 Mod 1/mobile)	18	2006	10 500	1 x (800 kt)	18
RS-24 Yars (SS-27 Mod 2/ mobile)	90	2010	10 500	4 x (100 kt)	360
RS-24 Yars (SS-27 Mod 2/silo)	12	2014	10 500	4 x (100 kt)	48
RS-26 Yars-M (SS-X-28)	. .	(2018)	5 500+	MIRV (. . kt)	. .
RS-28 Sarmat (SS-X-29)	. .	(2020)	10 000+	MIRV (. . kt)	. .
SLBMs	*11/176*[h]				*768*[h]
RSM-50 Volna (SS-N-18 M1 Stingray)	2/32	1978	6 500	3 x 50 kt	96
RSM-54 Sineva (SS-N-23 M1)	6/96	1986/2007	9 000	4 x 100 kt	384
RSM-56 Bulava (SS-N-32)	3/48	2014	>8 050	6 x (100 kt)	288
Non-strategic forces					**1 830**[i]
ABM, air/coastal defence	*898*				*373*
53T6 (SH-08, Gazelle)	68	1986	30	1 x 10 kt	68
S-300 (SA-10/20)	800[j]	1980/1992	. .	1 x low kt	290
3M-55 Yakhont (SS-N-26)	20	(2014)	400+	1 x (. . kt)	10
SSC-1B (Sepal)	10	1973	500	1 x 350	5
Air Force weapons[k]	*358*				*498*
Tu-22M3 (Backfire-C)	100	1974	. .	3 x ASM, bombs	250
Su-24M/M2 (Fencer-D)	150	1974	. .	2 x bombs	150
Su-34 (Fullback)	98	2006	. .	2 x bombs	98
MiG-31K (Foxhound)	10	1983	. .	1 x ASM	. .
Army weapons	*148*				*148*
Tochka (SS-21 Scarab)	12	1981	120	(1 x 10–100 kt)	12

Type/ Russian designation (NATO designation)	No. of launchers	Year first deployed	Range (km)[a]	Warhead loading	No. of warheads[b]
Iskander-M (SS-26 Stone)	120	2005	350[l]	(1 x 10–100 kt)	120
9M729 (SSC-8)	16	2016	(2 500)	1 x . . kt	16
Navy weapons					*810*
Submarines/surface ships/air		LACM, SLCM, ASW, SAM, depth bombs, torpedoes[m]			
Total stockpile					**4 350**
Deployed warheads					1 600[n]
Reserve warheads					2 750
Retired warheads awaiting dismantlement					**2 500**
Total inventory					**6 850**

. . = not available or not applicable; ( ) = uncertain figure; ABM = anti-ballistic missile; ALCM = air-launched cruise missile; ASM = air-to-surface missile; ASW = anti-submarine warfare; ICBM = intercontinental ballistic missile; kt = kiloton; LACM = land-attack cruise missile; MIRV = multiple independently targetable re-entry vehicle; NATO = North Atlantic Treaty Organization; SAM = surface-to-air missile; SLBM = submarine-launched ballistic missile; SLCM = sea-launched cruise missile.

Note: The table lists the total number of warheads estimated to be available for the delivery systems. Only some of these are deployed and they do not necessarily correspond to the New START Treaty data counting rules.

[a] Aircraft range is for illustrative purposes only; actual mission range will vary according to flight profile and weapon loading.

[b] The number shows the total number of available warheads, both deployed and in storage, assigned to the delivery systems.

[c] Approximately 1600 of these strategic warheads are deployed on land- and sea-based ballistic missiles and at bomber bases. The remaining warheads are in central storage.

[d] The first number is the number of bombers estimated to be counted under the New START Treaty. The second number is the total number of bombers in the inventory. Because of ongoing bomber modernization, there is considerable uncertainty about how many bombers are operational.

[e] Of the 616 weapons estimated to be assigned to long-range bombers, only 200 weapons are thought to be present at the 2 strategic bomber bases. The remaining weapons are in central storage facilities.

[f] Of the 1138 warheads available for operational ICBMs, nearly 800 are thought to be deployed on the missiles, with the remaining warheads in storage.

[g] The number is uncertain because several SS-25 garrisons are upgrading to the SS-27 Mod 2.

[h] Two of the Delta SSBNs are in overhaul at any given time and do not carry their assigned nuclear missiles and warheads. It is possible that only 1 Delta III is operational.

[i] Non-strategic nuclear warheads are not deployed with their delivery systems but are kept in a central storage facility, according to the Russian Government. Some storage facilities are near operational bases.

[j] There are at least 80 S-300 sites across Russia, each with an average of 12 launchers, each with 2–4 interceptors. Each launcher has several reloads. The SA-10 has almost been replaced by the SA-20.

[k] The numbers show total nuclear-capable aircraft but only some of them are thought to have nuclear missions. Most can carry more than 1 nuclear weapon. Other potential nuclear-capable aircraft include Su-25 Frogfoot and MiG-25 Foxbat.

[l] Although many unofficial sources and news media reports say the SS-26 has a range of nearly 500 km, the US Air Force, National Air and Space Intelligence Center (NASIC) lists the range as 350 km.

[m] Only submarines are thought to be assigned nuclear torpedoes.

[n] Note that the number is different from the New START Treaty number for deployed warheads because of the treaty's counting rules.

Sources: Russian Ministry of Defence, various press releases; US Department of State, START Treaty Memoranda of Understanding, 1990–July 2009; New START aggregate data releases, various years; US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat* (NASIC: Wright-Patterson Air Force Base, OH, July 2017); BBC Monitoring; Russian news media; Russian Strategic Nuclear Forces website; International Institute for Strategic Studies, *The Military Balance* (Routledge: London, various issues); Cochran, T. B. et al., *Nuclear Weapons Databook*, vol. 4, *Soviet Nuclear Weapons* (Harper & Row: New York, 1989); *IHS Jane's Strategic Weapon Systems*, various issues; *Proceedings*, US Naval Institute, various issues; 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

'manoeuvrable warheads'.[10] Test launches of the 200-tonne missile have begun and will be followed by serial production, before eventual deployment in upgraded RS-20V silos in a few years. Production of a rail-based ICBM seems to have been delayed or cancelled.[11]

Russia normally conducts two large-scale exercises with road-mobile ICBMs each year. The biannual exercises in 2017 involved RS-12M Topol (SS-25), RS-12M1 Topol-M (SS-27 Mod 1) and RS-24 mobile launchers from all the operational missile divisions. The launchers were deployed further from their bases and for longer periods than in previous years. Russian ICBMs also participated in broader strategic exercises along with nuclear-powered ballistic missile submarines (SSBNs) and bombers.[12] These included several test launches of strategic missiles, some of which took place around the time of the Zapad-17 exercise in western Russia and Belarus in September 2017.[13]

Ballistic missile submarines and sea-launched ballistic missiles

The Russian Navy has a fleet of 11 deployable nuclear-armed SSBNs. The fleet includes 9 Soviet-era SSBNs and 3 (of a planned total of 8) SSBNs of a new class that will gradually replace the old SSBNs over the next decade. A

[10] Gavrilov, Y., 'Sarmat will fly over pole: Russia designing unique missile', *Rossiyskaya Gazeta*, 2 June 2014. Translation from Russian, BBC Monitoring.

[11] TASS, 'Russia excludes rail-mobile ICBM system from armament, focuses on Sarmat missile', 6 Dec. 2017. For further detail on the planned rail-based ICBM see Kristensen H. M., 'Russian nuclear forces', *SIPRI Yearbook 2017*, p. 423.

[12] See e.g. TASS, 'Some 20 Topol-M, Yars mobile ICBM systems take part in massive Central Russian drills', 28 Mar. 2017; TASS, 'Eleven strategic missile regiments to hold large-scale drills across Russia', 4 Sep. 2017; and TASS, 'Topol ballistic missile test launched from range in Russia's south', 26 Sep. 2017.

[13] For further detail on the Zapad-17 exercise see Johnson, D., 'Zapad 2017 and Euro-Atlantic security', NATO Review, 14 Dec. 2017.

former SSBN has been converted to a test-launch platform for submarine-launched ballistic missiles (SLBMs) but it is not nuclear armed.

The current backbone of the Russian SSBN fleet is made up of six Project 667BDRM Delfin (designated Delta IV class by the North Atlantic Treaty Organization, NATO) submarines assigned to the Northern Fleet. Two Project 667BDR Kalmar (Delta III) SSBNs are believed to be operational with the Pacific Fleet, although reports in early 2018 suggested that it is possible that only one of these is still operational.[14] A third Project 667BDR Kalmar SSBN is held in reserve. All three will be decommissioned in the near future.

Three of the new Borei class SSBNs (Project 955/A) are operational: two with the Pacific Fleet and one with the Northern Fleet. Five more of an improved design, known as Borei-A (Project 955A), are under construction and scheduled to enter service between 2018 and 2022. Each Borei class SSBN carries 16 RSM-56 Bulava (SS-N-32) SLBMs. It is possible that Russia will buy four more Borei class SSBNs to maintain an SSBN fleet comparable in size to that of the United States.[15]

Non-strategic nuclear weapons

According to SIPRI data, as of January 2018, Russia had approximately 1830 warheads assigned for potential use by non-strategic forces. Many more Soviet-era non-strategic warheads have been retired and are awaiting dismantlement (see table 6.3).

Russia's large arsenal of non-strategic nuclear weapons chiefly serves to compensate for perceived weaknesses in its conventional forces. There has been considerable debate about the role that non-strategic nuclear weapons have in Russian nuclear strategy, including potential first use.[16] Development of new dual-capable weapons demonstrates that Russia continues to see non-strategic nuclear weapons as important in its military strategy. As targeting accuracy has improved, some weapons have been equipped with warheads with lower yields than they had during the cold war. Others are likely to be replaced with advanced conventional weapons over the next decade.

The most significant naval development is the fielding of a nuclear version of the new long-range, land-attack Kalibr sea-launched cruise missile

[14] The scheduled defuelling was first published by Rosatom and reported on Twitter by @7FBTK. The Rosatom notification is no longer available, but a description is available at the Russianforces.org website. Podvig, P., 'Two Project 667BDR submarines withdrawn from service', Russianforces.org, 14 Mar. 2018.

[15] Bogdanov, K., ['Great Fleet' on the horizon], Lenta, 23 Jan. 2015 (in Russian).

[16] See e.g. Scaparrotti, C. M., 'NATO's military commander concerned about Russia's tactical nuclear weapons in Europe', Atlantic Council, NATO Source, 3 May 2017; and Ven Bruusgaard, K., 'The myths of Russia's lowered nuclear threshold', War on the Rocks, 22 Sep. 2017.

(SLCM), known as the 3M-14 (SS-N-30A).[17] While the conventional version is being fielded on a wide range of ships and submarines, the nuclear version will probably be integrated on front-line nuclear-powered attack submarines to replace the S-10 Granat (SS-N-21 Sampson) SLCM. However, it is possible that the nuclear 3M-14 might also be integrated on some surface ships. It is estimated that there are about 810 warheads for non-strategic naval nuclear weapons, which include land-attack cruise missiles, anti-ship cruise missiles, anti-submarine rockets, depth charges, torpedoes, and naval aviation.

The 3M-55 Yakhont (SS-N-26) SLCM has been included in the estimate of Russia's non-strategic forces for January 2018 because NASIC designates it as 'nuclear possible' and notes that it is used to arm submarines, ships and coastal defence units (see table 6.3).[18] The 3M-55 is replacing the SS-N-9 (P-120), SS-N-12 (P-500) and SS-N-19 (P-700) anti-ship cruise missiles, which are dual-capable.[19]

The Russian Air Force has an estimated 498 weapons for use by Tu-22M3 (Backfire-C) intermediate-range bombers, Su-24M (Fencer-D) fighter-bombers and the new Su-34 (Fullback) fighter-bomber. A new air-to-surface missile (Kh-32) is in development to replace the Kh-22N (AS-4) used on the Tu-22M3. The Air Force also appears close to deploying a hypersonic air-launched ballistic missile, known as the Kh-47M2 Kinzhal.[20]

It is estimated that a total of around 373 nuclear warheads are in use by dual-capable air defence forces, the Moscow A-135 missile defence system and coastal defence units (although only a small number of warheads are assigned to the coastal defence units). All these defensive systems are being modernized.[21]

It is estimated that there are approximately 148 warheads assigned to Russian short-range ballistic missiles (SRBMs) and ground-launched cruise missiles (GLCMs). Ground-based non-strategic nuclear forces include the dual-capable Iskander-M (SS-26) SRBM, which is replacing the Tochka (SS-21) SRBM in 10 or more missile brigades. Deployment started in 2004

[17] There is considerable confusion about the designation of what is commonly referred to as the Kalibr missile. The Kalibr designation is actually not a missile but a family of weapons that, in addition to the 3M-14 (SSN30/A) land-attack versions, includes the 3M-54 (SS-N-27) anti-ship cruise missile and the 91R anti-submarine missile. For further detail see US Navy, Office of Naval Intelligence (ONI), *The Russian Navy: A Historic Transition* (ONI: Washington, DC, Dec. 2015), pp. 34–35; and US Air Force, National Air and Space Intelligence Center (note 6), p. 37.

[18] US Air Force, National Air and Space Intelligence Center (note 6), p 37.

[19] US Navy, Office of Naval Intelligence (note 17), p. 34.

[20] TASS, 'Russian Aerospace Forces test launch Kinzhal hypersonic missile', 11 Mar. 2018.

[21] TASS, 'Russia's missile early warning system helps ward off any threat', 29 June 2017; and Novichkov, N., 'Russian Defence Minister summarises modernisation progress in 2017', *Jane's Defence Weekly*, 4 Jan. 2018.

and, by the end of 2017, the army had received 10 Iskander-M brigades.[22] Facilities in the Kaliningrad oblast were nearing completion at the end of 2017 and were expected to receive the Iskander-M in early 2018.[23] Construction of a missile storage facility, similar to those constructed at other Iskander bases, has yet to be identified in Kaliningrad.

Army non-strategic nuclear weapons also include a new dual-capable GLCM, known as the 9M729 (SSC-8), which is a modified version of the 9M728 (SSC-7) used on the Iskander-M system.[24] According to the USA, the new cruise missile violates the 1987 Soviet–US Treaty on the Elimination of Intermediate-Range and Shorter-Range Missiles (INF Treaty).[25] Russia has rejected the accusation. Unconfirmed reports suggest that the 9M729 has been deployed in at least one garrison and it appears that further deployments are planned.[26]

[22] Interfax, 'Ten brigade sets of Iskander-M missile systems delivered to Russia's ground forces: commander', 22 Dec. 2017.

[23] Blank, S., 'Baltic build-up', *Jane's Intelligence Review*, vol. 29, no. 5 (May 2017), pp. 6–13.

[24] US Department of State, Bureau of Arms Control, Verification and Compliance, 'INF Treaty: at a glance', Fact Sheet, 8 Dec. 2017, p. 1.

[25] For a summary and other details of the INF Treaty see annex A, section III, in this volume. On the INF Treaty controversy see chapter 7, section II, in this volume; and Kile, S., 'Russian–US nuclear arms control and disarmament', *SIPRI Yearbook 2017*, pp. 477–78.

[26] Gordon, M., 'Russia deploys missile, violating treaty, and challenging Trump', *New York Times*, 14 Feb. 2017.

III. British nuclear forces

SHANNON N. KILE AND HANS M. KRISTENSEN

As of January 2018, the British nuclear stockpile consisted of approximately 215 warheads (see table 6.4). In its 2015 Strategic Defence and Security Review (SDSR), the British Government reaffirmed its plans to cut the size of the nuclear arsenal. The number of operationally available nuclear warheads has been reduced to no more than 120. The overall size of the nuclear stockpile, including non-deployed warheads, will decrease to no more than 180 by the mid-2020s.[1]

The British nuclear deterrent consists exclusively of a sea-based component: four Vanguard class Trident nuclear-powered ballistic missile submarines (SSBNs).[2] In a posture known as continuous at-sea deterrent, one British SSBN is on patrol at all times.[3] While the second and third SSBNs can be put to sea rapidly, the fourth would take longer because of the cycle of extensive overhaul and maintenance. In September 2017, the British Ministry of Defence (MOD) marked the 350th nuclear deterrence patrol conducted by Royal Navy submarines since 1969.[4]

The Vanguard class SSBNs can each be armed with up to 16 UGM-133 Trident II (D5) submarine-launched ballistic missiles (SLBMs). The United Kingdom does not own the missiles but leases them from a pool of 58 Trident SLBMs shared with the United States Navy. Under limits set out in the 2010 SDSR, when on patrol, the submarines are armed with no more than 8 operational missiles with a total of 40 nuclear warheads.[5] The missiles are kept on a reduced operational alert status and would require several days' notice to be able to fire.[6]

In January 2017 the Trident programme became the centre of controversy when a newspaper revealed that the British Government had not publicly disclosed the failed test launch of a Trident SLBM the previous summer, shortly before a vote in the British House of Commons on the Trident submarine successor programme (see below).[7] US officials confirmed that a missile test fired in June 2016 at a US test range off the Florida coast had

[1] British Government, *National Security Strategy and Strategic Defence and Security Review 2015: A Secure and Prosperous United Kingdom*, Cm 9161 (Stationery Office: London, Nov. 2015), para. 4.66.

[2] *HMS Vanguard* entered service in Dec. 1994, while the last in class, *HMS Vengeance*, entered service in Feb. 2001. Mills, C. and Dempsey, N., 'Replacing the UK's nuclear deterrent: progress of the Dreadnought class', Briefing Paper 8010, House of Commons Library, 19 June 2017, p. 7.

[3] British Government (note 1), para. 4.65.

[4] British Royal Navy, 'UK marks 350th UK deterrent patrol', Press release, 29 Sep. 2017.

[5] British Ministry of Defence, *Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review*, Cm 7948 (Stationery Office: London, Oct. 2010), pp. 5, 38.

[6] British Ministry of Defence, 'UK nuclear deterrent', Fact sheet, updated 24 Mar. 2016, p. 1.

[7] *Sunday Times*, 'Nuclear cover-up', 22 Jan. 2017.

deviated from its programmed course and crashed into the sea.[8] The MOD declined to comment on the cause of the failure, which marked its first unsuccessful Trident missile flight test.[9] The UK had previously conducted successful flight tests in 2000, 2005, 2009 and 2012.

