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NORTH KOREA'S NUCLEAR TEST EXPLOSION, 2009

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INTRODUCTION

In May 2009 the Democratic People's Republic of Korea (DPRK, or North Korea) conducted what is widely believed to be a nuclear test explosion. This was North Korea's second nuclear explosion, following one conducted in October 2006. This Fact Sheet presents a brief discussion of the North Korean explosion, in particular how international researchers have sought to determine its nature, location and yield based on the available data, and then presents up-to-date data on the number of nuclear explosions conducted since 1945.

THE NUCLEAR TEST IN NORTH KOREA

On 29 April 2009 North Korea's official news agency, the Korean Central News Agency (KCNA), issued a statement warning that the country was prepared to conduct a nuclear test explosion as a response to the imposition of sanctions by the United Nations Security Council.[1]

On 25 May 2009, the Chinese and United States governments were reportedly given less than one hour's notice that North Korea would conduct a nuclear test.[2] The explosion itself took place at 00:54 UTC (see table 1).[3] At 02:24 UTC the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization Preparatory Commission (CTBTO) issued the first report to CTBTO member states on the time, location and magnitude of the event.[4] A few hours later the KCNA announced that North Korea has conducted 'one more successful underground nuclear test' that was 'on a new higher level in terms of its explosive power and technology'.[5]

[1] Korean Central News Agency, 'UNSC urged to retract anti-DPRK steps', 29 Apr. 2009, <http://www.kcna.co.jp/item/2009/200904/news29/20090429-14ee.html>. Following North Korea's missile test launch of 5 Apr., on 24 Apr. the UN Security Council had designated 3 North Korean companies as being subject to the embargo imposed in 2006. See United Nations, Security Council, Report of the Security Council Committee established pursuant to Resolution 1718 (2006) prepared in accordance with the Presidential Statement of 13 April 2009, S/2009/222, 24 Apr. 2009; United Nations, Security Council, Statement by the President of the Security Council, S/PRST/2009/7, 13 Apr. 2009; and UN Security Council Resolution 1718, 14 Oct. 2006.

[2] Agence France-Presse, 'NKorea informed US of nuclear test: official', 25 May 2009, <http://www.google.com/hostednews/afp/article/ALeqM5gRTYYuI6qR20V2-SERacQVXo4Zhg>.

[3] UTC is Coordinated Universal Time, which approximates to Greenwich Mean Time (GMT).

[4] CTBTO, 'CTBTO's initial findings on the DPRK's 2009 announced nuclear test', Press release, 25 May 2009, <http://www.ctbto.org/press-centre/press-releases/2009/ctbtos-initial-findings-on-the-dprks-2009-announced-nuclear-test/>.

[5] Korean Central News Agency, 'KCNA report on one more successful underground nuclear test', 25 May 2009, <http://www.kcna.co.jp/item/2009/200905/news25/20090525-12ee.html>.

SUMMARY

● On 25 May 2009 the Democratic People's Republic of Korea (DPRK, or North Korea) conducted what is widely believed to be a nuclear test explosion. Following the event, a combination of seismology, radionuclide monitoring and satellite imagery analysis was employed by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), individual states and many research institutions to verify whether there had indeed been an explosion and, if so, its characteristics such as location, yield and nature.

From the evidence available, it is possible to conclude (with varying degrees of certainty) that the event was an underground nuclear test explosion of a plutonium device, that it took place in North Korea's North Hamgyong province, and that the yield was approximately a few kilotons. Full verification of these conclusions would require on-site inspection.

Since 1945 there has been a total of 2054 nuclear explosions, including tests, explosions carried out for peaceful purposes and the two nuclear bombs dropped in August 1945.

