XI. Nuclear explosions, 1945–2016

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In January and September 2016 the Democratic People's Republic of Korea (DPRK, or North Korea) conducted its fourth and fifth nuclear test explosions, following tests conducted in February 2013, May 2009 and October 2006.[1] These events brought the total number of nuclear explosions recorded since 1945 to 2057.

The January 2016 nuclear test

On 6 January 2016 North Korea's official news agency, the Korean Central News Agency (KCNA), issued a number of statements first announcing and then declaring as successful the 'first H-bomb test' conducted by the country.[2] The test explosion took place at 01:30 Coordinated Universal Time (UTC) that day (10:00 local time). The KCNA announcement claimed that the tested explosive device was 'indigenous', and that the test explosion had been successful, safe and had not had any adverse impact on the environment. The same announcement stated that after 'succeeding in the H-bomb test' North Korea considered itself to have 'proudly joined the advanced ranks of nuclear weapons states', and to be equipped with 'the most powerful nuclear deterrent'.[3]

The September 2016 nuclear test

On 9 September 2016 at 00:30 UTC (09:00 local time) North Korea conducted its second nuclear test of the year. Shortly after, the KCNA disseminated a statement by the Nuclear Weapons Institute of the DPRK, claiming that a successful nuclear test explosion had been conducted to confirm the design of a 'standardized' nuclear warhead 'to be mounted on Hwasong strategic ballistic missiles of units of the Strategic Forces of the Korean People's Army'.[4] The statement again included a claim that the test had been safe for the environment and no 'radioactive leakage' had occurred. One novel feature of the statement was the announcement that the yield and efficiency

[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*; and Fedchenko, V., 'Nuclear explosions, 1945–2013', *SIPRI Yearbook 2014*.

[2] Korean Central News Agency (KCNA), 'WPK Central Committee issues order to conduct first H-bomb test', 6 Jan. 2016; and Korean Central News Agency (KCNA), 'DPRK proves successful in H-bomb test', 6 Jan. 2016. The KCNA's statements are available at its website hosted in Japan, <http://www.kcna.co.jp/>. The website is blocked to internet users outside of Japan.

[3] Korean Central News Agency, 'DPRK proves successful in H-bomb test' (note 2).

[4] Korean Central News Agency, 'DPRK succeeds in nuclear warhead explosion test', 9 Sep. 2016.

of the explosive device had been measured and found to correspond with calculated estimates.[5] Another interesting feature was a reference to North Korea's capability to produce 'various fissile materials' for use in weapons, which might be understood as a reference to the use of 'composite core' nuclear explosive devices, or devices that utilize fission of both HEU and plutonium. The experience of the United States and other states with advanced nuclear weapon programmes demonstrates that such a design feature could be advantageous in several scenarios, such as a shortage of any of the two fissile materials. The claim that the tested explosive device was small enough to be fitted on to a ballistic missile might mean that a 'levitated core' was used.[6]

Verification of 2016 North Korean tests by the international community

The international community—international organizations, individual states and many research institutions—sought to verify North Korea's claims concerning both tests using a combination of available technologies, including seismology, radionuclide monitoring and satellite imagery analysis.[7]

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.[8] 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, including through the establishment of an International Monitoring System (IMS) to detect nuclear explosions. While the CTBT had been ratified by 166 states by 31 December 2016, it cannot enter into force until it has been signed and ratified by 44 states with 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 two events in January and

[5] 'Efficiency' of a nuclear explosive device is normally understood as the fraction of fissile material that fissioned in the explosion.

[6] 'Levitated core' is a concept of suspending the pit at a distance within the tamper and high explosives assembly (e.g. on wires or stilts) to create space for the tamper to gather momentum before striking the fissile core-initiator assembly. This creates better compression, increases efficiency and allows the production of smaller explosive devices. Rhodes, R., *Dark Sun: The Making of the Hydrogen Bomb* (Simon & Schuster: New York, 1995), pp. 188–89. The concepts of levitated core and composite pits were developed and tested simultaneously in nuclear weapon development programmes. The USA tested both concepts during the Operation Sandstone tests in 1948. Hansen, C., *Swords of Armageddon*, vol. 1 (Chukelea Publications: Sunnyvale, CA, 2007), pp. 201–06.