The Trident submarine successor programme

In 2016 the House of Commons approved by a large majority a motion supporting the government's commitment to a 'like-for-like' replacement of the current Vanguard class SSBNs with four new SSBNs.[10] While recognizing that the UK's nuclear deterrent would 'remain essential to the UK's security today as it has for over 60 years', the motion did not give final approval for the new submarine programme. In order to control costs, the government had previously announced that approval of the investment would be made in stages rather than as a single 'main gate' decision.[11]

The new class of SSBN, which has been named Dreadnought, will carry the new life-extended Trident II D5LE SLBMs but will have a missile compartment that holds 12 missile launch tubes, a reduction from the 16 carried by the Vanguard class. As a cost-saving measure, a common missile compartment is being designed in cooperation with the US Navy that will also equip the latter's new Columbia class SSBNs.[12] The replacement of the Trident II (D5) missile is not part of the Dreadnought development and acquisition programme. However, the UK is participating in the US Navy's current programme to extend the service life of the Trident II (D5) missile to the early 2060s.[13]

The Dreadnought submarines were originally expected to begin to enter into service by 2028 but are now expected to enter into service in the early 2030s. The delay was part of the extended development and acquisition programme announced in the 2015 SDSR. The service life of the Vanguard class SSBNs was commensurately extended.[14]

[8] Star, B. and Masters, J., 'US official confirms Trident missile failure', CNN, 23 Jan. 2017.

[9] Kuenssberg, L., 'Trident: defence secretary refuses to give test missile details', BBC News, 23 Jan. 2017; and MacAskill, E., 'How did the Trident test fail and what did Theresa May know?', *The Guardian*, 23 Jan. 2017.

[10] British Parliament, House of Commons, 'UK's nuclear deterrent', *House of Commons Hansard*, col. 559, vol. 613, 18 July 2016; and Kuenssberg, L., 'MPs vote to renew Trident weapons system', BBC News, 19 July 2016.

[11] British Government (note 1), para. 4.75.

[12] British Ministry of Defence, 'The United Kingdom's future nuclear deterrent: the Dreadnought programme', 2017 Update to Parliament, 20 Dec. 2017; Allison, G., 'A guide to the Dreadnought class nuclear submarine', UK Defence Journal, 3 Jan. 2018; and US Navy, 'United States Navy: fact file: Trident II (D5) missile', 11 May 2017.

[13] Mills, C. and Brooke-Holland, L., 'The costs of the UK strategic nuclear deterrent', Briefing Paper 08166, House of Commons Library, 8 Dec. 2017, p. 9.

[14] Mills and Dempsey (note 2).

Table 6.4. British nuclear forces, January 2018

Type	Designation	No. deployed	Year first deployed	Range (km)[a]	Warheads x yield	No. of warheads
Submarine-launched ballistic missiles[b]						
D5	Trident II	48	1994	>7 400	1–3 x 100 kt[c]	215[d]

kt = kilotons.

[a] Range is for illustrative purposes only; actual mission range will vary according to flight profile and weapon loading.

[b] The operational nuclear-powered ballistic missile submarines (SSBNs) carry a reduced loading of no more than 8 Trident II missiles and 40 nuclear warheads. One submarine is on patrol at any given time.

[c] The British warhead is called the Holbrook, a modified version of the United States' W76-1 warhead, with a lower-yield option.

[d] Of the estimated 215 warheads currently in the stockpile, 120 are operationally available. The process to reduce the stockpile to 180 warheads by the mid-2020s is under way.

Sources: British Ministry of Defence, white papers, press releases and website; British House of Commons, *Hansard*, various issues; 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

The 2015 SDSR also postponed the replacement of the current British-manufactured Holbrook warhead for the Trident II missiles, at least until the late 2030s.[15] A decision on a new warhead is planned for the current parliament, and work continues on developing replacement options.[16] In the meantime, the British Atomic Weapons Establishment (AWE) has begun a programme to improve the performance and extend the life of the current Trident warhead—which is modelled on the US W76-1 warhead and incorporated into the US-produced Mk4A re-entry vehicle—in collaboration with US nuclear weapon laboratories.[17]

The MOD has estimated the cost of the Dreadnought programme to be £31 billion ($47.4 billion), including defence inflation over the life of the programme. It has set aside a further contingency of £10 billion ($15.3 billion) to cover possible increases.[18] In its 2017 update to parliament, the MOD confirmed that the programme remained within budget, and that £4.3 billion

[15] British Government (note 1), paras 4.72, 4.76.

[16] Mills and Dempsey (note 2), p. 3; and British Ministry of Defence (note 12).

[17] Nuclear Information Service, 'AWE: past, present, and possibilities for the future', June 2016, pp. 26–28.

[18] British Government (note 1), para. 4.76.

($5.5 billion) had been spent so far on the design and early manufacture phases.[19] However, there were reports during the year of significant cost overruns related to the submarine's next-generation nuclear reactor propulsion plant.[20] As the year ended, concerns were raised in parliament about the impact of the Trident successor programme on the affordability of the MOD's overall equipment plan.[21]

[19] British Ministry of Defence (note 12).

[20] Hookham, M. and Ripley, T., '"Red alert" over Trident reactor costs', *Sunday Times*, 23 July 2017.

[21] MacAskill, E., 'Trident may be removed from MoD budget, MPs told', *The Guardian*, 18 Dec. 2017; and Haynes, D., 'Defence cuts: take expensive Trident out of MoD budget, Hammond urged', *Sunday Times*, 25 Nov. 2017.

IV. French nuclear forces

SHANNON N. KILE AND HANS M. KRISTENSEN

France's nuclear arsenal contains approximately 300 warheads, a number that has remained stable in recent years. The warheads are earmarked for delivery by 48 submarine-launched ballistic missiles (SLBMs) and 54 air-launched cruise missiles, which provides France with both strategic and tactical nuclear capabilities.[1]

The main component of France's strategic nuclear deterrence force consists of four Triomphant class nuclear-powered ballistic missile submarines (SSBNs), each of which carries 16 submarine-launched ballistic missiles (SLBMs). The submarines began to enter operational service in 1997. The French Navy maintains a continuous at-sea deterrent posture, whereby one SSBN is on patrol at all times. The SSBN force is complemented by nuclear-capable land- and sea-based combat aircraft (see table 6.5).

France continues to modernize its Strategic Oceanic Force (Force Océanique Stratégique, FOST). The French Navy is modifying the Triomphant class submarines to carry the M51 SLBM, which has replaced the M45 missile.[2] As of December 2017, all four submarines had been upgraded to the M51.1 SLBM.[3] Each of the M51 missiles is capable of carrying up to six multiple independently targetable re-entry vehicle (MIRV) TN-75 warheads. The number of warheads on some of the missiles is believed to have been reduced in order to improve targeting flexibility.

The French SSBN fleet will be equipped with a longer-range version of the missile, the M51.2, by 2020. An M51.2 missile was successfully test launched under operational conditions from *Le Triomphant* in July 2016, after which the missile was certified and commissioned for service.[4] The French Minister of the Armed Forces, Florence Parly, confirmed in December 2017 that the M51.2 was operational.[5] The M51.2 is designed to carry the new, stealthier tête nucléaire océanique (TNO, oceanic nuclear warhead) with a

[1] Hollande, F., French President, 'Discours sur la dissuasion nucléaire: Déplacement auprès des forces aériennes stratégiques' [Speech on nuclear deterrence: visit to the strategic air forces], Istres, 19 Feb. 2015.

[2] French Navy, 'Modernisation de la force océanique stratégique: le SNLE Le Triomphant adapté au M51' [Modernization of the strategic naval force: the SSBN Le Triomphant adapted for M51], 13 Aug. 2015.

[3] French Ministry of the Armed Forces, 'Madame Florence Parly, Ministre des armées Visite de l'usine des Mureaux: Ariane Group' [Florence Parly, Minister of the Armed Forces, Visit to the Mureaux factory: Ariane Group], Mureaux, 14 Dec. 2017, p. 6.

[4] Groizeleau, V., 'DCNS débute la refonte du Téméraire' [DCNS begins the recasting of Le Téméraire], *Mer et Marine*, 8 Dec. 2016; and French Ministry of Defence, 'Le système d'armes SNLE Le Triomphant/M51 validé en conditions opérationnelles' [Le Triomphant/M51 SSBN weapon system validated under operational conditions], Press release, updated 20 Sep. 2016.

[5] French Ministry of the Armed Forces (note 3).

Table 6.5. French nuclear forces, January 2018

Type	No. deployed	Year first deployed	Range (km)[a]	Warheads x yield	No. of warheads
Land-based aircraft					
Mirage 2000N	20	1988	2 750	1 x up to 300 kt TNA	20
Rafale F3[b]	20	2010–11	2 000	1 x up to 300 kt TNA	20
Carrier-based aircraft					
Rafale MF3	10	2010–11	2 000	1 x up to 300 kt TNA	10
Submarine-launched ballistic missiles[c]					
M51.1	32	2010	>6 000	4–6 x 100 kt TN-75	160[d]
M51.2	16	2016	>6 000[e]	4–6 x 150 kt TNO	80
M51.3[f]	0	(2025)	>(6 000)	(up to 6 x 150 kt) TNO	0
Reserves					*10*[g]
Total					**300**[h]

. . = not available or not applicable; ( ) = uncertain figure; kt = kiloton; TNA = tête nucléaire aéroportée (airborne nuclear warhead); TNO = tête nucléaire océanique (oceanic nuclear warhead).

[a] Aircraft range is for illustrative purposes only; actual mission range will vary according to flight profile and weapon loading.

[b] The Mirage 2000N and Rafale carry the air-sol moyenne portée-améliorée (ASMP-A, improved medium-range air-to-surface) air-launched cruise missile. A mid-life upgrade of the ASMP-A is scheduled to begin in 2022.

[c] France has only produced enough submarine-launched ballistic missiles (SLBMs) to equip 3 operational nuclear-powered ballistic missile submarines (SSBNs); the 4th SSBN is out of service for overhaul and maintenance work at any given time.

[d] Although the M51 SLBM can carry up to 6 warheads, the number of warheads is believed to have been reduced on some of the missiles in order to improve targeting flexibility.

[e] The M51.2 has a 'much greater range' than the M51.1, according to the French Ministry of Defence.

[f] The M51.3 is under development and has not yet been deployed.

[g] The reserve includes 4 ASMP-A missiles.

[h] President François Hollande confirmed a cap of 300 warheads in a speech in Feb. 2015.

Sources: French Ministry of the Armed Forces, 'Madame Florence Parly, Ministre des armées Visite de l'usine des Mureaux: Ariane Group' [Florence Parly, Minister of the Armed Forces, Visit to the Mureaux factory: Ariane Group], Mureaux, 14 Dec. 2017; Hollande, F., French President, 'Discours sur la dissuasion nucléaire–Déplacement auprès des forces aériennes stratégiques' [Speech on nuclear deterrence: visit to the strategic air forces], Istres, 19 Feb. 2015; Sarkozy, N., French President, Speech on defence and national security, Porte de Versailles, 17 June 2008; Sarkozy, N., French President, 'Presentation of SSBM "Le Terrible"', Speech, Cherbourg, 21 Mar. 2008; Chirac, J., French President, Speech during visit to the Strategic Forces, Landivisiau–L'lle Longue, Brest, 19 Jan. 2006; French Ministry of Defence, various publications; French National Assembly, various defence bills; International Institute for Strategic Studies, *The Military Balance 2018* (Routledge: London, 2018); *Air Actualités*, various issues; *Aviation Week & Space Technology*, various issues; 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

reported yield of up to 150 kilotons.[6] France has commenced design work on a new M51.3 SLBM with improved accuracy.[7] It is scheduled to become operational in 2025.[8] France is also beginning preliminary design work on a third-generation SSBN, designated the SNLE 3G, which will be equipped with the M51.3 SLBM. The goal is to have an operational successor to the Triomphant class submarine by 2035.[9]

The airborne component of the French nuclear forces consists of two squadrons of the land-based Mirage 2000N and Rafale F3 combat aircraft. The remaining Mirage 2000Ns will be replaced by Rafale B aircraft by 2018.[10] The French Navy also operates a single squadron of Rafale MF3 aircraft deployed aboard its aircraft carrier the *Charles de Gaulle*.

The Rafale aircraft are equipped with the extended-range air-sol moyenne portée-améliorée (ASMP-A, improved medium-range air-to-surface) cruise missile, which entered service in 2009. There are 54 ASMP-As in France's nuclear arsenal.[11] A mid-life refurbishment programme for the ASMP-A is scheduled to begin in 2022.[12] The missiles are armed with the tête nucléaire aéroportée (TNA, airborne nuclear warhead), which has a reported yield of up to 300 kt. The French Ministry of Defence has initiated research on a successor missile, designated air-sol nucléaire (air-to-surface nuclear) fourth-generation (ASN-4G), with enhanced stealth and manoeuvrability to counter potential technological improvements in air defences.[13]

The French Government's commitment to the long-term modernization of the country's air- and sea-based nuclear deterrent forces will require a substantial increase in military nuclear expenditure.[14] The draft law on military

[6] French Senate, 'Avis présenté au nom de la Commission des Affaires Étrangères, de la Défense et des Forces Armées (1) sur le Projet de Loi de Finances pour 2014, adopté par L'Assemblée Nationale: Défense: equipement des forces et excellence technologique des industries de défense' [Opinions submitted on behalf of the committee on foreign affairs, defence and the armed forces (1) on the draft finance law for 2014, adopted by the National Assembly: defence: equipment of the forces and technological excellence of the defence industries], no. 158, 21 Nov. 2013, pp. 51–52.

[7] Loi relative à la programmation militaire pour les années 2014 à 2019 [Law on military planning for the years 2014 to 2019], French Law no. 2013-1168 of 18 Dec. 2013.

[8] French Ministry of the Armed Forces (note 3).

[9] Hollande (note 1); and Le Drian, J. Y., French Minister of Defence, 'Discours de clôture du colloque pour les 50 ans de la dissuasion' [Conference closing speech on the 50th anniversary of deterrence], French Ministry of Defence, Paris, 20 Nov. 2014.

[10] Hollande (note 1).

[11] Hollande (note 1).

[12] French Senate (note 6), p. 52.

[13] Le Drian (note 9); and Tran, P., 'France studies nuclear missile replacement', *Defense News*, 29 Nov. 2014.

[14] Guisnel, J., 'Le casse-tête financier de la modernisation de la dissuasion nucléaire' [The financial puzzle of modernization of nuclear deterrence], *Le Point*, 12 May 2016.

planning for 2019–25 has allocated €37 billion to maintain and modernize France's nuclear forces and infrastructure.[15] This is a significant increase on the €23 billion allocated to nuclear forces and infrastructure in the military planning law for 2014–19.[16]

[15] Agence France-Presse, 'La France va consacrer 295 milliards d'euros à sa défense entre 2019 et 2025' [France will spend €295 billion on defence between 2019 and 2025], *Le Figaro*, 7 Feb. 2018.

[16] Collin, J. M., 'Dissuasion nucléaire: l'obstination française' [Nuclear deterence: French obstinance], Group for Research and Information on Peace and Security (GRIP), Report, 19 Feb. 2015.

V. Chinese nuclear forces

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China maintains an estimated stockpile of about 280 nuclear warheads. The size of the stockpile has remained fairly stable over the past decade but is now increasing slowly. Around 234 warheads are assigned to China's land- and sea-based ballistic missiles. The remainder are assigned to non-operational forces, such as new systems in development, operational systems that may increase in number in the future and reserves. China may also have some residual nuclear air-strike capability (see table 6.6). China's nuclear warheads are believed to be 'de-mated' from their delivery vehicles—that is, stored separately and not available for immediate use.[1]

China continues to modernize its nuclear arsenal as part of a long-term programme to develop more survivable and robust forces consistent with its nuclear strategy of assured retaliation. The Chinese Government's stated goal is to 'strengthen [China's] capabilities for strategic deterrence and nuclear counterattack' by improving the 'strategic early warning, command and control, rapid reaction, and survivability and protection' capabilities of its nuclear forces.[2] In accordance with its self-declared minimum deterrence posture, China has focused on making qualitative improvements to its nuclear arsenal rather than significantly increasing its size.[3] These have included the development of new capabilities in response to the ballistic missile defences and precision-guided conventional strike systems being deployed by the United States and other countries.[4]

The Chinese Government has reorganized the country's nuclear forces as part of a larger move to restructure and modernize the military under a streamlined command system.[5] At the beginning of 2016 it established a new People's Liberation Army (PLA) Rocket Force (PLARF) as the fourth service in China's military. It has command responsibility for all three legs of China's nuclear triad and maintains custodial and operational control over the country's nuclear warheads.[6] While remaining the 'core force of strategic deterrence', the PLARF has also been put in charge of conventional

[1] Stokes, M. A., *China's Nuclear Warhead Storage and Handling System* (Project 2049 Institute: Arlington, VA, 12 Mar. 2010), p. 8; and Bin, L., 'China's potential to contribute to multilateral nuclear disarmament', *Arms Control Today*, vol. 41, no. 2 (Mar. 2011), pp. 17–21.

[2] Chinese State Council, *China's Military Strategy*, Defense White Paper, section 4 (Information Office of the State Council: Beijing, May 2015).

[3] Cunningham, F. and Fravel, M. T., 'Assuring assured retaliation: China's nuclear posture and US–China strategic stability', *International Security*, vol. 40, no. 2 (fall 2015), pp. 12–15.

[4] Saalman, L., 'China's calculus on hypersonic glide', SIPRI Commentary, 15 Aug. 2017.

[5] Chinese Ministry of National Defense, 'China establishes Rocket Force and Strategic Support Force', 1 Jan. 2016.

[6] Cordesman, A. and Kendall, J., *The PLA Rocket Force: Evolving Beyond the Second Artillery Corps (SAC) and Nuclear Dimension* (Center for Strategic and International Studies: Washington,

missile systems and tasked with strengthening China's medium- and long-range precision strike capabilities.[7]

Chinese officials have emphasized that the reorganization of the country's nuclear command structure does not herald changes to its nuclear policies or strategy. China remains committed to its no-first-use policy on nuclear weapons and has pledged to keep its 'nuclear capability at the minimum level required for safeguarding its national security'.[8] Nor has the Chinese Government given any indication that it will change its long-standing policy of maintaining nuclear forces at a low level of alert in peacetime. In recent years there have been internal discussions within the Chinese military about raising the alert level and moving towards a more launch-ready posture in order to ensure responsiveness.[9]

Land-based ballistic missiles

China's nuclear-capable land-based ballistic missile arsenal is undergoing gradual modernization as China replaces ageing silo-based, liquid-fuelled missiles with new mobile solid-fuelled models. China's shift towards more survivable mobile missiles has been motivated by concerns that US advances in intelligence, surveillance and reconnaissance (ISR) capabilities and in precision-guided conventional weapons pose a pre-emptive threat to fixed missile launch sites and supporting infrastructure.[10]

In its most recent annual report on Chinese military developments, the US Department of Defense (DOD) estimated that China deployed 75–100 intercontinental ballistic missiles (ICBMs) in 2017.[11] The silo-based, liquid-fuelled, two-stage Dong Feng (DF)-5A and the road-mobile, solid-fuelled, three-stage DF-31A are currently China's longest-range operational ICBMs and the only missiles in its arsenal capable of targeting all of the continental USA.