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Table 1. Data on North Korea's nuclear explosion, 25 May 2009

Source[a]	Origin time (UTC)	Latitude	Longitude	Error margin[b]	Body wave magnitude[c]
IDC[d]	00:54:42.8	41.3110° N	129.0464° E	±9.6 km[e]	4.52
BJI	00:54:43.10	41.3000° N	129.0000° E	. .	4.6
CEME	00:54:40.9	41.29° N	129.07° E	. .	5.0
NEIC	00:54:43	41.306° N	129.029° E	±3.8 km[f]	4.7
NORSAR	00:54:43	41.28° N	129.07° E	. .	4.7

UTC = Coordinated Universal Time; km = kilometres; . . = data not available.

[a] Because of differences between estimates, particularly regarding the precise site of the explosion, data from 5 sources—1 internationally recognized body and 4 national bodies—is provided for comparison. IDC = Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO), International Data Centre, Vienna; CEME = Russian Academy of Sciences, Geophysical Survey, Central Experimental Methodical Expedition, Obninsk, Kaluga oblast; BJI = China Earthquake Administration, Institute of Geophysics, Beijing; NEIC = US Geological Survey, National Earthquake Information Center, Denver, CO; NORSAR = Norwegian national data centre for the CTBTO, Karasjok.

[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 75% 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.

[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: *IDC data*: Excerpts from the CTBTO Reviewed Event Bulletin (REB) provided by the CTBTO Public Information Section and the Swedish Defence Research Agency (FOI); and CTBTO, 'CTBTO's initial findings on the DPRK's 2009 announced nuclear test', Press release, 25 May 2009, <http://www.ctbto.org/press-centre/press-releases/2009/ctbtos-initial-findings-on-the-dprks-2009-announced-nuclear-test/>; *CEME data*: CEME, 'Information message on underground nuclear explosion conducted in North Korea on May 25, 2009', 26 May 2009, <http://www.ceme.gsras.ru/cgi-bin/info_quakee.pl?mode=1&id=125>; *BJI data*: International Seismological Centre (ISC), 'Event 13193113 North Korea', ISC On-line Bulletin, <http://www.isc.ac.uk/cgi-bin/web-db-v3?event_id=13193113>; *NEIC data*: NEIC, 'Magnitude 4.7: North Korea', Preliminary Earthquake Report, 7 Aug. 2009, <http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/us2009hbaf.php>; *NORSAR data*: NORSAR, 'Announced nuclear test by North Korea', Press release, <http://www.norsar.no/pc-61-99-Announced-Nuclear-Test-by-North-Korea.aspx>.

The KCNA claim had to be verified by available technologies. The technologies used for verification of underground nuclear tests include seismology, radionuclide monitoring and satellite imagery analysis.[6] Following the event, a combination of these technologies was employed by the IMS, individual states and many research institutions outside North Korea to verify whether there had indeed been an explosion and, if so, its characteristics such as location, yield and nature. Different estimates of the time, location and size of the 25 May explosion are given in table 1.

Location

Seismic monitoring networks record the various seismic waves propagating from a source through the earth's deep interior and surface. Analysis of these records often allows the azimuth (direction) and the distance of the event to be calculated.

[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.

On 25 May 2009 a seismic event was recorded at 00:54 UTC by several monitoring networks, which calculated its origin as being approximately 70 kilometres north of the city of Kimchaek in North Korea's North Hamgyong province, no more than a few kilometres from the location of the 2006 nuclear test.[7]

Event identification

In order to discriminate between seismic signals from an earthquake and those from an explosion, the location, depth and wave patterns associated with the event are normally studied. If the seismic signals originate in an area where earthquakes are rare or unheard of, the event would naturally receive additional scrutiny. If the depth of an event can confidently be estimated as being more than 10 km, then it can normally be screened out as being too deep for a man-made explosion.[8]

The fact that the seismic event in question is an explosion, rather than an earthquake, can also be confirmed by analysis of seismic wave patterns. Two types of seismic waves propagate through the earth's deep interior: compressional (or longitudinal) waves and shear (or transverse) waves. An explosion has a compact symmetrical wave source, which blasts outwards evenly in all directions and excites compressional waves particularly efficiently. Earthquakes, in contrast, are caused by large sections of the earth's crust grinding past each other along a fault line, which produces stronger shear waves. Thus, if the compressional waves—which travel faster than shear waves and arrive first at seismic monitoring stations—are the stronger of the two types associated with an event, then that would suggest that the seismic event was an explosion. Other wave characteristics can also help to distinguish an earthquake from an explosion.[9]