[7] 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.

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

Table 11.15. Data on North Korea's nuclear explosion, 6 January 2016

Source[a]	Origin time (UTC)	Latitude	Longitude	Error margin[b]	Body wave magnitude[c]
IDC[d]	01:30:00.49±0.28	41.3039° N	129.0481° E	±8.4 km[e]	4.82
CEME	29:58.5	41.29° N	129.08° E	..	5.2
IGGCAS		41.3001° N	129.0716° E	..	4.67
NEIC	30:01.5	41.300° N	129.047° E	±6.0 km[f]	5.1
NORSAR	1:30:00	41.28° N	129.07° E	..	4.9

.. = data not available; CEME = Russian Academy of Sciences, Geophysical Survey, Central Experimental Methodical Expedition, Obninsk, Kaluga oblast, Russia; IDC = Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), International Data Centre, Vienna; IGGCAS = Chinese Academy of Sciences, Institute of Geology and Geophysics, Beijing, China; km = kilometres; NEIC = US Geological Survey, National Earthquake Information Center, Denver, CO, United States; NORSAR = Norwegian Seismic Array, Karasjok, Norway; UTC = Coordinated Universal Time.

[a] Because of differences between estimates, regarding the precise site and magnitude of the explosion, data from 5 sources—1 internationally recognized body and 4 national bodies—is provided for comparison (i.e. IDC and CEME, IGGCAS, NEIC, NORSAR).

[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 therefore an unambiguous way of giving the size of an explosion.

[d] The IDC was 'in a test and provisional operation mode only' and only *c.* 90% of the 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 semi-minor axis was 7.3 km (giving the confidence area of 193 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 14 January 2016', 14 Jan. 2014; CEME, [Information message about underground nuclear explosion made in North Korea on 6 January 2016], [n.d.] (in Russian); Zhao, L. et al., [Preliminary findings on 6 January 2016 Korean nuclear test identification and yield estimation], IGGCAS, 7 Jan. 2016 (in Chinese); NEIC, 'M 5.1 nuclear explosion—21km ENE of Sungjibaegam, North Korea', US Geological Survey, 6 Jan. 2016; NORSAR, 'New nuclear test by North Korea', Press release, [n.d.].

September 2016 (see tables 11.15 and 11.16 respectively). The recorded seismic wave patterns, the depth of both events (less than 1 kilometre) and the fact that they occurred so close to each other and to the three previous nuclear tests (a characteristic distance being a few hundred metres) indicated that they were explosions rather than earthquakes.[9]

Strictly speaking, seismic data alone is insufficient to confirm that an underground explosion is nuclear. Following North Korea's 2006 and 2013 tests, the nuclear nature of the explosion was confirmed when air sampling

[9] Gibbons, S. J. et al., 'Accurate relative location estimates for the North Korean nuclear tests using empirical slowness corrections', *Geophysical Journal International*, vol. 208, no 1 (Jan. 2017), pp. 101–17; and Richards, P., 'Seismic detective work: CTBTO monitoring system "very effective" in detecting North Korea's third nuclear test', *CTBTO Spectrum*, no. 20 (July 2013), p. 22.