China is developing another longer-range ICBM: the road-mobile, solid-fuelled, three-stage DF-41, which has an estimated range in excess of 12 000 kilometres, making it capable of striking targets throughout the

DC, 13 Oct. 2016); and Tiezzi, S., 'The new military force in charge of China's nuclear weapons', The Diplomat, 5 Jan. 2016.

[7] Chinese Ministry of National Defense (note 5).

[8] Xinhau, 'China's nuclear policy, strategy consistent: spokesperson', 1 Jan. 2016.

[9] See Heginbotham, E. et al. (eds), *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States* (RAND Corporation: Santa Monica, CA, 2017), pp. 131–33; and Kulacki, G., 'China's military calls for putting its nuclear forces on alert', Union of Concerned Scientists, Jan. 2016.

[10] O'Connor, S., 'Sharpened Fengs: China's ICBM modernisation alters threat profile', *Jane's Intelligence Review*, vol. 27, no. 12 (Dec. 2015), pp. 44–49.

[11] US Department of Defense (DOD), *Military and Security Developments Involving the People's Republic of China 2017*, Annual Report to Congress (DOD: Washington, DC, May 2017), p. 31.

Table 6.6. Chinese nuclear forces, January 2018

Type/Chinese designation (US designation)	Launchers deployed	Year first deployed	Range (km)[a]	Warheads x yield	No. of warheads[b]
Land-based ballistic missiles[c]	*131*[d]				*186*
DF-4 (CSS-3)	5	1980	5 500	1 x 3.3 Mt	10
DF-5A (CSS-4 Mod 2)	10	2015	12 000	3 x 200–300 kt	10
DF-5B (CSS-4 Mod 3)	10	. .	. .	MIRV	30
DF-15 (CCS-6 Mod 1)	. .	1994	600	(1 x 10–50 kt)	. .[e]
DF-21 (CSS-5 Mods 1/2)	<50	1991	2 100[f]	1 x 200–300 kt	80
DF-21 (CSS-5 Mod 6)	. .	2016	2 100[f]	1 x 200–300 kt	. .
DF-26 (CSS-. .)	16	(2018)	>4 000	1 x 200–300 kt	16
DF-31 (CSS-10 Mod 1)	8	2006	>7 000	(1 x 200–300 kt)	8
DF-31A (CSS-10 Mod 2)	32	2007	>11 200	(1 x 200–300 kt)	32
DF-31AG (CSS-10 Mod . .)	. .	(2018)	. .	. .	. .
DF-41 (CSS-X-20)	. .	(2018)	(12 000)	MIRV	. .
Sea-based ballistic missiles[g]	48				*48*[h]
JL-2 (CSS-NX-14)	48	(2016)	>7 000	(1 x 200–300 kt)	48
Aircraft[i]	*(20)*				*(20)*
H-6 (B-6)	(20)	1965	3 100	1 x bomb/ (ALCM)	(20)
Attack (. .)	. .	1972–. .	. .	1 x bomb	. .
Cruise missiles[j]	. .				. .
Total					**280**[k]

. . = not available or not applicable; ( ) = uncertain figure; ALCM = air-launched cruise missile; kt = kiloton; Mt = megaton; MIRV = multiple independently targetable re-entry vehicle.

[a] Aircraft range is for illustrative purposes only; actual mission range will vary according to flight profile and weapon loading.

[b] Figures are based on estimates of 1 warhead per nuclear-capable launcher, except the MIRVed DF-5B, which is estimated to have 3 warheads. The DF-4 and DF-21 have reload missiles with additional warheads. The warheads are not thought to be deployed on launchers under normal circumstances but kept in storage facilities. All estimates are approximate.

[c] China defines missile ranges as short range, <1000 km; medium range, 1000–3000 km; long range, 3000–8000 km; and intercontinental range, >8000 km.

[d] The estimate only counts nuclear launchers. Some launchers might have 1 or more reloads of missiles.

[e] The US Central Intelligence Agency concluded in 1993 that China had ‘almost certainly’ developed a warhead for the DF-15, although it is unclear whether the capability was ever fielded.

[f] The range of the nuclear DF-21 variants (CSS-5 Mods 1, 2, and 6) is thought to be greater than the 1750 km normally reported.

[g] The JL-1 submarine-launched ballistic missile (SLBM), which dates from the 1980s, is no longer considered to be operational.

[h] The estimate is based on the assumption that warheads have been produced for the JL-2 SLBMs on China’s 4 Type 094 (Jin class) nuclear-powered ballistic missile submarines (SSBNs). The operational status of the missile is unclear.

[i] Chinese aircraft do not currently have a nuclear weapon delivery mission but it is assumed here that some residual nuclear capability exists.

[j] The US Air Force National Air and Space Intelligence Center’s (NASIC) 2013 assessment on ballistic and cruise missile threats listed the DH-10 ground-launched cruise missile as

'conventional or nuclear' and the US Air Force Global Strike Command's command brief from 2013 listed the CJ-20 as nuclear. These designations were not used in the NASIC 2017 assessment on ballistic and cruise missile threats but it is possible that China is developing nuclear-capable cruise missiles.

[k] As well as the *c*. 254 warheads thought to be assigned to operational forces (which includes the estimate for residual air-strike capability), a further 26 or so warheads are believed to be in storage or production to arm additional DF-26s and future DF-41 missiles. The total stockpile is believed to comprise *c*. 280 warheads and is slowly increasing.

Sources: US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat*, various years; US Air Force Global Strike Command, various documents; US Central Intelligence Agency, various documents; US Defense Intelligence Agency, various documents; US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, various years; International Institute for Strategic Studies, *The Military Balance 2018* (Routledge: London, 2018); Kristensen, H. M., Norris, R. S. and McKinzie, M. G., *Chinese Nuclear Forces and US Nuclear War Planning* (Federation of American Scientists/Natural Resources Defense Council: Washington, DC, Nov. 2006); 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; Google Earth; and authors' estimates.

continental USA.[12] It is also believed to be developing rail- and silo-based versions of the missile.[13] According to a Chinese state media report in 2017, the DF-41 could enter service in the first half of 2018.[14] The PLARF carried out a flight test of a DF-41 ICBM, apparently carrying two dummy warheads, near the South China Sea on 6 November 2017. This was the eighth test of the system since 2012.[15]

After many years of research and development, China has modified a small number of ICBMs to deliver nuclear warheads in multiple independently targetable re-entry vehicles (MIRVs). China has prioritized the deployment of MIRVs in order to improve its warhead penetration capabilities in response to advances in US and, to a lesser extent, Indian and Russian missile defences.[16] The missile identified as being MIRV-equipped is a modified version of the liquid-fuelled, silo-based DF-5A ICBM, the DF-5B.[17] In February 2017 the Chinese Ministry of National Defense acknowledged the test launch of a new variant of the missile, the DF-5C, and cited US media reports that it might carry as many as 10 warheads. However, it did not confirm the reports.[18] The deployment of MIRVs on the ageing DF-5 missiles may have

[12] Gady, F. S., 'China tests new missile capable of hitting entire United States', The Diplomat, 19 Aug. 2015.

[13] O'Halloran, J. (ed.), 'DF-41', *IHS Jane's Weapons: Strategic, 2015–16* (IHS Jane's: Coulsdon, 2015), pp. 21–22.

[14] Deng, X., 'Missile Dongfeng-41 matures considerably, will serve PLA within months: analysts', *Global Times*, 19 Nov. 2017.

[15] Gertz, B., 'China confirms DF-41 missile test', Washington Free Beacon, 6 Dec. 2017.

[16] Lewis, J., 'China's belated embrace of MIRVs', eds M. Krepon, T. Wheeler and S. Mason, *The Lure and Pitfalls of MIRVs: From the First to the Second Nuclear Age* (Stimson Center: Washington, DC, May 2016), pp. 95–99.

[17] US Department of Defense (note 11).

[18] Chinese Ministry of National Defense, 'China says its trial launch of DF-5C missile normal', Press release, 6 Feb. 2017; and Gertz, B., 'China tests missile with 10 warheads', Washington Free Beacon, 31 Jan. 2017.

been an interim arrangement necessitated by delays in the development of the DF-41 mobile ICBM.[19] Chinese analysts have speculated that the DF-41 can carry 6–10 MIRVed warheads , although there is significant uncertainty about the actual capability.[20] In 2017 Chinese state media reports indicated that a new variant of the DF-31A ICBM, the DF-31AG, might be armed with MIRVed warheads.[21] However, MIRVed warheads would require a significantly modified DF-31A missile, which according to the US Air Force National Air and Space Intelligence Center (NASIC) carries only one warhead.[22] The DF-31AG might therefore be an improved launcher for the existing DF-31A.

In 2016 China began deploying the new DF-26 intermediate-range ballistic missile (IRBM), which is capable of precision conventional or nuclear strikes against ground targets, as well as conventional strikes against naval targets. It has an estimated maximum range exceeding 4000 km and can reach targets in the western Pacific Ocean, including the US territory of Guam.[23]

The PLARF currently deploys one nuclear-capable medium-range ballistic missile. The DF-21 is a two-stage, solid-fuelled mobile missile that was first deployed in 1991. A modified version, the DF-21A, was deployed beginning in 1996.[24] Reports indicate that a new version of the DF-21 was deployed in 2016.[25]

Ballistic missile submarines

China continues to pursue its long-standing strategic goal of developing and deploying a sea-based nuclear deterrent. According to the US DOD's 2017 annual report on China's military power, the PLA Navy (PLAN) has commissioned four Type 094 nuclear-powered ballistic missile submarines (SSBNs).[26] A fifth submarine with a modified hull structure, designated by some sources as the Type 094A, may be under construction.[27]

[19] Minnick, W., 'Chinese parade proves Xi in charge', *Defense News*, 6 Sep. 2015.

[20] Deng (note 14); and Gertz (note 15).

[21] Fisher, R., 'DF-31AG ICBM can carry multiple warheads, claims China's state media', *Jane's Defence Weekly*, 16 Aug. 2017, p. 9.

[22] US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat* (NASIC: Wright-Patterson Air Force Base, OH, July 2017), p. 29.

[23] US Department of Defense (note 11), pp. 31, 49; and Wilson, J., 'China's expanding ability to conduct conventional missile strikes on Guam', US–China Economic and Security Review Commission, Staff Research Report, 10 May 2016, p. 8.

[24] O'Halloran, J. (ed.), 'DF-21', *IHS Jane's Weapons: Strategic, 2015–16* (IHS Jane's: Coulsdon, 2015), pp. 15–17. Two subsequent versions of the missile were designed for conventional anti-ship and anti-access/area-denial (A2/AD) missions.

[25] US Department of Defense (DOD), *Military and Security Developments Involving the People's Republic of China 2016*, Annual Report to Congress (DOD: Washington, DC, May 2016), p. 58.

[26] US Department of Defense (note 11), p. 24. The Type 094 SSBN is designated the Jin class by the United States and the North Atlantic Treaty Organization.

[27] Fisher, R., 'Images show possible new variant of China's Type 094 SSBN', *Jane's Defence Weekly*, 15 July 2016.

The Type 094 submarine can carry up to 12 three-stage, solid-fuelled JL-2 submarine-launched ballistic missiles (SLBMs). The JL-2 is a sea-based variant of the DF-31 ICBM. It has an estimated maximum range in excess of 7000 km and is believed to carry a single nuclear warhead. The PLAN is thought to have deployed the JL-2 SLBM. According to the US DOD's 2017 annual report, the four operational Type 094 SSBNs are equipped to carry up to 12 JL-2s.[28]

There has been considerable speculation about when a Type 094 SSBN carrying nuclear-armed JL-2 SLBMs will begin deterrence patrols. Although there were media reports in 2016 that China would soon commence patrols, there was no evidence in 2017 that they had begun.[29] In May 2017 the Director of the US Defense Intelligence Agency, Lieutenant General Vincent R. Stewart, stated that, when armed with a JL-2 SLBM, the PLAN's Type 094 SSBN 'will provide Beijing with its first sea-based nuclear deterrent'.[30] The annual US DOD reports on China's military power have been predicting since 2014 that commencement of submarine deterrence patrols was imminent, but the 2017 report does not refer to the issue. The routine deployment by China of nuclear weapons on its SSBNs would constitute a significant change to the country's long-held practice of keeping nuclear warheads in central storage in peacetime.

The PLAN is developing its next-generation SSBN, the Type 096. In 2017 the US DOD assessed that construction is likely to begin in the early 2020s.[31] Reports vary widely on the design parameters, but the new submarine is expected to be larger, quieter and equipped with more missile launch tubes than the Type 094. The Type 096 will reportedly be armed with a longer-range successor to the JL-2, the JL-3 SLBM.[32]

Aircraft and cruise missiles

According to the US DOD's 2017 annual report on China's military power, the PLA Air Force (PLAAF) 'does not currently have a nuclear mission'.[33] However, it is likely that some residual nuclear capability exists. In 2016 the

[28] US Department of Defense (note 11), p. 60.

[29] Borger, J., 'China to send nuclear-armed submarines into Pacific amid tensions with US', *The Guardian*, 26 May 2016.

[30] Stewart, V. R., Director, US Defense Intelligence Agency, Statement for the Record, 'Worldwide Threat Assessment', Armed Services Committee, US Senate, 23 May 2017, p. 10.

[31] US Department of Defense (note 11), p. 24.

[32] Dempsey, J. and Boyd, H., 'Beyond JL-2: China's development of a successor SLBM continues', Military Balance blog, International Institute for Strategic Studies, 7 Aug. 2017.

[33] US Department of Defense (note 11), p. 61. Medium-range combat aircraft were China's earliest means of delivering nuclear weapons and were used to conduct more than 12 atmospheric nuclear tests in the 1960s and 1970s. Norris, R., Burrows, A. S. and Fieldhouse, R. W., *Nuclear Weapons Databook, vol. 5: British, French, and Chinese Nuclear Weapons*, National Resources Defense Council (Westview Press: Boulder, CO, 1994), pp. 367–68.

PLAAF confirmed reports in the Chinese state media that it was building a long-range strategic bomber.[34] According to Chinese military sources, the aircraft, known as the H-20, will have stealth characteristics comparable to those of the US B-2 bomber.[35] The PLAAF was reportedly assigned a 'strategic deterrence' mission in 2012.[36] However, it has not confirmed whether the new aircraft will have a nuclear role.

The PLA currently deploys or is believed to be developing several types of ground-, sea- and air-launched cruise missiles. In its 2017 assessment of ballistic missile and cruise missile threats, NASIC did not list any Chinese cruise missile as being nuclear-capable.[37] In its previous assessment, published in 2013, NASIC had listed the ground-launched Donghai-10 (DH-10, also designated Changjian-10, CJ-10) as a 'conventional or nuclear' (dual-capable) system. In his statement in May 2017, Stewart noted that China was developing two new air-launched ballistic missiles, 'one of which may include a nuclear payload', but he did not identify the systems.[38]

[34] Zhao, L., 'PLA Air Force commander confirms new strategic bomber', *China Daily*, 2 Sep. 2016; and Zhao, L., 'Long-range bomber may be in China's plans', *China Daily*, 7 July 2015.

[35] Tate, A., 'Details emerge about requirement for China's new strategic bomber', *Jane's Defence Weekly*, 4 Jan. 2017, p. 4.

[36] US Department of Defense (note 25), p. 38.

[37] US Air Force, National Air and Space Intelligence Center (note 22).

[38] Stewart (note 30).

VI. Indian nuclear forces

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India is estimated to have a growing arsenal of 130–40 nuclear weapons (see table 6.7). This figure is based on calculations of India's inventory of weapon-grade plutonium and the number of operational nuclear-capable delivery systems. India is widely believed to be gradually expanding the size of its nuclear weapon stockpile as well as its infrastructure for producing nuclear warheads.

Military fissile material production

India's nuclear weapons are believed to be plutonium-based. The plutonium was produced at the Bhabha Atomic Research Centre (BARC) in Trombay, Mumbai, by the 40-megawatt-thermal (MW(t)) heavy water CIRUS reactor, which was shut down at the end of 2010, and the 100-MW(t) Dhruva heavy water reactor. India operates a plutonium reprocessing plant for military purposes at the BARC.[1]

India plans to build six fast breeder reactors by the 2030s, which will significantly increase its capacity to produce plutonium that could be used for building weapons.[2] An unsafeguarded 500-megawatt-electric (MW(e)) prototype fast breeder reactor (PFBR) is being built at the Indira Gandhi Centre for Atomic Research (IGCAR) complex at Kalpakkam, Tamil Nadu. The PFBR is expected to be commissioned in mid-2018 following a series of technical delays.[3] The IGCAR has announced that a fast reactor fuel cycle facility will be built at Kalpakkam to reprocess spent fuel from the PFBR and future fast breeder reactors. The plant is scheduled to be commissioned by 2022.[4]

India is currently expanding its uranium enrichment capabilities. It continues to enrich uranium at the small gas centrifuge facility at the Rattehalli Rare Materials Plant (RMP) near Mysore, Karnataka, to produce highly enriched uranium (HEU) for use as naval reactor fuel. India has begun construction of a new industrial-scale centrifuge enrichment plant, the Special Material Enrichment Facility (SMEF), at a site in Karnataka. This will be a dual-use facility that produces HEU for both military and civilian purposes.[5]

[1] International Panel on Fissile Material (IPFM), 'Facilities: reprocessing plants', 12 Feb. 2018.

[2] Ramana, M. V., 'A fast reactor at any cost: the perverse pursuit of breeder reactors in India', *Bulletin of the Atomic Scientists*, 3 Nov. 2016.

[3] *Deccan Herald*, 'Plan to make 6 N-reactors operational by 2039', 5 Nov. 2017.