In the case of the North Korean event of 25 May 2009, the wave patterns recorded at monitoring stations, the depth of the event (less than 1 km) and the fact that it occurred so close to the site of the 2006 nuclear test indicate that it was an explosion rather than an earthquake.[10]

Explosion yield

Data on the seismic magnitude of the event is normally used to estimate the yield of an explosion, although the accuracy of such estimates is affected by the amount of information available on the geology of the test site.[11]

Based on the seismic data, most estimates of the yield of the May 2009 explosion vary between 2 and 7 kilotons, which is about 'about 5 times stronger' than the 2006 test.[12] In June 2009 the US Government estimated

[7] Pearce, R. G. et al., 'The announced nuclear test in the DPRK on 25 May 2009', *CTBTO Spectrum*, no. 13 (Sep. 2009), p. 27. See also table 1 for estimates of the location.

[8] US National Academy of Sciences (note 6), p. 43.

[9] US National Academy of Sciences (note 6), p. 39.

[10] Pearce et al. (note 6), p. 27.

[11] US National Academy of Sciences (note 6), pp. 41–42.

[12] MacKenzie, D., 'North Korea's nuke test could have positive outcome', *New Scientist*, 26 May 2009. The nuclear test explosion in 2006 was estimated to have had a yield under 1 kt. Fedchenko, V. and Ferm Hellgren, R., 'Nuclear explosions, 1945–2006', *SIPRI Yearbook 2007: Armaments, Disarmament and International Security* (Oxford University Press: Oxford, 2007), p. 553.

the yield as 'approximately a few kilotons'.[13] Non-governmental scientists tend to agree with this assessment.[14] The Russian Ministry of Defence estimated that 'The nuclear device had a yield of between 10 and 20 kilotons'.[15] The South Korean Institute of Geoscience and Mineral Resources estimated the yield to have been 5.2 kt.[16] Won-Young Kim and Paul Richards of Columbia University estimated a yield of about 2.2 kt, assuming that the explosion took place in hard rock. This estimate matches the results of Jungmin Kang of Stanford University, who estimated the yield as being 2.2–2.8 kt for an underground nuclear test in hard rock.[17]

Nature of the explosion

Seismic data alone is insufficient to confirm that an underground explosion is nuclear. Air sampling—which aims to collect and identify radioactive material such as particulate and gaseous effluents and debris in the vicinity of an event—can provide the most useful evidence following a nuclear explosion.

Air sampling can help to measure: (*a*) the neutron fluence and spectrum (i.e. the volume and energy of neutrons emitted by the explosion); (*b*) the yield of the device; (*c*) the design of the nuclear weapon (using information from *a* and *b*); (*d*) the age of the plutonium used (if plutonium was detonated); (*e*) when the detonation took place; (*f*) the general location of the detonation; (*g*) whether the detonation was atmospheric or submerged; and (*h*) the source of the nuclear materials used.[18]

For air sampling to be successful, the following factors must be favourable: (*a*) there must be an accessible radioactive plume; (*b*) the meteorology must be favourable; and (*c*) the background radionuclide concentration must be low relative to the concentration of the nuclides in the plume.[19] With these limitations, a negative result from air sampling cannot be used to conclude that no nuclear test took place: if no radionuclides are detected, the conclusion must be that either no nuclear explosion took place or one of the above limitations influenced the detection process.

Following North Korea's 2006 test, several states and the CTBTO radionuclide monitoring network used air sampling to detect traces of radioxenon, which confirmed the nuclear nature of the explosion.[20] However, after the

[13] US Office of the Director of National Intelligence, 'Statement by the Office of the Director of National Intelligence on North Korea's declared nuclear test on May 25, 2009', News Release no. 23-09, 15 June 2009, <http://www.dni.gov/press_releases/20090615_release.pdf>.