Table 11.16. Data on North Korea's nuclear explosion, 9 September 2016

Source[a]	Origin time (UTC)	Latitude	Longitude	Error margin[b]	Body wave magnitude[c]
IDC[d]	00:30:00.87±0.24	41.2992° N	129.0491° E	±7.6 km[e]	5.1
CEME	29:59.0	41.30° N	129.13° E	. .	5.4
NEIC	30:01.4	41.287° N	129.078° E	±5.2 km[f]	5.3
NORSAR	0:30:00	41.28° N	129.07° E	. .	5.2

. . = data not available; CEME = Russian Academy of Sciences, Geophysical Survey, Central Experimental Methodical Expedition, Obninsk, Kaluga oblast, Russia; IDC = Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), International Data Centre, Vienna; km = kilometres; NEIC = US Geological Survey, National Earthquake Information Center, Denver, CO, United States; NORSAR = Norwegian Seismic Array, Karasjok, Norway; UTC = Coordinated Universal Time.

[a] Because of differences between estimates, regarding the precise site and magnitude of the explosion, data from 4 sources—1 internationally recognized body and 3 national bodies—is provided for comparison (i.e. IDC and CEME, NEIC, NORSAR).

[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 giving the size of an explosion.

[d] The IDC was 'in a test and provisional operation mode only' and only *c.* 90% of the 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 semi-minor axis was 6.4 km (giving the confidence area of 153 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, 'Summary of results for the DPRK announced nuclear test, 9 September 2016', 22 Oct. 2016 and CTBTO, IDC, 'Reviewed event bulletin', 10 Sep. 2016; CEME, [Information message about underground nuclear explosion made in North Korea on 9 September 2016], 19 Sep. 2016 (in Russian); NEIC, 'M 5.3 nuclear explosion—23km ENE of Sungjibaegam, North Korea', US Geological Survey, 7 Dec. 2016; NORSAR, 'North Korean underground nuclear test larger than previous tests', Press release, 9 Sep. 2016.

detected traces of radioxenon—radioactive isotopes of xenon, which are released from a nuclear explosion.[10] No trace of radioxenon or other radioactive debris was reported found after the 2009 event, or after either of the events in 2016.

Discussion of the January 2016 test results

North Korea does not announce the planned or measured yields from its test explosions. Estimates made by international researchers vary quite signifi-

[10] 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.

cantly. Most estimates for the January 2016 test fall within the range of 7–15 kilotons.[11]

The absence of any detection of radioactive debris makes it difficult to analyse the KCNA's claims that the January 2016 test explosion was a detonation of a hydrogen bomb. Some verification of such claims might have been possible, in principle, through sophisticated analysis of radioactive particles from the weapon's fallout.[12]

The US Director of National Intelligence, James Clapper, dismissed the claim that the January 2016 test featured an 'H-bomb', stating that 'the low yield of the test [was] not consistent with a successful test of a thermonuclear device'.[13] Russia's Minister of Foreign Affairs, Sergei Lavrov, also expressed doubts that the test was thermonuclear.[14] Some non-governmental experts speculated that the North Korean Government's use of the term 'H-bomb' may have been a reference to the use of tritium, a hydrogen isotope, in a boosted-fission weapon designed to generate a higher yield from a plutonium core.[15] These experts also suggested that while it was highly unlikely that the test involved a boosted or thermonuclear device, the available data, including on the relatively low yield of the January 2016 test, did not necessarily mean that the test 'was not of some form of boosted or thermonuclear device, or that the device failed', because 'a true thermonuclear bomb can have a useful yield of only tens of kilotons if it has been designed to give the correct weight and balance in a re-entry vehicle'.[16]

[11] Vishwanatan, A. et al., *North Korea's 2016 Nuclear Test: An Analysis* (National Institute of Advanced Studies: Bangalore, Jan. 2016), p. 4; University of Science and Technology of China (USTC), 'North Korea's 2016 nuclear test location and yield: seismic results from USTC', 6 Jan. 2016; and German Federal Institute for Geosciences and Natural Resources (BGR), 'Nordkorea: BGR registriert vermutlichen Kernwaffentest' [North Korea: BGR registers presumed nuclear weapon test], 9 Sep. 2016.

[12] 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.