[4] *The Hindu*, 'HCC to construct fuel processing facility at Kalpakkam', 7 Aug. 2017; and World Nuclear News, 'India awards contract for fast reactor fuel cycle facility', 8 Aug. 2017.

[5] Albright, D. and Kelleher-Vergantini, S., *India's Stocks of Civil and Military Plutonium and Highly Enriched Uranium, End 2014* (Institute for Science and International Security: Washington, DC,

Table 6.7. Indian nuclear forces, January 2018

Type (US/Indian designation)	Launchers deployed	Year first deployed	Range (km)[a]	Warheads x yield[b]	No. of warheads[c]
Aircraft[d]	*48*				*48*
Mirage 2000H	32	1985	1 850	1 x bomb	32
Jaguar IS	16	1981	1 600	1 x bomb	16
Land-based ballistic missiles	*60*				*60*
Prithvi-II	24	2003	250	1 x 12 kt	24
Agni-I	20	2007	>700	1 x 10–40 kt	20
Agni-II	8	2011	>2 000	1 x 10–40 kt	8
Agni-III	8	2014	>3 200	1 x 10–40 kt	8
Agni-IV	0	(2018)	>3 500	1 x 10–40 kt	0
Agni-V	0	(2020)	>5 200	1 x 10–40 kt	0
Sea-based ballistic missiles	*14*				*16*
Dhanush	2	(2013)	400	1 x 12 kt	4[e]
K-15 (B05)[f]	(12)[g]	(2018)	700	1 x 12 kt	(12)
K-4	(4)[g]	. .	3 500	1 x 10–40 kt	0
Cruise missiles	. .	. .	. .	. .	. .
Nirbhay ALCM[h]	. .	. .	(>700)	. .	. .
Total					**130–140**[i]

. . = not available or not applicable; ( ) = uncertain figure; ALCM = air-launched cruise missile; kt = kiloton.

[a] Aircraft range is for illustrative purposes only; actual mission range will vary according to flight profile and weapon loading. Missile payloads may have to be reduced in order to achieve maximum range.

[b] The yields of India's nuclear warheads are not known. The 1998 nuclear tests demonstrated yields of up to 12 kt. Since then it is possible that boosted warheads have been introduced with a higher yield, perhaps up to 40 kt. There is no open-source evidence that India has developed 2-stage thermonuclear warheads.

[c] Aircraft and several missile types are dual-capable. Cruise missile launchers carry more than 1 missile. This estimate counts an average of 1 warhead per launcher. Warheads are not deployed on launchers but kept in separate storage facilities. All estimates are approximate.

[d] Other fighter-bombers that could potentially have a secondary nuclear role include the Su-30MKI.

[e] Each Dhanush-equipped ship is thought to have possibly 1 reload.

[f] Some sources have referred to the K-15 submarine-launched ballistic missile (SLBM) as Sagarika, which was the name of the missile development project.

[g] The K-15 and K-4 use the same 4 launch tubes on the *INS Arihant* nuclear-powered ballistic missile submarine (SSBN). Each launch tube can hold either 3 K-15s contained in a triple-missile canister or 1 of the larger K-4 SLBMs (once the K-4 becomes operational). Thus, according to the US Air Force National Air and Space Intelligence Center (NASIC), the K-15 has 12 possible launchers and the K-4 has 4.

[h] There are reports that the Nirbhay, which is in development, might have a nuclear capability, but the Indian Government has not confirmed them.

[i] In addition to the 124 warheads estimated to be assigned to fielded launchers, warheads for additional Agni-III and future Agni-IV medium-range ballistic missiles may already have been produced giving a total stockpile of 130–40 warheads.

Sources: Indian Ministry of Defence, annual reports and press releases; International Institute for Strategic Studies, *The Military Balance 2018* (Routledge: London, 2018); US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat*, various years; Indian news media reports; 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

India's expanding centrifuge enrichment capacity is motivated by plans to build new naval propulsion reactors. However, the HEU produced at the plants could also hypothetically be used to manufacture thermonuclear or boosted-fission nuclear weapons.[6]

Aircraft

Aircraft constitute the most mature component of India's nuclear strike capabilities. The Indian Air Force has reportedly certified the Mirage 2000H multi-role combat aircraft for delivery of nuclear gravity bombs.[7] It is widely speculated that the Air Force's Jaguar IS fighter-bomber may also have a nuclear delivery role.[8]

Land-based missiles

Under its Integrated Guided Missile Development Programme, which began in 1983, India's Defence Research and Development Organization (DRDO) has developed two families of nuclear-capable, land-based ballistic missiles: the Prithvi family (although only the Prithvi-II is thought to be nuclear-capable), consisting of three types of road-mobile, short-range missiles; and the Agni family of longer-range, solid-fuelled ballistic missiles. The latter are designed to provide a quick-reaction nuclear capability and have taken over much of the Prithvi's nuclear delivery role.

The Agni-I is a single-stage, road-mobile missile that has a range of 700 kilometres. The nuclear-capable missile was first deployed in 2007. The Agni-II is a two-stage, solid-fuelled rail-mobile ballistic missile that can deliver a 1000-kilogram payload to a range exceeding 2000 km. The missile is in service with the Indian Army under the Strategic Forces Command (SFC), which is the body responsible for exercising operational command and control over the country's nuclear weapons. The Agni-II appears to have been plagued by technical problems; according to estimates in 2017,

2 Nov. 2015).

[6] Levy, A., 'India is building a top-secret nuclear city to produce thermonuclear weapons, experts say', *Foreign Policy*, 16 Dec. 2015.

[7] Kampani, G., 'New Delhi's long nuclear journey: how secrecy and institutional roadblocks delayed India's weaponization', *International Security*, vol. 38, no. 4 (spring 2014), pp. 94, 97–98.

[8] Cohen, S. and Dasgupta, S., *Arming Without Aiming: India's Military Modernization* (Brookings Institution Press: Washington, DC, 2010), pp. 77–78; and India Defence Update, 'SEPECAT Jaguar is India's only tactical nuclear carrying and ground attack aircraft', 13 Dec. 2016.

fewer than 10 launchers have been deployed.[9] On 4 May 2017 a user trial of an Agni-II failed when the test had to be aborted shortly after the launch of the missile. Indian defence officials did not comment on the cause of the failure.[10]

The Agni-III is a two-stage, rail-mobile missile with a range exceeding 3200 km. It was inducted into service in 2011 but, according to estimates in 2017, fewer than 10 launchers have been deployed.[11] On 27 April 2017 the SFC successfully test launched an Agni-III as part of a user training exercise. The missile was randomly chosen from the production lot.[12]

India is developing two longer-range ballistic missiles, the Agni-IV and the Agni-V, which would give it the capability to strike targets throughout China for the first time. The two-stage, road-mobile Agni-IV missile, which has a range of over 3500 km, is in development and undergoing user trials. An Agni-IV was successfully test launched by the SFC on 2 January 2017—the sixth consecutive successful test of the missile.[13]

The DRDO has prioritized the development of the three-stage, road-mobile Agni-V missile with a range in excess of 5000 km. Unlike the other Agni missiles, the Agni-V is designed to be stored in and launched from a new mobile canister system, an arrangement that, among other things, increases operational readiness by reducing the time required to place the missiles on alert in a crisis.[14] On 18 January 2018 an Agni-V missile was test launched from a sealed canister mounted on a truck located at the Integrated Test Range complex on Abdul Kalam Island (formerly Wheeler Island). The missile flew on a programmed trajectory for 4900 km. This was the third consecutive launch from a canister on a road-mobile launcher and the fifth successful flight test of the Agni-V since 2012.[15] The missile will undergo several additional test flights before it is inducted into service.

India is pursuing a technology development programme for multiple independently targetable re-entry vehicles (MIRVs). However, there are conflicting statements from DRDO officials as to whether India will deploy MIRVs on the Agni-V or a future Agni-VI with an even longer range.[16] The

[9] US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat* (NASIC: Wright-Patterson Air Force Base, OH, July 2017), p. 25.

[10] Pandit, R., 'Trial of Agni-II ballistic missile fails: sources', *Times of India*, 4 May 2017.

[11] US Air Force, National Air and Space Intelligence Center (note 9).

[12] *New Indian Express*, 'India successfully test fires nuclear capable Agni-III missile off Odisha coast', 27 Apr. 2017.

[13] Subramanian, T. S., 'Agni-IV test a "grand success"', *The Hindu*, 2 Jan. 2017.

[14] Aroor, S., 'New chief of India's military research complex reveals brave new mandate', *India Today*, 13 July 2013.

[15] Gurung, S. K., 'India successfully test-fires nuclear-capable Agni-5 ballistic missile', *Economic Times*, 18 Jan. 2018.

[16] Basrur, R. and Sankaran, J., 'India's slow and unstoppable move to MIRV', eds M. Krepon, T. Wheeler and S. Mason, *The Lure and Pitfalls of MIRVs: From the First to the Second Nuclear Age* (Stimson Center: Washington, DC, May 2016), pp. 149–76.

Agni-VI is in the design phase and awaiting approval but may begin testing as early as 2018.

Sea-based missiles

India continues to develop the naval component of its triad of nuclear forces in pursuit of an assured second-strike capability. It is building a fleet of up to five nuclear-powered ballistic missile submarines (SSBNs) as part of its four-decade-old Advanced Technology Vessel project.

India's first indigenously built SSBN, the *INS Arihant*, was launched in 2009 and formally commissioned in 2016.[17] According to Indian media reports in January 2018, the *Arihant* had been out of service for 10 months for repairs after its propulsion compartment suffered significant flood damage when a hatch was left open by mistake while leaving harbour.[18] A second SSBN, the *INS Arighat* (originally thought to have been named *Aridhaman*), was launched in November 2017.[19] Construction work has reportedly begun on a third and fourth submarine, with expected launch dates in 2020 and 2022, respectively.[20]

The *Arihant* is equipped with a four-tube vertical launch system and will carry up to 12 two-stage, 700-km range K-15 (also known as B05) submarine-launched ballistic missiles (SLBMs). Unconfirmed reports have claimed that the *Arighat* is equipped with eight launch tubes to carry up to 24 K-15 missiles (three per launch tube), but the United States Air Force National Air and Space Intelligence Center made no mention of additional launch tubes on a second submarine in its 2017 assessment of ballistic missile and cruise missile threats.[21] In November 2015 the SFC and the DRDO conducted an underwater ejection test of a dummy missile, reportedly from the *Arihant*, but the maiden flight test of a K-15 from the submarine had not been conducted as of the end of 2017.[22]

The DRDO is developing a two-stage, 3500-km range SLBM, known as the K-4, that will eventually replace the K-15.[23] The *Arihant* will be capable of carrying four K-4s but the *Arighat* and subsequent SSBNs will be able

[17] Dinakar, P., 'Now, India has a nuclear triad', *The Hindu*, 18 Oct. 2016.

[18] Peri, D. and Joseph, J., '*INS Arihant* left crippled after "accident" 10 months ago', *The Hindu*, 8 Jan. 2018.

[19] Gady, F. S., 'The Indian Navy's second nuclear-powered ballistic missile submarine was quietly launched in November', The Diplomat, 13 Dec. 2017.

[20] Unnithan, S., 'A peek into India's top secret and costliest defence project, nuclear submarines', *India Today*, 10 Dec. 2017.

[21] Indian Defence Update, 'India's 2nd nuclear submarine "*INS Aridhaman*" to be deadlier than *INS Arihant*', 27 Dec. 2016; and US Air Force, National Air and Space Intelligence Center (note 9).

[22] Indian Defence News, 'Confirmed: first ejection test of K-15 (B-05) SLBM from *INS Arihant* SSBN', 28 Nov. 2015.

[23] Jha, S., 'India's undersea deterrent', The Diplomat, 30 Mar. 2016; and US Air Force, National Air and Space Intelligence Center (note 9), p. 33.

to carry eight. On 17 December 2017 the test launch of a K-4 missile from an underwater pontoon in the Bay of Bengal failed. Indian officials did not release information on the cause of the failure.[24] The missile had previously been tested four times, including a test launch from the *Arihant* in 2016.[25] The DRDO is currently developing a K-5 SLBM, which is expected to have a range in excess of 5000 km, and has announced plans to develop a longer-range K-6 SLBM.[26]

The nuclear-capable Dhanush missile is a naval version of the Prithvi-II that is launched from a surface ship. It can reportedly carry a 500-kg warhead to a maximum range of 400 km and is designed to be able to hit both sea- and shore-based targets.[27] The Dhanush has been inducted into service with the Indian Navy on two Sukanya class coastal patrol ships based at the naval base near Karwar on the west coast of India.

Cruise missiles

The DRDO has been developing a long-range subsonic cruise missile since 2004. Known as the Nirbhay, it has a range exceeding 700 km and is believed to have ground-, sea- and air-launched versions. Development of the missile has been delayed by technical problems with its flight control software and navigation system. Following a second consecutive failed test flight in December 2016, sources within the DRDO indicated that the Nirbhay programme was likely to be terminated.[28] However, on 7 November 2017 the Indian Ministry of Defence announced that the DRDO had conducted a successful test flight of a Nirbhay cruise missile at the Integrated Test Range on Abdul Kalam Island that 'had achieved all the mission objectives'.[29] The Indian Government has not confirmed media reports that the Nirbhay has the capability to carry nuclear warheads.[30]

[24] Pubby, M., 'Setback for Indian missile programme: two failures in a week, submarine version stuck', *The Print*, 24 Dec. 2017.

[25] Rout, H. K., 'Maiden test of undersea K-4 missile from Arihant submarine', *New Indian Express*, 9 Apr. 2016.

[26] Unnithan (note 20); and Jha (note 23).

[27] Mallikarjun, Y., 'Dhanush missile successfully test-fired from ship', *The Hindu*, updated 3 Nov. 2016; and US Air Force, National Air and Space Intelligence Center (note 9), p. 33.

[28] Subramanian, T. S., 'Nirbhay missile test "an utter failure"', *The Hindu*, 21 Dec. 2016; and Rout, H. K., 'DRDO's cruise missile project Nirbhay on verge of closure', *New Indian Express*, 23 Dec. 2016.

[29] Indian Ministry of Defence, Press Information Bureau, 'DRDO conducts successful flight trial of "Nirbhay" sub-sonic cruise missile', 7 Nov. 2017.

[30] Pandit, R., 'India successfully tests its first nuclear-capable cruise missile', *Times of India*, 8 Nov. 2017; and Gady, F. S., 'India successfully test fires indigenous nuclear-capable cruise missile', The Diplomat, 8 Nov. 2017.

VII. Pakistani nuclear forces

SHANNON N. KILE AND HANS M. KRISTENSEN

Pakistan continues to prioritize the development and deployment of new nuclear weapons and delivery systems as part of its 'full spectrum deterrence posture' vis-à-vis India. It is estimated that Pakistan possessed 140–50 warheads as of January 2018 (see table 6.8). Pakistan's nuclear weapon arsenal is likely to expand significantly over the next decade, although estimates of the increase in warhead numbers vary considerably.[1]

Pakistan is believed to be gradually increasing its military fissile material holdings, which include both plutonium and highly enriched uranium (HEU) (see section X). Pakistan's plutonium production complex is located at Khushab in the province of Punjab. It consists of four operational heavy water nuclear reactors and a heavy water production plant.[2] Pakistan appears to be increasing its capacity to reprocess spent nuclear fuel—that is, to chemically separate plutonium from irradiated reactor fuel. A small reprocessing plant has been expanded at the New Laboratories facility of the Pakistan Institute of Science and Technology (PINSTECH) near Rawalpindi. A larger reprocessing plant has been constructed at the Chashma Nuclear Power Complex in Punjab and may already be operational.[3]

Uranium enrichment takes place at the gas centrifuge plant in the Khan Research Laboratories (KRL) complex at Kahuta in Punjab and at a smaller plant located at Gadwal, also in Punjab. A new uranium enrichment centrifuge plant may be under construction in the KRL complex at Kahuta.[4] Pakistan's capacity to produce HEU for nuclear weapons is constrained by its limited indigenous supply of natural uranium.[5]

Aircraft

The Pakistan Air Force's (PAF) Mirage III and Mirage V combat aircraft are the most likely aircraft to have been given a nuclear delivery role. The Mirage III has been used for developmental test flights of the nuclear-capable

[1] Dalton, T. and Krepon, M., *A Normal Nuclear Pakistan* (Stimson Center and Carnegie Endowment for International Peace: Washington, DC, Aug. 2015); and Kristensen, H. M. and Norris, R., 'Pakistani nuclear forces, 2016', *Bulletin of the Atomic Scientists*, vol. 72, no. 6 (Oct.–Nov. 2016), pp. 368–76.

[2] Burkhard, S., Lach, A. and Pabian, F., 'Khushab update', Institute for Science and International Security, Report, 7 Sep. 2017.

[3] Albright, D. and Kelleher-Vergantini, S., 'Pakistan's Chashma plutonium separation plant: possibly operational', Institute for Science and International Security, Imagery Brief, 20 Feb. 2015.

[4] Cartwright, C. and Dewey, K., 'Spin strategy: likely uranium facility identified in Pakistan', *Jane's Intelligence Review*, vol. 28, no. 11 (Nov. 2016), pp. 48–52.

[5] International Panel on Fissile Material (IPFM), 'Pakistan may be building a new enrichment facility', IPFM Blog, 16 Sep. 2016.

Table 6.8. Pakistani nuclear forces, January 2018

Type (US/Pakistani designation)	Launchers deployed	Year first deployed	Range (km)[a]	Warheads x yield[b]	No. of warheads[c]
Aircraft	*36*				*36*
F-16A/B[d]	24	1998	1 600	1 x bomb	24
Mirage III/V	12	1998	2 100	1 x bomb or Ra'ad ALCM	12
Land-based missiles	*102*[e]				*102*
Abdali (Hatf-2)	10	(2015)	200	1 x 12 kt	10
Ghaznavi (Hatf-3)	16	2004	290	1 x 12 kt	16
Shaheen-I (Hatf-4)	16	2003	750	1 x 12 kt	16
Shaheen-IA (Hatf-4)[f]	. .	(2017)	900	1 x 12 kt	. .
Shaheen-II (Hatf-6)	12	2014	1 500	1 x 10–40 kt	12
Shaheen-III (Hatf-6)[g]	. .	(2018)	2 750	1 x 10–40 kt	. .
Ghauri (Hatf-5)	24	2003	1 250	1 x 10–40 kt	24
Nasr (Hatf-9)	24	(2013)	60–70	1 x 12 kt	24
Ababeel (Hatf-. .)	0	. .	2 200	MIRV or MRV	0[h]
Cruise missiles	*12*				*12*
Babur GLCM (Hatf-7)	12	(2014)	350[i]	1 x 12 kt	12
Babur-2 GLCM (Hatf-. .)	. .	. .[j]	700	1 x 12 kt	. .
Babur-3 SLCM (Hatf-. .)	0	. .[k]	450	1 x 12 kt	0
Ra'ad ALCM (Hatf-8)	. .	(2017)	350	1 x 12 kt	. .
Ra'ad-2 ALCM (Hatf-. .)	. .	(2018)	>350	1 x 12 kt	. .
Total					**140–150**

. . = not available or not applicable; ( ) = uncertain figure; ALCM = air-launched cruise missile; GLCM = ground-launched cruise missile; kt = kiloton; MIRV = multiple independently targetable re-entry vehicle; MRV = multiple re-entry vehicle; SLCM = sea-launched cruise missile.