[14] Kalinowski, M. B., 'Second nuclear test conducted by North Korea on 25 May 2009', Fact sheet, University of Hamburg, Carl Friedrich von Weizsäcker Centre for Science and Peace Research (ZNF), 27 May 2009, <http://www.znf.uni-hamburg.de/Factsheet_NK.pdf>.

[15] RIA Novosti, 'Russia confirms N.Korea nuclear test, voices concern - 2', 25 May 2009, <http://en.rian.ru/russia/20090525/155081541.html>. This estimate is the highest of all announced and was not independently confirmed. The Russian Ministry of Defence is also believed to have overestimated the yield of the 2006 explosion. See Fedchenko, V. and Ferm Hellgren, R. (note 12).

[16] Yoo J., 'Test threatens regional stability', *JoongAng Daily* (Seoul), 26 May 2009.

[17] Kang, J., 'The North Korean nuclear test: Seoul goes on the defensive', *Bulletin of the Atomic Scientists*, 12 June 2009.

[18] Williams, D. L., 'Characterizing nuclear weapons explosions based upon collected radionuclide effluents', Memorandum, Massachusetts Institute of Technology, Department of Nuclear Science and Engineering, 21 Oct. 2006, <http://web.mit.edu/tyler9/www/Characterizing Nuclear Weapons Explosions.doc>.

[19] Williams (note 18).

[20] Fedchenko and Ferm Hellgren (note 12), p. 553.

2009 event no trace of radioxenon or other debris was reported to have been found.[21] The failure to find radioactive effluents in 2009 might be attributable to two reasons: (*a*) the test was buried deeper than the 2006 event; or (*b*) a broad region of high atmospheric pressure suppressed the exhalation of xenon isotopes when they might have been detected before their decay to background levels.[22]

Despite this, there is consensus among scientists and CTBTO officials that the explosion on 25 May 2009 in North Korea was most probably nuclear. The alternative to a nuclear explosion would have been the highly synchronized detonation of thousands of tonnes of explosive material. Chemical explosions of this size are not unheard of. For example, the Soviet Union was reported to have set off 'several immense explosions' in the last half of 1956, with charges of 1640–9200 tons.[23] However, the preparation by North Korea of such an explosion would have been a massive undertaking, easily detectable by satellite imagery.[24]

In order to establish the nuclear nature of the event with absolute certainty, on-site inspection is needed. As the CTBTO has pointed out, had the 1996 Comprehensive Nuclear-Test-Ban Treaty been in force, it would have been possible to conduct such an inspection because the location of the explosion was determined 'precisely enough to stay within the 1,000 km^2 to which on-site inspections are limited'.[25] Indeed, the size of the error ellipse determined by the CTBTO was about four times smaller than the area of 1000 km^2 allowed by the treaty.[26]

Due to the absence of detected radioactive effluents from the explosion, it is not possible to establish whether the North Korean test in 2009 used uranium or plutonium. It is widely assumed that it used plutonium.[27]

The extent to which the North Korean nuclear test was successful is uncertain because, unlike in 2006, North Korea did not pre-announce the expected yield of the explosion. Some experts have questioned the success of the test, because the several-kiloton yield of the North Korean device is still a few times smaller than the yield that the initial nuclear tests by nuclear weapon states have historically produced.[28]

[21] Pearce et al. (note 7), pp. 28–29.

[22] Pearce et al. (note 7), p. 29.

[23] Kramish, A., *Atomic Energy in the Soviet Union* (Stanford University Press: Palo Alto, CA, 1960), p. 137.

[24] CTBTO, 'Experts sure about nature of the DPRK event', Press release, 12 June 2009, <http://www.ctbto.org/press-centre/highlights/2009/experts-sure-about-nature-of-the-dprk-event/>; and Clery, D., 'Verification experts puzzled over North Korea's nuclear test', *Science*, 19 June 2009.