[13] Clapper, J. R., US Director of National Intelligence, Statement for the Record: Worldwide Threat Assessment of the US Intelligence Community, Armed Services Committee, US Senate, 9 Feb. 2016, p. 7.

[14] Russian Ministry of Foreign Affairs, 'Sergey Lavrov's remarks and answers to media questions at a news conference on Russia's diplomacy performance in 2015', Moscow, 26 Jan. 2016.

[15] Kelley, R., and Evans, A., 'Testing times: North Korea carries out fourth nuclear test', *Jane's Intelligence Review*, Feb. 2016, pp. 42–43; and Fyffe, S., 'Hecker assesses North Korean hydrogen bomb claims', *Bulletin of the Atomic Scientists*, 7 Jan. 2016.

[16] Hansen, N. and Kelley, R., 'North Korea H-bomb claims examined', *Jane's Intelligence Review*, 9 Aug. 2016.

Discussion of the September 2016 test results

There is a consensus that the second test was significantly larger. Most yield estimates ranged from 12 to 25 kt.[17] As in previous tests, the lack of radionuclide data makes it difficult to verify specific assumptions concerning North Korean nuclear explosive devices—the most important in this case being the claim that the September 2016 event tested a warhead compact enough to be placed on a ballistic missile.

In March 2016 North Korea released imagery of its various missile components and a mock-up warhead. Experts who analysed this imagery concluded that the mock-up represented 'a credible design of a simple one-stage fission device, possibly boosted', that it was probably small enough to fit into a KN-08-type (Hwasong-13) warhead, and that this configuration could re-enter the atmosphere in a stable manner.[18] The claim by North Korea's Nuclear Weapons Institute that the September 2016 test confirmed the design of a nuclear warhead small enough to fit on to a Hwasong missile is now considered plausible by most analysts.[19]

Estimated number of nuclear explosions, 1945–2016

Since 1945 there have been 2057 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 11.17). 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.[20] 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

[17] German Federal Institute for Geosciences and Natural Resources (BGR) (note 11); University of Science and Technology China (USTC), 'North Korea's 9 September 2016 Nuclear test location and yield: seismic results from USTC', 10 Sep. 2016; and Hecker, S. S., 'What to make of North Korea's latest nuclear test?', 38 North, US–Korea Institute, 12 Sep. 2016.

[18] Hansen, N., Kelley, R. and Puccioni, A., 'North Korean nuclear programme advances', *Jane's Intelligence Review*, 29 Mar. 2016; and Schiller, M. and Kelley, R., 'Evolving threat: North Korea's quest for an ICBM', *Jane's Defence Weekly*, 12 Jan. 2017.

[19] Schiller and Kelley (note 18); and Hecker (note 17).

[20] 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 no or very small releases of fission energy. The UK has also carried out numerous safety tests, but they are not included in table 11.17.

Table 11.17. Estimated number of nuclear explosions, 1945–2016

	USA[a]		Russia/ USSR		UK[a]		France		China		India		Pakistan		North Korea		
Year[b]	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**
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**
Total	**217**	**815**	**219**	**496**	**21**	**24**	**50**	**160**	**23**	**22**	–	**3**	–	**2**	–	**5**	
Total		**1032**		**715**		**45**		**210**		**45**		**3**		**2**		**5**	**2057**

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

[a] 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.

[b] Table includes only those years in which a known explosion took place.

[c] 1 of these tests was carried out under water.

[d] 2 of these tests were carried out under water.

[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 Center (VNIIEF): Sarov, 1996); and Natural Resources Defense Council, 'Archive of nuclear data', <http://www.nrdc.org/nuclear/nudb/datainx.asp>.

reasons.[21] 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.[22]

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

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

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

(PTBT), which prohibits nuclear explosions in the atmosphere, in outer space and under water, entered into force on 10 October 1963.[23] 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.[24]

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

[24] The signatories include China, France, Russia, the UK and the USA. For a full list see annex A, section I, in this volume.