[a] Aircraft range is for illustrative purposes only; actual mission range will vary according to flight profile and weapon loading. Missile payloads may have to be reduced in order to achieve maximum range.

[b] The yields of Pakistan's nuclear warheads are not known. The 1998 nuclear tests demonstrated a yield of up to 12 kt. Since then it is possible that boosted warheads have been introduced with higher yields. There is no open-source evidence that Pakistan has developed 2-stage thermonuclear warheads.

[c] Aircraft and several missile types are dual-capable. Cruise missile launchers carry more than 1 missile. This estimate counts an average of 1 warhead per launcher. Warheads are not deployed on launchers but kept in separate storage facilities.

[d] There are unconfirmed reports that some of the 40 F-16 combat aircraft procured from the USA in the 1980s were modified by Pakistan for a nuclear delivery role.

[e] Some launchers might have 1 or more reloads of missiles.

[f] It is unclear whether the Shaheen-IA has the same designation as the Shaheen-I.

[g] It is unclear whether the Shaheen-III has the same designation as the Shaheen-II.

[h] According to the Pakistani armed forces, the missile is 'capable of delivering multiple warheads', using MIRV technology.

[i] The Pakistani Government claims the range is 700 km, double the range reported by the US Air Force, National Air and Space Intelligence Center (NASIC).

[j] The Babur-2, which was first test launched on 14 Dec. 2016, is an improved version of the original Babur GLCM.

[k] The first test launch of a Babur-3 SLCM was carried out from an underwater platform on 9 Jan. 2017.

Sources: Pakistani Ministry of Defence; various documents; US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat*, various years; International Institute for Strategic Studies, *The Military Balance 2018* (Routledge: London, 2018); 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

Ra'ad air-launched cruise missile (ALCM), while the Mirage V is believed to have been given a strike role with nuclear gravity bombs.[6]

Pakistan is acquiring the JF-17 Thunder aircraft, a multi-role lightweight fighter jointly developed with China, to replace the ageing Mirage aircraft. There are reports that the PAF intends to integrate the dual-capable Ra'ad ALCM (see below) on to the JF-17, although whether this signifies a nuclear delivery role for the aircraft is unclear.[7]

Pakistan procured 40 F-16A/B combat aircraft from the United States in the mid-1980s. There are unconfirmed reports that some of these aircraft were modified by Pakistan for a nuclear delivery role.[8]

Land-based missiles

Pakistan is expanding its nuclear-capable ballistic missile arsenal, which consists of a series of short- and medium-range systems. It currently deploys the Ghaznavi (also designated Hatf-3) and Shaheen-I (Hatf-4) solid-fuelled, road-mobile short-range ballistic missiles (SRBMs). An extended-range version of the Shaheen-I, the Shaheen-IA, is still in development.

Pakistan deploys two types of nuclear-capable medium-range ballistic missile (MRBM): the liquid-fuelled, road-mobile Ghauri (Hatf-5) with a range of 1250 kilometres; and the two-stage, solid-fuelled, road-mobile Shaheen-II (Hatf-6) with a range of 1500 km.[9] A longer-range variant, the Shaheen-III, is currently in development and was first test launched in 2015.[10] The missile has a declared range of 2750 km, making it the longest-range system to be tested by Pakistan to date.

Pakistan's National Defence Complex is developing a new MRBM, the nuclear-capable Ababeel, based on the Shaheen-III's airframe and solid-fuel motors.[11] On 24 January 2017 Pakistan announced that the first test launch

[6] Kerr, P. and Nikitin, M. B., *Pakistan's Nuclear Weapons*, Congressional Research Service (CRS) Report for Congress RL3248 (US Congress, CRS: Washington, DC, 1 Aug. 2016), p. 7.

[7] Fisher, R., 'JF-17 Block II advances with new refuelling probe', *Jane's Defence Weekly*, 27 Jan. 2016; and Ansari, U., 'Despite missile integration, nuke role unlikely for Pakistan's JF-17', *Defense News*, 7 Feb. 2013.

[8] For further analysis on the role of the F-16 see Kristensen and Norris (note 1).

[9] US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat* (NASIC: Wright-Patterson Air Force Base, OH, July 2017), p. 25.

[10] Pakistan Inter Services Public Relations, 'Shaheen 3 missile test', Press Release PR-61/2015-ISPR, 9 Mar. 2015.

[11] The National Defence Complex (also referred to as the National Development Complex or National Development Centre) and its supervisory organization, the National Engineering and Scientific Commission (NESCOM), are the principal bodies responsible for Pakistan's missile

of the Ababeel, aimed at 'validating various design and technical parameters of the weapon system', had been successfully carried out.[12] According to the armed forces' press service, the missile is 'capable of delivering multiple warheads, using Multiple Independent Re-entry Vehicle (MIRV) technology' and is being developed to '[ensure the] survivability of Pakistan's ballistic missiles in the growing regional Ballistic Missile Defence (BMD) environment'.[13] Pakistan's National Defence Complex is reportedly developing the technology to deploy MIRV-equipped missiles as a countermeasure to India's prospective ballistic missile defence system.[14]

Pakistan has prioritized the development of nuclear-capable short-range missiles that appear to be intended for tactical nuclear roles and missions. In pursuing its 'full-spectrum deterrence' posture, Pakistan's defence planners have given particular attention to nuclear options for responding to an Indian military doctrine that envisages carrying out rapid but limited conventional attacks on Pakistani territory using forward-deployed forces.[15]

Pakistan has deployed two land-based, single-stage ballistic missiles capable of delivering compact, low-yield nuclear warheads as well as conventional warheads: the 200-km range, road-mobile Abdali (Hatf-2); and the 60-km range, road-mobile Nasr (Hatf-9). The Nasr system was initially tested in 2011 using a single-tube launcher but has subsequently appeared with a mobile multi-tube launcher that can fire a four-missile salvo.[16] An improved 70-km range version was test launched on 5 July 2017.[17]

Sea-based cruise missiles

As part of its efforts to achieve a secure second-strike capability, Pakistan is seeking to match India's nuclear triad by developing a sea-based nuclear force. On 9 January 2017 Pakistan announced that the first test launch of a submarine-launched cruise missile (SLCM), the Babur-3, had been successfully carried out from 'an underwater, mobile platform' deployed in the Indian Ocean.[18] The missile was said to be a sea-based variant of the

development programmes. Nuclear Threat Initiative, 'National Defence Complex', updated 27 Sep. 2011.

[12] Pakistan Inter Services Public Relations, Press Release PR-34/2017-ISPR, 24 Jan. 2017.

[13] Pakistan Inter Services Public Relations (note 12).

[14] Tasleem, S., 'No Indian BMD for no Pakistani MIRVS', Stimson Center, Off Ramps Initiative, Paper, 2 Oct. 2017.

[15] Ahmed, M., 'Pakistan's tactical nuclear weapons and their impact on stability', Carnegie Endowment for International Peace, Regional Insight, 30 June 2016; and Sankaran, J., 'Pakistan's battlefield nuclear policy: a risky solution to an exaggerated threat', *International Security*, vol. 39, no. 3 (winter 2014/15), pp. 118–51.

[16] Ansari, U., 'Pakistan holds parade after 7-year break', *Defense News*, 24 Mar. 2015; and Haroon, A., 'Pakistan test fires Hatf-IX', Dispatch News Desk, 26 Sep. 2014.

[17] Pakistan Inter Services Public Relations, Press Release PR-344/2017-ISPR, 5 July 2017.

[18] Pakistan Inter Services Public Relations, Press Release PR-10/2017-ISPR, 9 Jan. 2017.

Babur-2 ground-launched cruise missile (GLCM) and to have a range of 450 km (see below). It is most likely to be deployed on the Pakistan Navy's diesel-electric Agosta class submarines, which are currently in service.[19]

In 2012 Pakistan established a Naval Strategic Force Command as the 'custodian of the nation's second-strike capability'.[20] It is unclear whether the Pakistan Navy has developed a command and control infrastructure to manage a submarine-based nuclear force or custodial arrangements for nuclear warheads deployed on patrol.[21]

Ground- and air-launched cruise missiles

In addition to the sea-based Babur-3 SLCM, Pakistan continues to develop two types of nuclear-capable cruise missile as an integral part of its pursuit of a full-spectrum deterrence posture. The 700-km range Babur-2 is an improved version of the Babur (Hatf-7) GLCM that incorporates stealth design features. It was first test launched in 2016.[22] The Ra'ad (Hatf-8) ALCM, which Pakistan claims can carry either conventional or nuclear warheads to a range of over 350 km, has been flight tested seven times since 2007.[23] Although the initial tests were conducted using a PAF Mirage III combat aircraft, some reports indicate that the missile may have been integrated with the JF-17 aircraft.[24] In 2017 Pakistan revealed an improved version, the Ra'ad-2 ALCM, which reportedly has an extended range.[25]

[19] See e.g. Khan, F. H., 'Going tactical: Pakistan's nuclear posture and implications for stability', Institut Français des Relations Internationales (IFRI), *Proliferation Papers*, no. 53, Sep. 2015, p. 41.

[20] Iskander, R., *Murky Waters: Naval Nuclear Dynamics in the Indian Ocean* (Carnegie Endowment for International Peace: Washington, DC, Mar. 2015), p. 17.

[21] Panda, A. and Narang, V., 'Pakistan tests new sub-launched nuclear-capable cruise missile: what now?', The Diplomat, 10 Jan. 2017.

[22] Pakistan Inter Services Public Relations, Press Release PR-482/2016-ISPR, 14 Dec. 2016.

[23] Pakistan Inter Services Public Relations, Press Release PR-16/2016-ISPR, 19 Jan. 2016.

[24] Fisher (note 7).

[25] Khan, B., 'Pakistan officially unveils extended range Ra'ad 2 air-launched cruise missile', Quwa Defence News and Analysis Group, 23 Mar. 2017.

VIII. Israeli nuclear forces

SHANNON N. KILE AND HANS M. KRISTENSEN

Israel continues to maintain its long-standing policy of nuclear opacity: it neither officially confirms nor denies that it possesses nuclear weapons.[1] Like India and Pakistan, Israel has never been a party to the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty, NPT).[2]

Declassified US and Israeli government documents indicate that Israel began building a stockpile of nuclear weapons in the early 1960s, using plutonium produced by the Israel Research Reactor 2 (IRR-2) at the Negev Nuclear Research Center near Dimona.[3] There is little publicly available information about the operating history and power capacity of the unsafeguarded IRR-2. The ageing heavy water reactor remained operational in 2017 despite the existence of a number of identified structural problems.[4] It may now be operated primarily to produce tritium.[5]

It is estimated that Israel has approximately 80 nuclear weapons (see table 6.9). Of these, approximately 30 are gravity bombs for delivery by combat aircraft. Several bunkers thought to contain nuclear bombs are located at the Tel Nof airbase south of Tel Aviv. The remaining 50 weapons are for delivery by land-based ballistic missiles. Israel's arsenal includes solid-fuelled, two-stage Jericho II medium-range ballistic missiles, which are believed to be based, along with their mobile transporter-erector-launchers, in caves at an airbase near Zekharia in the Negev desert.[6] A three-stage Jericho III intermediate-range ballistic missile, with a range exceeding 4000 kilometres, was declared operational in 2011.[7] In 2013 Israel tested a Jericho III with a new motor that some sources believe may give the missile an intercontinental range—that is, a range exceeding 5500 km.[8] Its development status is unknown.

There are numerous unconfirmed reports that Israel has equipped its fleet of German-built Dolphin class diesel-electric submarines with

[1] On the role of this policy in Israel's national security decision making see Cohen, A., 'Israel', eds H. Born, B. Gill and H. Hänggi, SIPRI, *Governing the Bomb: Civilian Control and Democratic Accountability of Nuclear Weapons* (Oxford University Press: Oxford, 2010).

[2] For a summary and other details of the NPT see annex A, section I, in this volume.

[3] For a history of Israel's nuclear weapon programme see Cohen, A., *The Worst-kept Secret: Israel's Bargain with the Bomb* (Columbia University Press: New York, 2010).

[4] *Times of Israel*, 'Government has no plans to close aging Dimona nuclear facility', 19 Sep. 2017.

[5] International Panel on Fissile Material (IPFM), *Global Fissile Material Report 2015: Nuclear Weapon and Fissile Material Stockpiles and Production* (IPFM: Princeton, NJ, Dec. 2015), p. 26.

[6] O'Halloran, J. (ed.), 'Jericho missiles', *IHS Jane's Weapons: Strategic, 2015–16* (IHS Jane's: Coulsdon, 2015), p. 53.

[7] O'Halloran, ed. (note 6).

[8] Ben David, A., 'Israel tests Jericho III missile', *Aviation Week & Space Technology*, 22 July 2013.

Table 6.9. Israeli nuclear forces, January 2018

Type	Range (km)[a]	Payload (kg)	Status	No. of warheads
Aircraft[b]				. .
F-16A/B/C/D/I Falcon	1 600	5 400	205 aircraft in the inventory; some are believed to be equipped for nuclear weapon delivery	30
Land-based ballistic missiles[c]				. .
Jericho II	1 500–1 800	750–1 000	*c.* 25 missiles; first deployed in 1990	25
Jericho III	>4 000	1 000–1 300	First became operational in 2011–15 and is gradually replacing Jericho II	25
Cruise missiles				. .
. .	. .	. .	Dolphin class diesel-electric submarines are rumoured to have been equipped with nuclear-armed SLCMs; denied by Israeli officials	. .
Total				**80**[d]

. . = not available or not applicable; SLCM = sea-launched cruise missile.

[a] Aircraft range is for illustrative purposes only; actual mission range will vary. Missile payloads may have to be reduced in order to achieve maximum range.

[b] Some of Israel's 25 F-15I aircraft may also have a long-range nuclear delivery role.

[c] The Jericho III is based on the Shavit space launch vehicle, which if converted to a ballistic missile, could deliver a 775-kg payload to a distance of 4000 km.

[d] SIPRI's estimate, which is approximate, is that Israel has 80 stored warheads. There is significant uncertainty about the size of Israel's nuclear arsenal and its warhead capabilities.

Sources: Cohen, A., *The Worst-kept Secret: Israel's Bargain with the Bomb* (Columbia University Press: New York, 2010); Cohen, A. and Burr, W., 'Israel crosses the threshold', *Bulletin of the Atomic Scientists*, vol. 62, no. 3 (May/June 2006); Cohen, A., *Israel and the Bomb* (Columbia University Press: New York, 1998); Albright, D., Berkhout, F. and Walker, W., SIPRI, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies* (Oxford University Press: Oxford, 1997); *IHS Jane's Strategic Weapon Systems*, various issues; International Institute for Strategic Studies, *The Military Balance 2018* (Routledge: London, 2018); Fetter, S., 'Israeli ballistic missile capabilities', *Physics and Society*, vol. 19, no. 3 (July 1990); 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

nuclear-armed sea-launched cruise missiles, giving it a sea-based second-strike capability. German and Israeli officials have consistently denied these reports. Israel has purchased six Dolphin class submarines, five of which have been delivered to Israel. The sixth submarine is scheduled to be delivered by the end of 2019.[9] In October 2017 the German Government announced that it had agreed to subsidize the sale of three new submarines to Israel to replace the first three Dolphin class boats, which were delivered in the late 1990s.[10] The new submarines will enter service from 2027.

[9] Opall-Rome, B., 'Israeli Navy backs Netanyahu's submarine scheme', *Defense News*, 19 Apr. 2017.

[10] Reuters, 'Deutschland beteiligt sich finanziell an U-Booten für Israel' [Germany participates financially in submarines for Israel], *Der Spiegel*, 23 Oct. 2017.

IX. North Korea's military nuclear capabilities

SHANNON N. KILE AND HANS M. KRISTENSEN

The Democratic People's Republic of Korea (DPRK, or North Korea) maintains an active but highly opaque nuclear weapon programme. It is estimated that North Korea may have produced 10–20 nuclear weapons (see table 6.10). This is based on calculations of the amount of plutonium that North Korea may have separated from the spent fuel produced by its 5 megawatt-electric (MW(e)) graphite-moderated research reactor at the Yongbyon Nuclear Scientific Research Center (YNSRC) and assumptions about North Korean weapon design and fabrication skills. North Korea is believed to be increasing its limited holdings of weapon-usable plutonium (see section X), although assessments differ about the scale and pace of the increase.[1] In 2017 commercial satellite imagery and thermal imagery indicated that the Radiochemical Laboratory at the YNSRC might be continuing to operate intermittently to separate plutonium from the reactor's spent fuel rods.[2]

In 2016 North Korea publicly acknowledged that it was producing highly enriched uranium (HEU) for nuclear weapons.[3] There has been considerable speculation that North Korea is seeking to build warheads using HEU as the fissile material in order to overcome the constraints imposed by its limited holding of separated plutonium. However, it is not known whether it has done so. Furthermore, little is known about North Korea's stock of HEU or its uranium enrichment capacity.[4]

On 3 September 2017 North Korea conducted its sixth nuclear test explosion at the Punggye-ri underground test site in the north-east of the country.[5] Following the explosion, the North Korean Nuclear Weapons Institute announced that the event was a successful test of a hydrogen bomb that could be delivered by an intercontinental ballistic missile (ICBM).[6] Many commentators assessed, based on indirect evidence, that North Korea's

[1] See e.g. Yonhap News Agency, 'North Korea has 50 kg of weapons-grade plutonium: Seoul's Defense White Paper', 11 Jan. 2017; and Albright, D. and Kelleher-Vergantini, S., 'Plutonium, tritium and highly enriched uranium production at the Yongbyon nuclear site', Institute for Science and International Security, Imagery Brief, 14 June 2016.