[25] CTBTO, 'Homing in on the event', Press release, 29 May 2009, <http://www.ctbto.org/press-centre/highlights/2009/homing-in-on-the-event/>. The Comprehensive Nuclear-Test-Ban Treaty was opened for signature on 24 Sep. 1996. It will enter into force after it has been ratified by 44 states with certain nuclear facilities. As of May 2009, 9 of these states (including North Korea) had not ratified the treaty. For the text of the treaty see United Nations Treaty Collection, <http://treaties.un.org/Pages/CTCTreaties.aspx?id=26>.

[26] The error ellipse is the ellipse-shaped region within which it is highly likely that the event took place. According to the CTBTO Reviewed Event Bulletin, the semi-major axis of the error ellipse is 9.6 km and the semi-minor axis is 8.8 km. Thus, the area of the error ellipse is approximately 265.4 km^2. Excerpts from the CTBTO Reviewed Event Bulletin were provided by the CTBTO Public Information Section and the Swedish Defence Research Agency (FOI).

[27] See Kile, S. N., 'Nuclear arms control and non-proliferation', *SIPRI Yearbook 2010: Armaments, Disarmament and International Security* (Oxford University Press: Oxford, forthcoming 2010).

[28] Park, J., 'The North Korean nuclear test: what the seismic data says', *Bulletin of the Atomic Scientists*, 26 May 2009.

Table 2. Estimated number of nuclear explosions, 1945–2009

a = atmospheric (or in a few cases underwater); u = underground.

	USA[a]		Russia/ USSR		UK[a]		France		China		India		Pakistan		North Korea		
Year	a	u	a	u	a	u	a	u	a	u	a	u	a	u	a	u	Total
1945	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
1946	2[b]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
1947	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1948	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
1949	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
1950	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1951	15	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	18
1952	10	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	11
1953	11	–	5	–	2	–	–	–	–	–	–	–	–	–	–	–	18
1954	6	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	16
1955	17[b]	1	6[b]	–	–	–	–	–	–	–	–	–	–	–	–	–	24
1956	18	–	9	–	6	–	–	–	–	–	–	–	–	–	–	–	33
1957	27	5	16[b]	–	7	–	–	–	–	–	–	–	–	–	–	–	55
1958[c]	62[d]	15	34	–	5	–	–	–	–	–	–	–	–	–	–	–	116
1959[c]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1960[c]	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	3
1961[c]	–	10	58[b]	1	–	–	1	1	–	–	–	–	–	–	–	–	71
1962	39[b]	57	78	1	–	2	–	1	–	–	–	–	–	–	–	–	178
1963[e]	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[f]	–	17	–	10	–	1	–	8	–	–	–	–	–	–	–	–	36
1986[f]	–	14	–	–	–	1	–	8	–	–	–	–	–	–	–	–	23
1987[f]	–	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[g]	–	7	–	–	–	1	–	6	–	–	–	–	–	–	–	–	14

Year	USA[a]		Russia/ USSR		UK[a]		France		China		India		Pakistan		North Korea		Total
	a	u	a	u	a	u	a	u	a	u	a	u	a	u	a	u	
1992[g]	–	6	–	–	–	–	–	–	–	2	–	–	–	–	–	–	8
1993[g]	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1
1994[g]	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	2
1995[g]	–	–	–	–	–	–	–	5	–	2	–	–	–	–	–	–	7
1996[g]	–	–	–	–	–	–	–	1	–	2	–	–	–	–	–	–	3
1997	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
1998	–	–	–	–	–	–	–	–	–	–	–	2[h]	–	2[h]	–	–	4
1999	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2001	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2002	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2003	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2004	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2005	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2006	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
2007	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2008	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
2009	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Subtotal	**217**	**815**	**219**	**496**	**21**	**24**	**50**	**160**	**23**	**22**	**–**	**3**	**–**	**2**	**–**	**2**	
Total	**1032**		**715**		**45**		**210**		**45**		**3**		**2**		**2**		**2054**

Notes: This table is based on tables previously published in the SIPRI Yearbook, most recently Fedchenko, V. and Ferm Hellgren, R., 'Nuclear explosions, 1945–2006', *SIPRI Yearbook 2007: Armaments, Disarmament and International Security* (Oxford University Press: Oxford, 2007), table 12B.2.