[2] Bermudez, J. et al., 'North Korea's Yongbyon facility: probable production of additional plutonium for nuclear weapons', 38 North, US–Korea Institute, 14 July 2017.

[3] Kyodo News Agency, 'North Korea confirms restart of plutonium processing', *Japan Times*, 17 Aug. 2016.

[4] Albright and Kelleher-Vergantini (note 1); and Hecker, S. et al., *North Korean Nuclear Facilities After the Agreed Framework*, Working Paper (Freeman Spogli Institute for International Studies, Stanford University: Stanford, CA, 2016).

[5] For a technical assessment of the test and an overview of global nuclear weapon tests since 1945 see section XI of this chapter.

[6] Korean Central News Agency, 'DPRK Nuclear Weapons Institute on successful test of H-bomb for ICBM', 3 Sep. 2017.

claim that the nuclear explosive device tested was a thermonuclear weapon was plausible.[7] However, some experts noted that in the absence of the detection of leaked radioactive debris characteristic of a thermonuclear explosion, it was not possible to rule out that North Korea had tested another type of weapon design, such as a boosted composite device or even a large fission-only device.[8]

North Korea had previously conducted nuclear tests at the site in October 2006, May 2009, February 2013, and January and September 2016.[9] The estimated yields (explosive energy) of the tests have progressively increased.

Ballistic missiles

North Korea is expanding and modernizing its ballistic missile force, which consists of 10 types of indigenously produced short-, medium- and intermediate-range systems that are either deployed or under development. It is developing a road-mobile ICBM as well as a submarine-launched ballistic missile (SLBM). In 2017 North Korea conducted 20 known missile tests, compared with 24 tests in 2016. Of the seven different types of missile tested in 2017, four had not been previously tested.[10]

In a speech on 1 January 2018, the North Korean leader, Kim Jong Un, said that the country would begin to mass-produce nuclear warheads and ballistic missiles.[11] There is no publicly available evidence to confirm North Korea's claim that it has built a nuclear warhead that is sufficiently compact to be delivered by a ballistic missile. In 2017 the Defense Intelligence Agency of the United States reportedly concluded that North Korea had successfully designed and produced an operational nuclear weapon that could be delivered by a ballistic missile.[12] In the 2016 edition of its biennial Defense White Paper, South Korea's Ministry of National Defense noted that North Korea had 'reached a significant level' of technical progress towards building a miniaturized warhead, but it did not state whether it believed that North Korea had succeeded in doing so.[13] Other elements of the

[7] See e.g. Lewis, J., 'Welcome to the thermonuclear club, North Korea!', *Foreign Policy*, 4 Sep. 2017.

[8] Dominguez, G., 'North Korea conducts its sixth and largest nuclear test', *Jane's Defence Weekly*, 13 Sep. 2017, p. 6.

[9] On the earlier tests see Fedchenko, V. and Ferm Hellgren, R., 'Nuclear explosions, 1945–2006', *SIPRI Yearbook 2007*; Fedchenko, V., 'Nuclear explosions, 1945–2009', *SIPRI Yearbook 2010*; Fedchenko, V., 'Nuclear explosions, 1945–2013', *SIPRI Yearbook 2014*; and Fedchenko, V., 'Nuclear explosions, 1945–2016', *SIPRI Yearbook 2017*.

[10] James Martin Center for Nonproliferation Studies, North Korea Missile Test Database, 30 Nov. 2017. North Korea conducted an additional test in 2017 but the missile type is not known.

[11] Korean Central News Agency, 'Kim Jong-un makes new year address', 1 Jan. 2018.

[12] Warrick, J., Nakashima, E. and Fifield, A., 'North Korea now making missile-ready nuclear weapons, US analysts say', *Washington Post*, 8 Aug. 2017.

[13] Park, B., '2016 Defense White Paper estimates North Korea has 50kg of plutonium', *Hankyoreh*, 12 Jan. 2017.

Table 6.10. North Korean forces with potential nuclear capability, January 2018

Type[a]	Range (km)	Payload (kg)	Status	No. of warheads
Land-based ballistic missiles				. .
Hwasong-7 (Nodong)	>1 200	1 000	Single-stage, liquid-fuel missile. Fewer than 100 launchers; first deployed in 1990	
Hwasong-9 (Scud-ER)	1 000	500	Scud missile variant, lengthened to carry additional fuel	
Bukkeukseong-2 (KN-15)	1 000	. .	2-stage, solid-fuel missile launched from canister launcher. Land-based version of Bukkeukseong-1 SLBM; test launched twice in 2017	
Hwasong-10 (BM-25, Musudan)	>3 000	(1 000)	Single-stage, liquid-fuel missile under development; several failed test launches in 2016	
Hwasong-12 (KN-17)	3 300–4 500	1 000	Single-stage, liquid-fuel missile under development; although half of 2017 test launches failed, North Korea declared it operational after Sep. 2017 test launch	
Hwasong-13 (KN-08)[b]	>5 500	. .	3-stage, liquid-fuel missile with potential intercontinental range under development; no known test launches	
Hwasong-14 (KN-20)	6 700–10 400	500–1 000	2-stage, liquid-fuel missile under development; test launched twice in 2017	
Hwasong-15 (KN-22)	8 500–13 000	1 000–1 500	2-stage, liquid-fuel missile under development; test launched once in 2017	
Taepodong-2[c]	12 000	. .	Under development; 3-stage space launch vehicle variant placed satellites in orbit in 2012 and 2016	
Submarine-launched ballistic missiles				
Bukkeukseong-1 (KN-11)	. .	. .	2-stage, solid-fuel SLBM under development, replacing earlier liquid-fuel version	
Total				**(10–20)**[d]

. . = not available or not applicable; ( ) = uncertain figure; SLBM = submarine-launched ballistic missile.

[a] The operational capability of North Korean warheads is uncertain. While there is speculation that some medium-range ballistic missiles might have operational nuclear capability, there is no authoritative open-source evidence that North Korea has developed and tested a functioning re-entry vehicle that is capable of carrying a nuclear warhead on a long-range ballistic missile and deployed warheads with operational forces. This table lists the ballistic missiles that could potentially have a nuclear delivery role, although that does not imply that each type is a mass-produced operational weapon system.

[b] A longer-range variant, the KN-14, is under development but has yet to be test launched.

[c] A 2-stage Taepodong-1 missile was unsuccessfully flight tested in 1998.

[d] SIPRI's estimate is that North Korea may have fissile material for between 20 and 30 warheads. After 6 tests, 1 of which was more than 200 kilotons, North Korea might have a small number of deliverable nuclear warheads.

Sources: US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat*, various years; *IHS Jane's Strategic Weapon Systems*, various issues; International Institute for Strategic Studies, *The Military Balance 2018* (Routledge: London, 2018); 'Nuclear notebook', *Bulletin of the Atomic Scientists*, various issues; and authors' estimates.

US intelligence community and military have expressed doubt about the operational capability of, in particular, the warheads on long-range missiles. The South Korean Vice Defense Minister, Suh Choo-suk, stated in August 2017 that 'Both the United States and South Korea do not believe North Korea has yet completely gained re-entry technology in material engineering terms'.[14] Vice Chairman of the Joint Chiefs of Staff, US General Paul Selva, added in January 2018 that 'What [North Korea] has not demonstrated yet are the fusing and targeting technologies and survivable re-entry vehicle'.[15]

Medium- and intermediate-range ballistic missiles

Assuming that North Korea is able to produce a sufficiently compact warhead, some observers assess that the size, range and operational status of the Hwasong-7, also known as the Nodong, medium-range missile make it the system most likely to be given a nuclear delivery role.[16] Based on a Soviet-era Scud missile design, the Nodong is a single-stage, liquid-fuelled ballistic missile with an estimated range exceeding 1200 kilometres. The North Korean Army's Strategic Rocket Force Command carried out five test launches of Nodong missiles in 2016.[17] No tests were conducted in 2017.

North Korea has developed the single-stage, liquid-fuelled Hwasong-9, also known as the Scud-ER (extended-range) system. Based on the Hwasong-6 (Scud C variant) missile with a lengthened fuselage to carry additional fuel, the Scud-ER has an estimated range of 1000 km.[18] On 6 March 2017 four Scud-ER missiles were test fired simultaneously from the Sohae Satellite Launch complex in north-western North Korea.[19] According to some reports, a fifth Scud-ER may have failed to launch.[20] The missiles flew nearly 1000 km and landed in the Sea of Japan, approximately

[14] 'N. Korea still needs time to perfect re-entry technology: S. Korea vice def min', Reuters, 13 Aug. 2017.

[15] Ali, I., 'US general says North Korea not demonstrated all components of ICBM', Reuters, 30 Jan. 2018.

[16] See e.g. Fitzpatrick, M., 'North Korea nuclear test on hold?', Shangri-La Voices, International Institute for Strategic Studies, 27 May 2014.

[17] Three of the missile flight tests were apparently successful, but 2 of the missiles exploded (1 in July 2016 and 1 in Aug. 2016) shortly after launch. Kwon, K., Berlinger, J. and Hanna, J., 'North Korea fires 2 ballistic missiles, South Korea and US say', CNN, 3 Aug. 2016.

[18] US Air Force, National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat* (NASIC: Wright-Patterson Air Force Base, OH, July 2017), pp. 18, 25.

[19] Bermudez, J. and Liu, J., 'North Korea's Sohae Satellite Launching Station: Scud-ER launch site visible; activity at vertical engine test stand', 38 North, US–Korea Institute, 17 Mar. 2017.

[20] Schmerler, D., 'Did North Korea test a fifth missile last week?', NK News, 16 Mar. 2017.

350 km from the Japanese island of Honshu.[21] The test raised concerns in Japan that North Korea was developing an ability to launch salvos of missiles capable of overwhelming Japan's ballistic missile defence systems, including those that have yet to be deployed.[22]

The Hwasong-10 missile, also designated the Musudan or BM-25, is a single-stage, liquid-fuelled missile with an estimated range exceeding 3000 km. The Musudan was first unveiled at a military parade in 2010. Flight testing began in 2016, with multiple failures.[23] No flight tests of the Musudan are known to have been conducted in 2017 and the status of the missile development programme is unclear.

The Hwasong-12 (also referred to by the US Department of Defense, DOD, designation KN-17) is a single-stage, intermediate-range missile that is believed to have a new liquid-propellant booster engine as well as design features that may serve as a technology test bed for a future ICBM.[24] Some analysts have speculated that the missile carries a small post-boost vehicle (PBV) that, in addition to increasing its maximum range, can be used to improve warhead accuracy.[25] The missile has an estimated range of 3300–4500 km, which would be sufficient to strike US military bases in the western Pacific Ocean, including on the island of Guam. A Hwasong-12 missile was successfully test launched for the first time on 14 May 2017.[26] Three tests conducted the previous month reportedly all failed.[27] On 28 August the North Korean Army's Strategic Rocket Force Command test launched a Hwasong-12 missile that travelled 2700 km, flying over Hokkaido in northern Japan before breaking up into three pieces during re-entry and falling into the Pacific Ocean.[28] The missile's flight path over Japan was strongly condemned by the Japanese Government.[29] A Hwasong-12 missile that was

[21] Hancocks, P. and Westcott, B., 'North Korea fires four missiles into the Sea of Japan', CNN, 7 Mar. 2017.

[22] Rich, M., 'North Korea launch could be test of new attack strategy, Japan analysts say', *New York Times*, 6 Mar. 2017.

[23] Savelsberg, R. and Kiessling, J., 'North Korea's Musudan missile: a performance assessment', 38 North, US–Korea Institute, 20 Dec. 2016. In 2016 North Korea conducted 8 flight tests of the Musudan system. Only 1 of the tests was judged to have been successful. In the other tests, the missiles exploded on launch or shortly thereafter.

[24] Yi, Y., 'Hwasong-12 a stepping stone in North Korea's ICBM development', *Hankyoreh*, 16 May 2017; and Savelsberg, R., 'A quick technical analysis of the Hwasong-12 missile', 38 North, US–Korea Institute, 19 May 2017.

[25] Elleman, M., 'North Korea's Hwasong-12 launch: a disturbing development', 38 North, US–Korea Institute, 30 Aug. 2017.

[26] Felstead, P. and Gibson, N., 'North Korea fires new missile to 2000 km altitude', *Jane's Defence Weekly*, 24 May 2017, p. 8.

[27] Panda, A., 'Exclusive: North Korea tested its new intermediate-range ballistic missile 3 times in April 2017', The Diplomat, 3 June 2017.

[28] Elleman (note 25); and Felstead, P. and Gibson, N., 'North Korean IRBM flies over Japan', *Jane's Defence Weekly*, 6 Sep. 2017, p. 5.

[29] Fifield, A., 'North Korean missile flies over Japan escalating tensions and prompting an angry response from Tokyo', *Washington Post*, 28 Aug. 2017; and McCurry, J., 'Trump and Abe vow to

test launched on 15 September also flew over Japan and travelled 3700 km—the longest distance by a North Korean missile to date—before landing in the Pacific Ocean.[30] Unlike previous tests, the missile was fired from a transporter-erector-launcher vehicle rather than from a concrete platform, which indicates a higher level of operational readiness.[31]

North Korea is developing the Bukkeukseong-2 missile ('Polaris-2', US DOD designation, KN-15), which is a land-based variant of the Bukkeukseong-1 SLBM. The two-stage, solid-fuelled missile has an estimated maximum range exceeding 1000 km.[32] The missile was first flight tested on 12 February 2017, followed by a second test on 21 May 2017.[33] Some analysts noted that North Korea's development of the Bukkeukseong-2 was probably part of an effort to improve the survivability of its nuclear-capable ballistic missile systems. Solid-fuelled missiles can be fired more quickly than liquid-fuelled systems and require fewer support vehicles that might give away their position to overhead surveillance.[34]

Intercontinental-range ballistic missiles

North Korea is widely believed to have prioritized building and deploying a long-range ballistic missile that can deliver a nuclear warhead to targets in the continental USA. In recent years it has pursued the serial development of several missile systems with progressively longer ranges and increasingly sophisticated delivery capabilities.

The Hwasong-13 (US DOD designation, KN-08) was first presented by North Korea as a road-mobile, three-stage missile with intercontinental range at a military parade in April 2012, although some non-governmental analysts have argued that the missiles displayed were only mock-ups.[35] Estimates of the range and payload capabilities of the missile are highly speculative. No test launch had been conducted as of the end of 2017.

North Korea has developed the Hwasong-14 (US DOD designation, KN-20), a prototype ICBM that first appeared in 2015 at a military parade in Pyongyang.[36] The two-stage missile appears to use the same high-energy

increase pressure after North Korea fires missile over Japan', *The Guardian*, 29 Aug. 2017.

[30] 'North Korea fires second missile over Japan', BBC News, 15 Sep. 2017.

[31] Graham, C., Boyle, D. and Connor, N., 'North Korea fires second missile over Japan as US tells China and Russia to take "direct action"', *Daily Telegraph*, 15 Sep. 2017; and Panda, A. 'North Korea shows increased operational confidence in the Hwasong-12 IRBM', The Diplomat, 17 Sep. 2017.

[32] US Air Force, National Air and Space Intelligence Center (note 18), p. 25.

[33] Felstead, P. and Gibson, N., 'North Korea tests Trump with ballistic missile launch', *Jane's Defence Weekly*, 22 Feb. 2017, p. 16; and BBC News, 'North Korea confirms "successful" new ballistic missile test', 21 May 2017.

[34] Panda, A., 'It wasn't an ICBM, but North Korea's first missile test of 2017 is a big deal', The Diplomat, 14 Feb. 2017.

[35] Schiller, M. and Kelley, R., 'Evolving threat: North Korea's quest for an ICBM', *Jane's Defence Weekly*, 18 Jan. 2017, p. 24.

[36] Schiller and Kelley (note 35).

liquid-propellant booster engine as the single-stage Hwasong-12.[37] The missile was test launched from mobile platforms twice in 2017, on 4 July and 28 July. In both tests the missiles were fired on elevated trajectories to avoid flying over Japan and reached maximum altitudes of 2800 km and 3700 km, respectively. The second test might not have been completely successful, as a lightweight re-entry vehicle carried by the missile apparently disintegrated before reaching the ground.[38] The Hwasong-14 is estimated to have a range of up to 10 400 km, depending on the payload and flight trajectory.[39]

North Korea is developing a new two-stage ICBM, the Hwasong-15 (US DOD designation, KN-22) that has a significantly larger second stage and more powerful booster engines than the Hwasong-14. The first flight test was conducted on 28 November 2017, when a Hwasong-15 was launched on an elevated trajectory and flew higher and for a longer duration than any previous North Korean missile. One estimate put the theoretical maximum range of the Hwasong-15 on a normal trajectory at up to 13 000 km—sufficient to reach Washington, DC, and other targets on the east coast of the USA.[40] The missile was assessed to be carrying a light payload, however, and the range would be significantly reduced if it were carrying a heavier payload such as a nuclear warhead.[41] According to a North Korean Government statement issued after the test, the Hwasong-15 is 'an intercontinental ballistic rocket tipped with super-large heavy warhead which is capable of striking the whole mainland of the US' that 'meets the goal of the completion of the rocket weaponry system'.[42]

Overall, in 2017 North Korea made progress towards building an operational ICBM across a range of technical challenges at a pace that surprised many experts.[43] Some analysts pointed out that North Korea had yet to validate the performance and reliability of an ICBM system, in particular that of the missile's re-entry vehicle.[44] However, estimates of the time required for it to do so shortened during the year. According to a July 2017 media report, the US Defense Intelligence Agency had concluded that North Korea would be able to produce a 'reliable, nuclear-capable ICBM' some time in 2018. The

[37] According to 1 non-governmental analyst, North Korea probably acquired the engine through illicit channels operating in Russia or Ukraine. Elleman, M., 'The secret to North Korea's ICBM success', IISS Voices blog, International Institute for Strategic Studies, 14 Aug. 2017.

[38] Schilling, J., 'What's next for North Korea's ICBM?', 38 North, US–Korea Institute, 1 Aug. 2017.

[39] Wright, D., 'North Korean ICBM appears able to reach major US cities', All Things Nuclear blog, Union of Concerned Scientists, 28 July 2017.