For the purposes of this table 'underground nuclear test' is defined according to Section I, para. 2 of the 1990 Protocol to the 1974 US–Soviet Treaty on the Limitation of Underground Nuclear Weapon Tests (Threshold Test Ban Treaty, TTBT): '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 kilometers and conducted within a total period of time of 0.1 second'. 'Underground nuclear explosion' is defined according to the 1976 US–Soviet Treaty on Underground Nuclear Explosions for Peaceful Purposes (Peaceful Nuclear Explosions Treaty, PNET): '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 interconnected by straight line segments, each of which joins two emplacement points and each of which does not exceed 40 kilometers' (Article II.c). For the text of the TTBT, its Protocol and the PNET see *United Nations Treaty Series*, vol. 1714 (1993).

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

[c] The UK, the Soviet Union and the USA observed a moratorium on testing from Nov. 1958 to Sep. 1961.

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

[e] On 5 Aug. 1963 the USSR, the UK and the USA signed the Partial Test-Ban Treaty (PTBT), prohibiting nuclear explosions in the atmosphere, in outer space and under water. It was subsequently opened for signature by all other states and entered into force on 10 Oct. 1963. For the text of the PTBT see *United Nations Treaty Series*, vol. 480 (1963).

[f] The USSR observed a unilateral moratorium on testing between Aug. 1985 and Feb. 1987.

[g] The USSR and then Russia observed a moratorium on testing from Jan. 1991 and the USA from Oct. 1992, until they signed the Comprehensive Nuclear-Test-Ban Treaty (CTBT); France observed a similar moratorium from Apr. 1992 to Sep. 1995. The CTBT was opened for signature on 24 Sep. 1996. It has not yet entered into force. For the text of the CTBT see United Nations Treaty Collection, <http://treaties.un.org/Pages/CTCTreaties.aspx?id=26>.

[h] 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.

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Sources for table 2: Swedish Defence Research Agency (FOI), various estimates, including information from the CTBTO International Data Centre; 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., 'British, French and Chinese nuclear weapons', *Nuclear Weapons Databook*, vol. 5 (Natural Resources Defense Council: Washington, DC, 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 Ministry of Atomic Energy and Russian Ministry of Defence, *USSR Nuclear Weapons Tests and Peaceful Nuclear Explosions, 1949 through 1990* (All-Russian Research Institute of Experimental Physics, Russian Federal Nuclear Center (VNIIEF): Sarov, 1996); Natural Resources Defense Council, 'Archive of nuclear data', <http://www.nrdc.org/nuclear/nudb/datainx.asp>; and Swedish Defence Research Agency (FOI), Swedish National Data Centre, Information provided to the authors, Feb. 2007 and Oct. 2009.

ESTIMATED NUMBER OF NUCLEAR EXPLOSIONS, 1945–2009

Table 2 lists the known nuclear explosions to date, including nuclear tests conducted in nuclear weapon test programmes, explosions carried out for peaceful purposes and the two nuclear bombs dropped on Hiroshima and Nagasaki in August 1945. The totals also include tests for safety purposes carried out by France, the Soviet Union/Russia and the USA, irrespective of the yield and of whether they caused a nuclear explosion.[29] The table does not include subcritical experiments. Simultaneous detonations, also called salvo explosions, were carried out by the USA (from 1963) and the Soviet Union (from 1965), mainly for economic reasons.[30] Of the Soviet tests, 20 per cent were salvo experiments, as were 6 per cent of the US tests.

[29] 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 United Kingdom also carried out numerous safety tests, but they are not included in table 2 because of their high number.

[30] The Soviet Union conducted simultaneous tests including as many as 8 devices on 23 Aug. 1975 and on 24 Oct. 1990 (the last Soviet test).