[40] Wright, D., 'Re-entry of North Korea's Hwasong-15 missile', All Things Nuclear blog, Union of Concerned Scientists, 7 Dec. 2017.

[41] Elleman, M., 'North Korea's third ICBM launch', 38 North, US–Korea Institute, 29 Nov. 2017; and Wright (note 40).

[42] Korean Central News Agency, 'DPRK Gov't statement on successful test-fire of new-type ICBM', 29 Nov. 2017.

[43] Broad, W. and Sanger, D., 'How US Intelligence agencies underestimated North Korea', *New York Times*, 6 Jan. 2018.

[44] Wright (note 40); and Elleman (note 41).

US intelligence community had previously assessed that North Korea would not have a credible ICBM capability until 2020 at the earliest.[45] In his statement in August 2017, Choo-suk noted that North Korea would need 'at least one or two more years' to master the re-entry vehicle technology required for a long-range missile delivery system.[46]

Submarine-launched ballistic missiles

North Korea is developing an SLBM called the Bukkeukseong-1 ('Polaris-1', US DOD designation, KN-11). The missile is now a two-stage, solid-fuelled design after initial test failures using a liquid-fuelled missile.[47] In August 2016, following a series of failed attempts, North Korea conducted the first successful underwater test launch of the Bukkeukseong-1 missile from an experimental submarine.[48] In 2017 North Korea conducted a series of successful underwater ejection tests—that is, tests designed to evaluate stabilization systems and the process of ejecting the missile from a submerged launch tube—but it did not conduct any flight tests of the missile.[49] Most observers assess that North Korea still has numerous technical challenges to overcome before it will be able to design, build and deploy an operational SLBM force. However, commercial satellite imagery of the shipyard in Sinpo from November 2017 revealed that North Korea appeared to be building a new, larger submarine capable of launching an SLBM.[50] As the year ended, concerns about North Korea's technical progress towards achieving an SLBM capability spurred the USA, Japan and South Korea to conduct military drills for tracking submarine missile launches by North Korea.[51]

[45] Nakashima, E., Fifield, A. and Warrick J., 'North Korea could cross ICBM threshold next year, US officials warn in new assessment', *Washington Post*, 25 July 2017.

[46] 'N. Korea still needs time to perfect re-entry technology: S. Korea vice def min' (note 14).

[47] Schilling, J., 'A new submarine-launched ballistic missile for North Korea', 38 North, US–Korea Institute, 25 Apr. 2016.

[48] Park, J. M. and Kim, J., 'North Korea fires submarine-launched ballistic missile towards Japan', Reuters, 24 Aug. 2016.

[49] Ryall, J., 'North Korea carries out "unprecedented" test of submarine missile system', *Daily Telegraph*, 1 Aug. 2017.

[50] Bermudez, J., 'North Korea's submarine ballistic missile program moves ahead: indications of shipbuilding and missile ejection testing', 38 North, US–Korea Institute, 16 Nov. 2017.

[51] Mullany, G., 'North Korean submarine missile threat prompts US-led military drills', *New York Times*, 11 Dec. 2017.

X. Global stocks and production of fissile materials, 2017

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INTERNATIONAL PANEL ON FISSILE MATERIALS

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 2017 of HEU (see table 6.11) and separated plutonium (see table 6.12), including in weapons, and details of the current capacity to produce these materials (see tables 6.13 and 6.14, respectively). The information in the tables is based on estimates prepared for the International Panel on Fissile Materials (IPFM). The most recent annual declarations on civilian plutonium and HEU stocks to the International Atomic Energy Agency (IAEA) were released in late 2017 and give data for the end of 2016.

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 6.11. Global stocks of highly enriched uranium, 2017

State	National stockpile (tonnes)[a]	Production status	Comments
China[b]	14 ± 3	Stopped 1987–89	
France[c]	30 ± 6	Stopped 1996	Includes 4.8 tonnes declared civilian
India[d]	4 ± 1.4	Continuing	Includes HEU in naval reactor cores
Israel[e]	0.3	–	
Pakistan	3.4 ± 0.4	Continuing	
Russia[f]	679 ± 120	Stopped 1987–88	
UK[g]	21.1	Stopped 1962	Includes 1.37 tonnes declared civilian
USA[h]	574.5 (95 not available for military purposes)	Stopped 1992	Includes HEU in a naval reserve
Other states[i]	~15		
Total[j]	**~1340 (95 not available for military purposes)**		

HEU = highly enriched uranium.

[a] Most of this material is 90–93% enriched uranium-235 (U-235), which is typically considered weapon-grade. Important exceptions are noted. Blending down (i.e. reducing the concentration of U-235) of excess Russian and US weapon-grade HEU and civilian HEU declarations up to the end of 2016 has been taken into account. The estimates are in effect for the end of 2016.

[b] This revised estimate is based on a new assessment for the International Panel on Fissile Materials (IPFM) of fissile material production and stocks in China.

[c] France declared 4.8 tonnes of civilian HEU to the International Atomic Energy Agency (IAEA) as of the end of 2016; it is assumed here to be 93% enriched HEU, even though 1.54 tonnes of the material is in irradiated form. The uncertainty in the estimate applies only to the military stockpile of about 26 tonnes and does not apply to the declared civilian stock. A recent analysis offers grounds for a significantly lower estimate of the stockpile of weapon-grade HEU (as large 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.

[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 about 300 kg of weapon-grade HEU from the USA in or before 1965.

[f] 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.

[g] The UK declared a stockpile of 21.9 tonnes of HEU as of 31 Mar. 2002, the average enrichment of which was not given. Some of this has been consumed since then in naval fuel. The UK declared a stock of 1.37 tonnes of civilian HEU to the IAEA as of the end of 2016.

[h] 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 Dec. 2016, another 11.1 tonnes had been down blended or shipped for blending down. The 95 tonnes declared excess includes the remaining 75.1 tonnes and 20 tonnes of HEU reserved for HEU fuel for research reactors.

[i] The 2016 IAEA Annual Report lists 181 significant quantities of HEU under comprehensive safeguards in non-nuclear weapon states as of the end of 2016. 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.

[j] 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). UK: British Ministry of Defence, 'Historical accounting for UK defence highly enriched uranium', Mar. 2006; and Office for Nuclear Regulation, 'Annual figures for holdings of civil unirradiated plutonium as at 31 December 2016', 2017. 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; and Irons, C. W., 'Status of surplus HEU disposition in the United States', Institute of Nuclear Materials Management, 57th Annual Meeting, Atlanta, 26 July 2016. Non-nuclear weapon states: IAEA, *IAEA Annual Report 2016* (IAEA: Vienna, 2017), Annex, Table A4, p. 123.

Table 6.12. Global stocks of separated plutonium, 2017

State	Military stocks (tonnes)	Military production status	Civilian stocks (tonnes)[a]
China	2.9 ± 0.6	Stopped in 1991	0.04
France	6 ± 1.0	Stopped in 1992	65.4 (excludes 16.3 foreign owned)
Germany[b]	–	–	0.6
India[c]	0.58 ± 0.15	Continuing	6.4 ± 3.5 (includes 0.4 under safeguards)
Israel[d]	0.9 ± 0.13	Continuing	–
Japan	–	–	47.0 (includes 37.1 in France and UK)
Korea, North[e]	0.04	Continuing	–
Pakistan[f]	0.28 ± 0.09	Continuing	–
Russia[g]	128 ± 8 (40 not available for weapons)	Stopped in 2010	57.2
UK[h]	3.2	Stopped in 1995	110.3 (excludes 23.2 foreign owned)
USA[i]	87.8 (49.4 not available for weapons)	Stopped in 1988	–
Other states[j]	–	–	2.3
Totals[k]	**~230 (89 not available for weapons)**		**~290**

[a] Some countries with civilian plutonium stocks do not submit an International Atomic Energy Agency (IAEA) INFCIRC/549 declaration. Of these countries, Italy, the Netherlands, Spain and Sweden store their plutonium abroad. The data is for the end of 2016.

[b] This may be an overestimate since Germany apparently reports plutonium as being in unirradiated mixed oxide (MOX) fuel even if the fuel is being irradiated in a reactor.

[c] India's estimate for military plutonium is reduced because of new publicly available information about the performance of its Dhruva reactor. 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 2016.

[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 conducted in 2009–17.

[f] As of the end of 2016, Pakistan was operating 4 plutonium production reactors at its Khushab site. This estimate assumes that in 2016 Pakistan separated plutonium from the cooled spent fuel from 2 new reactors, 1 of which began operating some time in 2013 and the other in late 2014 or early 2015.

[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 the plutonium not available for weapons (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 statement. Nor does it make the plutonium it reports as civilian available to IAEA safeguards.

[h] The UK declared 110.3 tonnes of civilian plutonium (not including 23.2 tonnes of foreign-owned plutonium in the UK) as of the end of 2016. This includes 4.4 tonnes of military plutonium declared excess and placed under Euratom safeguards.

[i] In 2012 the USA declared a government-owned plutonium inventory of 95.4 tonnes as of 30 Sep. 2009. In its 2016 IAEA INFCIRC/549 statement, the USA declared 49 tonnes of unirradiated plutonium (both separated and in 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. This includes 49 tonnes of unirradiated plutonium, 4.5 tonnes of plutonium disposed of as waste, 0.2 tonnes lost to radioactive decay since 1994 and 7.8 tonnes of irradiated government-owned plutonium. The plutonium reported in INFCIRC/549 also includes 0.4 tonnes of plutonium brought to the USA in 2016 from Japan, Germany and Switzerland (331 kg, 30 kg, and 18 kg, respectively). Like the 49 tonnes of unirradiated excess plutonium, this material will not be used for weapons. However, it has not been placed under IAEA safeguards, so it is accounted for together with military material.

[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 reports.

[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; and Hecker, S. S., 'What we really know about North Korea's nuclear weapons', *Foreign Affairs*, 4 Dec. 2017. 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).

Table 6.13. Significant uranium enrichment facilities and capacity worldwide, 2017

State	Facility name or location	Type	Status	Enrichment process[a]	Capacity (thousands SWU/yr)[b]
Argentina[c]	Pilcaniyeu	Civilian	Resuming operation	GD	20
Brazil	Resende Enrichment	Civilian	Expanding capacity	GC	120
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	4 000
India	Rattehalli	Military	Operational	GC	15–30
Iran[e]	Natanz	Civilian	Limited operation	GC	3.5–5
	Qom (Fordow)	Civilian	Idle	GC	. .
Japan	Rokkasho[f]	Civilian	Resuming operation	GC	75
Korea, North	Yongbyon[g]	. .	Uncertain	GC	8
Netherlands	Urenco Almelo	Civilian	Operational	GC	5 400
Pakistan	Gadwal	Military	Operational	GC	. .
	Kahuta	Military	Operational	GC	15–45
Russia[h]	Angarsk	Civilian	Operational	GC	4 000
	Novouralsk	Civilian	Operational	GC	13 300
	Seversk	Civilian	Operational	GC	3 800
	Zelenogorsk	Civilian	Operational	GC	7 900
UK	Capenhurst	Civilian	Operational	GC	4 700
USA[i]	Urenco Eunice	Civilian	Operational	GC	4 700

[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: an SWU is a measure of the effort required in an enrichment facility to separate uranium of a given content of U-235 into 2 components, 1 with a higher and 1 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.

[d] A new assessment of China's enrichment capacity in 2015 identified new enrichment sites and suggested a much larger total capacity than had previously been estimated. These estimates were again updated in a new report in 2017.

[e] In July 2015 Iran agreed a Joint Comprehensive Plan of Action 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.

[f] The Rokkasho centrifuge plant is being refitted with new centrifuge technology and is operating at very low capacity, about 75 000 SWU/yr as of Dec. 2016.

[g] North Korea revealed its Yongbyon enrichment facility in 2010. Its operating status is unknown.

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

[i] Plans for new centrifuge enrichment plants at Piketon (United States Enrichment Corporation, USEC) and Eagle Rock (AREVA) have been shelved for technical and financial reasons, respectively.

Table 6.14. Significant reprocessing facilities worldwide, as of 2017

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	To be shut down[d]	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
UK	BNFL B205 (Magnox fuel)	Civilian	To be shut down 2018	1 500
	BNFL Thorp, Sellafield	Civilian	To be shut down 2020	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 planning to build a pilot reprocessing facility at Jiuquan with a capacity of 200 tHM/yr.

[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 2016 it was still working with very small amounts of plutonium.

[e] A 250 tHM/yr Pilot Experimental Centre is under construction in Zheleznogorsk. It is supposed to begin operation in 2018.

Sources for table 6.13: 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; and Zhang, H., *China's Fissile Material Production and Stockpile* (International Panel on Fissile Materials: Princeton, NJ, Dec. 2017). Enrichment capacity data is based on International Atomic Energy Agency, Integrated Nuclear Fuel Cycle Information Systems (INFCIS); Urenco website; 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).

Sources for table 6.14: 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, Dec. 2015).

XI. Nuclear explosions, 1945–2017

VITALY FEDCHENKO

On 3 September 2017 the Democratic People's Republic of Korea (DPRK, or North Korea) conducted its sixth nuclear test explosion, following tests conducted in January and September 2016, February 2013, May 2009 and October 2006.[1] This 2017 test brought the total number of nuclear explosions recorded since 1945 to 2058.

The September 2017 nuclear test

On 3 September 2017 at 03:30 Coordinated Universal Time (12:00 local time) North Korea conducted an underground test explosion at the Punggye-ri Nuclear Test Facility under Mount Mantap in the north-east of the country.[2] Shortly after, the Korean Central News Agency (KCNA) announced that the event was a successful test of a hydrogen bomb for an intercontinental ballistic missile (ICBM) and published a statement by the Nuclear Weapons Institute (NWI) of North Korea detailing the features of the test device.[3]

The publication after a test of discussion by the NWI of the test device's features is a new development: it occurred for the first time after the fifth test in September 2016. The NWI noted that the test carried out in September 2017 was of a bomb of 'unprecedentedly big power' and proclaimed the test a success. The NWI also stated that North Korea had conducted 'experimental measurements' to verify the performance of a new 'H-bomb' design, in terms of (*a*) its 'total explosion power' (yield); (*b*) its 'fission to fusion power' ratio; (*c*) the 'precision of the compression technology and the fission chain reaction start control technology of the first system of the H-bomb', meaning the performance of the high explosive implosion assembly and the neutron initiator in the primary; and (*d*) the 'nuclear material utility rate in the first system and the second system', or the proportion of the fissile material in the primary that underwent fission, as opposed to being scattered by the explosion, and the amount of material that underwent either fusion or fission in the secondary.[4] Some descriptions of the test device's features,

[1] On the earlier tests see Fedchenko, V. and Ferm Hellgren, R., 'Nuclear explosions, 1945–2006', *SIPRI Yearbook 2007*; Fedchenko, V., 'Nuclear explosions, 1945–2009', *SIPRI Yearbook 2010*; Fedchenko, V., 'Nuclear explosions, 1945–2013', *SIPRI Yearbook 2014*; and Fedchenko, V., 'Nuclear explosions, 1945–2016', *SIPRI Yearbook 2017*.

[2] Lee, M. Y. H., 'North Korea's latest nuclear test was so powerful it reshaped the mountain above it', *Washington Post*, 14 Sep. 2017.

[3] Korean Central News Agency, 'DPRK Nuclear Weapons Institute on successful test of H-bomb for ICBM', 3 Sep. 2017.

[4] The ratio of fission to fusion energy (i.e. the share of energy from fission and fusion reactions in the total yield) determines the amount of long-term contamination by radioactive isotopes. Less fission means less long-lived radioactive isotopes in the fallout, so the weapon can be treated

Table 6.15. Data on North Korea's nuclear explosion, 3 September 2017

Source[a]	Origin time (UTC)	Latitude	Longitude	Error margin[b]	Body-wave magnitude[c]
IDC[d]	03:30:06.09 ± 3.7	41.3256° N	129.0760° E	±6.7 km[e]	6.07 ± 0.1
CEME	03:29:59.0	41.3° N	129.1° E	. .	6.3
NEIC	03:30:01.760	41.332° N	129.030° E	±1.4 km[f]	6.3
IES CAS	03:30:00	41.3° N	129.1° E	. .	6.3
KMA	03:29:58	41.302° N	129.080° E	. .	5.7
FOI	03:30	41.3° N	129.1° E	. .	6.1

. . = data not available; CEME = Russian Academy of Sciences, Geophysical Survey, Central Experimental Methodical Expedition, Obninsk, Kaluga oblast, Russia; FOI = Swedish Defence Research Agency, Stockholm, Sweden; IDC = Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), International Data Centre, Vienna, Austria; IES CAS = Institutions of Earth Science, Chinese Academy of Science, Beijing, China; km = kilometres; KMA = Korean Meteorological Administration, Seoul, South Korea; NEIC = US Geological Survey, National Earthquake Information Center, Denver, CO, United States; UTC = Coordinated Universal Time.

[a] Because of differences between estimates regarding the precise location and magnitude of the explosion, data from 6 sources—1 internationally recognized body and 5 national bodies—is provided for comparison.

[b] The error margins are as defined by the data sources.

[c] Body-wave magnitude indicates the size of the event. In order to give a reasonably correct estimate of the yield of an underground explosion, detailed information is needed (e.g. on the geological conditions in the area where the explosion took place). Body-wave magnitude is an unambiguous way of indicating the size of an explosion.

[d] The IDC was 'in a test and provisional operation mode only' so 41 of the 50 primary and 96 of the 120 auxiliary seismic monitoring stations in the CTBTO's International Monitoring System were contributing data at the time of the event.

[e] This figure is the length of the semi-major axis of the confidence ellipse. The confidence ellipse area was 109 square km, or almost 10 times smaller than the maximum area allowed to be inspected under the Comprehensive Nuclear-Test-Ban Treaty On-Site Inspection regime (1000 square km).

[f] This figure is the horizontal location error, defined as the 'length of the largest projection of the three principal errors on a horizontal plane'.

Sources: CTBTO, IDC, 'Technical briefing', 3 Sep. 2017; and CTBTO, IDC, 'Technical findings', 7 Sep. 2017; CEME, [Information message about underground nuclear explosion made in North Korea on 3 September 2017], 4 Sep. 2017 (in Russian); NEIC, 'M 6.3 nuclear explosion: 21 km ENE of Sungjibaegam, North Korea', US Geological Survey, [n.d.]; IES CAS, 'Research letters: September 3, 2017, preliminary results of seismological discrimination, depth and equivalence estimates for North Korea's nuclear tests', 4 Sep. 2017; KMA, Earthquake Volcano Monitoring Division, 'Artificial earthquake occurred in North Hamkyung Province', Press release, 3 Sep. 2017; and FOI, 'Nuclear weapons test in North Korea', Press release, 11 Sep. 2017.

such as 'the directional combination structure and multi-layer radiation explosion-proof structural design of the first system and the second system' and the 'light thermal radiation-resisting materials and neutron-resisting

as 'cleaner' by military planners. This could be important for those considering the tactical use of nuclear weapons.

materials', are harder to interpret specifically on the basis of open-source descriptions of thermonuclear weapon designs. However, these statements seem to be consistent with the 'Teller–Ulam' thermonuclear design, which is ostensibly used by all states with thermonuclear weapons.[5]

As was the case with the fifth test, the NWI statement noted that 'there were neither emission through ground surface nor leakage of radioactive materials nor did it have any adverse impact on the surrounding ecological environment'.

Verification of the September 2017 North Korean test by the international community

The international community—international organizations, individual states and many research institutions—sought to verify North Korea's claims concerning the test using a combination of available technologies, including seismology, radionuclide monitoring and satellite imagery analysis.[6]

The 1996 Comprehensive Nuclear-Test-Ban Treaty (CTBT) is a multilateral treaty that, once it enters into force, will prohibit the carrying out of any nuclear explosion.[7] The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has been established to prepare for the entry into force of the CTBT. These preparations include the creation of an International Monitoring System (IMS) to detect nuclear explosions. While the CTBT had been ratified by 166 states as of 1 February 2018, it cannot enter into force until it has been signed and ratified by 44 states that possess certain nuclear facilities. North Korea, which is one of these 44 states, has not signed the treaty and therefore does not participate in the IMS.

Seismic data recorded at monitoring stations around the world was used to estimate the time, location and size of the 3 September 2017 explosion (see table 6.15). The seismic wave patterns recorded, the depth of the event (less than 1 kilometre) and the fact that it occurred so close to the five previous nuclear tests (a characteristic distance being a few hundred metres) all indicate that it was an explosion rather than an earthquake.[8] The characteristic feature of this test was that its yield (see below) was large enough to produce aftershocks that themselves were large enough to be detected by seismic

[5] Korean Central News Agency (note 3).

[6] US National Academy of Sciences, *Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty* (National Academy Press: Washington, DC, 2002), pp. 39–41; and Dahlman, O. et al., *Detect and Deter: Can Countries Verify the Nuclear Test Ban?* (Springer: Dordrecht, 2011), pp. 29–76.

[7] For a summary and other details of the CTBT see annex A, section I, in this volume.

[8] Comprehensive Nuclear-Test-Ban Treaty Organization, International Data Centre, 'Technical findings', 7 Sep. 2017.

monitoring stations.[9] In addition, synthetic aperture radar (SAR) satellite imagery was used to show that the peak of Mount Mantap had 'incurred a visible amount of subsidence', and an area of about 35 hectares 'of the south-west flank of the mountain was displaced by several meters'.[10] The seismic events that followed the test explosion have reportedly led the governments of the United States and China to conclude that a collapse of an explosion cavity or tunnels had taken place.[11]

Even though there can be little doubt in cases of an explosion of this size, strictly speaking, seismic data alone is insufficient to confirm that an underground explosion is a nuclear explosion. Following North Korea's 2006 and 2013 tests, the nuclear nature of the explosion was confirmed when air sampling detected traces of radioxenon—radioactive isotopes of xenon that are released from a nuclear explosion.[12] No trace of radioxenon or other radioactive debris was reported found after the 2009 event, or after either of the events in 2016. Radioxenon detection after the 2017 test produced ambiguous results. The Government of the Republic of Korea (South Korea) announced that its Nuclear Safety and Security Commission found xenon-133 in 'ground, air and maritime' samples collected locally after the test.[13] The CTBTO also detected and investigated elevated concentrations of radioxenon, but found these 'not conclusive with regard to a possible association to the seismic event on 3 September'. It therefore determined that 'no CTBT-relevant radionuclides were detected by the IMS that could be unambiguously linked to a nuclear test in DPRK in September 2017'.[14]

Discussion of the September 2017 test results

North Korea does not announce the planned or measured yields from its test explosions. Estimates made by international researchers vary significantly. The published body-wave magnitude measurements—an unambiguous way of registering the size of a seismic event—ranged from 5.7 to 6.3.[15] As a result of this discrepancy and differences in the empirical methods used to convert

[9] Kitov, I. O. and Rozhkov, M. V., 'Discrimination of the DPRK underground explosions and their aftershocks using the P/S spectral amplitude ratio', Cornell University Library, Preprint, 5 Dec. 2017.

[10] Lee (note 2).

[11] Dill, C., 'North Korea nuclear test: "tunnel collapse" may provide clues', BBC News, 3 Sep. 2017.

[12] Fedchenko and Ferm Hellgren (note 1), p. 553; and Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), 'CTBTO detects radioactivity consistent with 12 February announced North Korean nuclear test', Press release, 23 Apr. 2013.

[13] Yonhap News Agency, 'Traces of xenon detected in S. Korea following N. Korea's nuke test', 8 Sep. 2017.

[14] American Geophysical Union (AGU), Proceedings of the AGU Fall Meeting 2017, New Orleans, 11–15 Dec. 2017. For a detailed discussion of CTBT-relevant radionuclides and the CTBTO procedures for their detection and analysis see De Geer, L. E., 'Radionuclide signatures for post-explosion environments', ed. V. Fedchenko, SIPRI, *The New Nuclear Forensics: Analysis of Nuclear Materials for Security Purposes* (Oxford University Press: Oxford, 2015), pp. 128–55.

[15] For further detail on body-wave magnitude see the United States Geological Survey website.

these values into explosive yields, yield estimates ranged from 50 kilotons to 1 megaton.[16] Most researchers agree, however, that the September 2017 test was about an order of magnitude larger than the previous one in September 2016. For example, the US Government's assessment of the explosive yield is 140 kt, the Norwegian Government's figure is 120 kt and the Swedish Government and Chinese university researchers, working independently, estimate a yield in the range of 100–200 kt.[17]

Most commentators found North Korea's claim that the nuclear explosive device tested on 3 September 2017 was a thermonuclear weapon to be plausible.[18] It should be noted, however, that these findings, which may indeed be correct, are based on indirect evidence. The only direct evidence associated with the event that is described in open sources is seismic wave data. Seismic waves can provide evidence of the size of the explosion but do not give information on the nuclear, boosted or thermonuclear nature of the explosive device, or on whether the test device used uranium or plutonium. The radioactive debris—and specifically the radioactive micro-particles—associated with the explosion must be analysed to discern that kind of detail.[19]

The explosive yield of the tested device is consistent with all three of the above-mentioned types of weapon (nuclear, boosted or thermonuclear) and therefore cannot be used to discriminate between them. For example, the B61 nuclear bomb—a true thermonuclear two-stage gravity bomb currently deployed in the US arsenal—reportedly has variants with yields of between a few kilotons and 300 kt.[20] By contrast, the largest publicly known pure-fission nuclear explosive device ever tested by the USA, the Ivy King test explosion on 16 November 1952, had a yield of about 500 kt.[21] Moreover, some commentators point out that it is technically easier to achieve a 100-kt yield in an underground test with no constraints on size and weight than to design a miniature warhead with a yield of 10–20 kt.[22]

[16] See table 6.15; and Incorporated Research Institutions of Seismology, 'Special event: 2017 North Korean nuclear test', 23 Jan. 2018.

[17] Panda, A., 'US intelligence: North Korea's sixth test was a 140 kiloton "advanced nuclear" device', The Diplomat, 6 Sep. 2017; NORSAR, 'Large nuclear test in North Korea on 3 September 2017', 3 Sep. 2017; University of Science and Technology of China (USTC), 'North Korea's 3 September 2017 nuclear test location and yield: seismic results from USTC', [n.d.]; and Swedish Defence Research Agency (FOI), 'Nuclear weapons test in North Korea', Press release, 11 Sep. 2017.

[18] See e.g. Lewis, J., 'Welcome to the thermonuclear club, North Korea!', *Foreign Policy*, 4 Sep. 2017.

[19] De Geer (note 14), pp. 128–55.

[20] Hansen, C., *Swords of Armageddon*, vol. 5 (Chukelea Publications: Sunnyvale, CA, 2007), p. 473.

[21] Hansen (note 20), pp. 96–97.

[22] Kelley, R., 'North Korea's sixth nuclear test: what do we know so far?', SIPRI Expert Comment, 5 Sep. 2017.

Table 6.16. Estimated number of nuclear explosions, 1945–2017

	USA[b]		Russia/ USSR		UK[b]		France		China		India		Pakistan		North Korea		
Year[a]	a	u	a	u	a	u	a	u	a	u	a	u	a	u	a	u	Total
1945	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
1946	2[c]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
1948	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
1949	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
1951	15	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	18
1952	10	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	11
1953	11	–	5	–	2	–	–	–	–	–	–	–	–	–	–	–	18
1954	6	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	16
1955	17[c]	1	6[c]	–	–	–	–	–	–	–	–	–	–	–	–	–	24
1956	18	–	9	–	6	–	–	–	–	–	–	–	–	–	–	–	33
1957	27	5	16[c]	–	7	–	–	–	–	–	–	–	–	–	–	–	55
1958	62[d]	15	34	–	5	–	–	–	–	–	–	–	–	–	–	–	116
1960	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	3
1961	–	10	58[c]	1	–	–	1	1	–	–	–	–	–	–	–	–	71
1962	39[c]	57	78	1	–	2	–	1	–	–	–	–	–	–	–	–	178
1963	4	43	–	–	–	–	–	3	–	–	–	–	–	–	–	–	50
1964	–	45	–	9	–	2	–	3	1	–	–	–	–	–	–	–	60
1965	–	38	–	14	–	1	–	4	1	–	–	–	–	–	–	–	58
1966	–	48	–	18	–	–	6	1	3	–	–	–	–	–	–	–	76
1967	–	42	–	17	–	–	3	–	2	–	–	–	–	–	–	–	64
1968	–	56	–	17	–	–	5	–	1	–	–	–	–	–	–	–	79
1969	–	46	–	19	–	–	–	–	1	1	–	–	–	–	–	–	67
1970	–	39	–	16	–	–	8	–	1	–	–	–	–	–	–	–	64
1971	–	24	–	23	–	–	5	–	1	–	–	–	–	–	–	–	53
1972	–	27	–	24	–	–	4	–	2	–	–	–	–	–	–	–	57
1973	–	24	–	17	–	–	6	–	1	–	–	–	–	–	–	–	48
1974	–	22	–	21	–	1	9	–	1	–	–	1	–	–	–	–	55
1975	–	22	–	19	–	–	–	2	–	1	–	–	–	–	–	–	44
1976	–	20	–	21	–	1	–	5	3	1	–	–	–	–	–	–	51
1977	–	20	–	24	–	–	–	9	1	–	–	–	–	–	–	–	54
1978	–	19	–	31	–	2	–	11	2	1	–	–	–	–	–	–	66
1979	–	15	–	31	–	1	–	10	1	–	–	–	–	–	–	–	58
1980	–	14	–	24	–	3	–	12	1	–	–	–	–	–	–	–	54
1981	–	16	–	21	–	1	–	12	–	–	–	–	–	–	–	–	50
1982	–	18	–	19	–	1	–	10	–	1	–	–	–	–	–	–	49
1983	–	18	–	25	–	1	–	9	–	2	–	–	–	–	–	–	55
1984	–	18	–	27	–	2	–	8	–	2	–	–	–	–	–	–	57
1985	–	17	–	10	–	1	–	8	–	–	–	–	–	–	–	–	36
1986	–	14	–	–	–	1	–	8	–	–	–	–	–	–	–	–	23
1987	–	14	–	23	–	1	–	8	–	1	–	–	–	–	–	–	47
1988	–	15	–	16	–	–	–	8	–	1	–	–	–	–	–	–	40
1989	–	11	–	7	–	1	–	9	–	–	–	–	–	–	–	–	28
1990	–	8	–	1	–	1	–	6	–	2	–	–	–	–	–	–	18
1991	–	7	–	–	–	1	–	6	–	–	–	–	–	–	–	–	14
1992	–	6	–	–	–	–	–	–	–	2	–	–	–	–	–	–	8

	USA[b]		Russia/ USSR		UK[b]		France		China		India		Pakistan		North Korea		
Year[a]	a	u	a	u	a	u	a	u	a	u	a	u	a	u	a	u	Total
1993	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1
1994	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	2
1995	–	–	–	–	–	–	–	5	–	2	–	–	–	–	–	–	7
1996	–	–	–	–	–	–	–	1	–	2	–	–	–	–	–	–	3
1998	–	–	–	–	–	–	–	–	–	–	–	2[e]	–	2[e]	–	–	4
2006	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
2009	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
2013	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
2016	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	2
2017	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Subtotal	**217**	**815**	**219**	**496**	**21**	**24**	**50**	**160**	**23**	**22**	–	**3**	–	**2**	–	**6**	
Total	**1 032**		**715**		**45**		**210**		**45**		**3**		**2**		**6**		**2 058**

– = no known test; a = atmospheric (or in a few cases underwater); u = underground[f]; USSR = Soviet Union.

[a] The table includes only those years in which a known explosion took place.

[b] All British tests from 1962 were conducted jointly with the USA at the US Nevada Test Site but are listed only under 'UK' in this table. Thus, the number of US tests is higher than shown. Safety tests carried out by the UK are not included in the table.

[c] One of these tests was carried out underwater.

[d] Two of these tests were carried out underwater.

[e] India's detonations on 11 and 13 May 1998 are listed as 1 test for each date. The 5 detonations by Pakistan on 28 May 1998 are also listed as 1 test.

[f] 'Underground nuclear test' is defined by the 1990 Protocol to the 1974 Soviet–US Threshold Test-Ban Treaty (TTBT) as 'either a single underground nuclear explosion conducted at a test site, or two or more underground nuclear explosions conducted at a test site within an area delineated by a circle having a diameter of two kilometres and conducted within a total period of time of 0.1 second' (section I, para. 2). 'Underground nuclear explosion' is defined by the 1976 Soviet–US Peaceful Nuclear Explosions Treaty (PNET) as 'any individual or group underground nuclear explosion for peaceful purposes' (Article II(a)). 'Group explosion' is defined as 'two or more individual explosions for which the time interval between successive individual explosions does not exceed five seconds and for which the emplacement points of all explosives can be inter-connected by straight line segments, each of which joins two emplacement points and each of which does not exceed 40 kilometres' (Article II(c)).

Sources: Bergkvist, N.-O. and Ferm, R., *Nuclear Explosions 1945–1998* (Swedish Defence Research Establishment/SIPRI: Stockholm, July 2000); Swedish Defence Research Agency (FOI), various estimates, including information from the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) International Data Centre and from the Swedish National Data Centre provided to the author in Feb. 2007 and Oct. 2009; Reports from the Australian Seismological Centre, Australian Geological Survey Organisation, Canberra; US Department of Energy (DOE), *United States Nuclear Tests: July 1945 through September 1992* (DOE: Washington, DC, 1994); Norris, R. S., Burrows, A. S. and Fieldhouse, R. W., Natural Resources Defense Council, *Nuclear Weapons Databook, vol. 5, British, French and Chinese Nuclear Weapons* (Westview: Boulder, CO, 1994); Direction des centres d'experimentations nucléaires (DIRCEN) and Commissariat à l'Énergie Atomique (CEA), *Assessment of French Nuclear Testing* (DIRCEN and CEA: Paris, 1998); Russian ministries of Atomic Energy and Defence, *USSR Nuclear Weapons Tests and Peaceful Nuclear Explosions, 1949 through 1990* (Russian Federal Nuclear Centre (VNIIEF): Sarov, 1996); and Natural Resources Defense Council, 'Archive of nuclear data', various years.

The estimated number of nuclear explosions, 1945–2017

Since 1945 there have been 2058 known nuclear explosions carried out by eight states—the USA, the Soviet Union, the United Kingdom, France, China, India, Pakistan and North Korea (see table 6.16). This total includes nuclear tests conducted in nuclear weapon test programmes, explosions carried out for peaceful purposes and the nuclear bombs dropped on Hiroshima and Nagasaki in August 1945. The total also includes tests for safety purposes carried out by France, the Soviet Union and the USA, irrespective of the yield and of whether they caused a nuclear explosion.[23] It does not include subcritical experiments that did not sustain a nuclear chain reaction. Simultaneous detonations, also known as salvo explosions, were carried out by the USA (from 1963) and the Soviet Union (from 1965), mainly for economic reasons.[24] A total of 20 per cent of the Soviet tests and 6 per cent of the US tests were salvo experiments.

No verified nuclear tests have been carried out by Israel. There are assertions that the unexpected 'double flash' registered by the US Vela 6911 satellite in September 1979 was an indication of a nuclear weapon test conducted by Israel with support from South Africa. However, this assertion has never been officially confirmed by either government.[25]

A number of moratoriums on testing, both voluntary and legal, have been observed. The Soviet Union, the UK and the USA observed a moratorium from November 1958 to September 1961. The 1963 Partial Test-Ban Treaty (PTBT), which prohibits nuclear explosions in the atmosphere, in outer space and underwater, entered into force on 10 October 1963.[26] The Soviet Union observed a unilateral moratorium on testing between August 1985 and February 1987. The Soviet Union and then Russia observed a moratorium on testing from January 1991 and the USA from October 1992, until they signed the CTBT on 24 September 1996. France observed a similar moratorium from April 1992 to September 1995. The CTBT, which has not yet entered into force, would prohibit the carrying out of any nuclear explosion.[27]

[23] In a safety experiment, or a safety trial, more or less fully developed nuclear devices are subjected to simulated accident conditions. The nuclear weapon core is destroyed by conventional explosives with either no or a very small release of fission energy. The UK has also carried out numerous safety tests but they are not included in table 6.16.

[24] The Soviet Union conducted simultaneous tests of up to 8 devices on 23 Aug. 1975 and 24 Oct. 1990 (the last Soviet test).

[25] Weiss, L., 'Flash from the past: why an apparent Israeli nuclear test in 1979 matters today', *Bulletin of the Atomic Scientists*, 8 Sep. 2015.

[26] India, Pakistan, Russia, the UK and the USA are among the parties. For a full list see annex A, section I, in this volume.

[27] China, France, Russia, the UK and the USA are among the parties. For a full list see annex A, section I, in this volume.