Technical Analysis of the DPRK Nuclear Test

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Article by Jungmin Kang and Peter Hayes

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I. Introduction

Jungmin Kang, Science Fellow at the Center for International Security and Cooperation (CISAC) at Stanford University, and Peter Hayes, Nautilus Institute Executive Director, write, "Having tested and failed, the DPRK can no longer rely on opacity as the basis for having a credible nuclear force, at least sufficiently credible to threaten its adversaries with a nuclear explosion. The DPRK might believe that a half kilotonne "mininuke" still provides it with a measure of nuclear deterrence and compellence; but it could not rely on other nuclear weapons states to perceive it to have anything more than an unusable, unreliable and relatively small nuclear explosive device."

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II. Report by Jungmin Kang and Peter Hayes

- Technical Analysis of the DPRK Nuclear Test
by Jungmin Kang and Peter Hayes

Introduction

In this study, we analyze the DPRK nuclear test on October 9, 2006 and provides basic insight into what information must be obtained in order to determine the size of the explosive force by the North Korean test, and whether it was only partly successful.   To this end, we review what can be determined from the test's seismic signature; from the release of gaseous fission products; and from hypothetical analysis of plutonium debris from the test.

We conclude that the DPRK test did not enable it to pole-vault into the ranks of nuclear weapons states. Although the timing remains uncertain, we forecast that the DPRK will test again in order to demonstrate decisively that it has a working nuclear device that can be weaponized, on a par with other nuclear weapons states. Meanwhile, the DPRK inhabits a peculiar and ambiguous status between having declared itself to be nuclear-armed, and having demonstrated by its test that it is not capable of such armament.

This uncomfortable status offers the United States new leverage whereby it may either make the situation worse, for example, by reasserting nuclear deterrence threats against the DPRK thereby hastening the day of a second test; or shape the external political factors that interact to affect the DPRK leadership's calculus in ways that may lead the DPRK to abandon its efforts to demonstrate decisively its acquisition of nuclear weapons capacity by a second test.

1. Relationship between seismic magnitude and yield of underground nuclear explosion
The relationship between the seismic magnitude and the yield of a nuclear explosion varies according to local geological conditions. (1) Nonetheless, the following equation is generally applicable in the interpretation of relationship between seismic magnitude and yield of nuclear explosion (less than 120 kt of TNT equivalent (2)) in a hard rock underground nuclear test. (3)

$$Mb = 4.262+0.973 \log Y$$

Where, Mb: Richter seismic scale, and
Y: yield of nuclear explosion.

The US Geological Survey has published a reading of 4.2 on the Richter scale at location of 41.294°N and 129.134°E for the DPRK nuclear test. The Complete Test Ban Treaty Organization announced that it registered at 4.0 on the Richter scale. (4)

A reading of 4.0 and 4.2 on the Richter scale would corresponding to a nuclear explosive yield of about 0.5 and 0.9 kt of TNT-equivalent, respectively, according to the above equation. Thus, the most easily obtained estimate of the size of the explosion is 0.5-0.9 kt. This is a yield given for small tactical nuclear warheads formerly in the American arsenal; and is a small fraction of the yield of first tests of other countries (19 kt US, 25 FSU, 25 UK, 60 France, 22 China, 12 India, ~9 Pakistan). (5) It led some pundits to wonder whether the DPRK even conducted a nuclear explosion at all at the test site.

2. Radionuclide measurement for the confirmation of nuclear explosion
This issue was resolved decisively when the US Director of National Intelligence stated decisively

that: "Analysis of air samples collected on October 11, 2006 detected radioactive debris which confirms that North Korea conducted an underground nuclear explosion in the vicinity of P'unggye on October 9, 2006. The explosion yield was less than a kiloton." (6) This statement is consistent, therefore, with the simply physical calculation provided in section 1 but adds some additional information from analysis of fission products from the test explosion.

The North Korean test was almost certainly a bomb that used plutonium rather than enriched uranium although the DNI did not state this in public. (7) When a small mass of plutonium fissions in a chain reaction that causes the explosion, various fission products are thereby created, including radioactive noble gas nuclides. Among these, Xe-131m, Xe-133, Xe-133m, and Xe-135 are good indicators that are widely used to monitor nuclear explosion because the minimum detectable concentration of these gases are so tiny in the downwind plume that spreads out from a test site--on the order of mBq per m3 of air. (8) Another noble radioactive gas, Kr-85, is much less useful than Xe because of its long half-life of 10.76 years and high atmospheric background concentration level that makes small pulses from small tests hard to identify. (9) However, due to the short decay time of radioactive xenon, collection and measurement of the radioactive xenon needs to be performed quickly after a nuclear explosion. Table 1 shows the half-lives of radioactive xenon and minimum detectable concentrations (MDC). (10)

Table 1. Half-lives of radioactive xenon and their minimum detectable concentration (MDC)

Radioactive Xenon	Half-life	MDC (mBq/m3 air)
Xe-131m	11.934 days	10
Xe-133	5.243 days	0.5
Xe-133m	2.19 days	4
Xe-135	9.1 hours	2

Using the ORIGEN2 code, Kang calculated the total radioactivities of radioactive xenon and Kr-85 produced from the DPRK nuclear test of Oct. 9, 2006 assuming that the test had a 1kt TNT equivalent explosive yield. (11) Table 2 shows the results of the calculations.

Table 2. Estimated radioactivities of radioactive xenon and Kr-85 from 1kt TNT ~ nuclear explosion (Unit: Bq)

Nuclides

Days after nuclear test

0

1

2

5

10

30

60

Xe-131m

5.0x1011

3.1x1012

5.5x1012

1.1x1013

1.6x1013

1.2x1013

2.9x1012

Xe-133

1.7x1015

7.2x1015

8.9x1015

7.7x1015

4.2x1015

3.0x1014

5.7x1012

Xe-133m

3.1x1014

5.9x1014

5.9x1014

3.1x1014

6.7x1013

1.2x1011

9.1x106

Xe-135

6.8x1016

4.3x1016

9.5x1015

4.9x1013

5.3x109

6.7x10-7

0.0

Kr-85

1.8x1011

3.5x1011

3.5x1011

3.5x1011

3.5x1011

3.5x1011

3.5x1011

How much of these fission products leaked from the DPRK underground test site is unknown although typically the quantities are a small fraction of the total radioactivity. The downwind concentration is then a function of topography, wind and weather patterns, and time. However, it appears certain from the public statement of the US Director of Intelligence that levels at or above the minimum detectable concentration were found and sampled. Given a detailed modeling of the air transport plume and the possible geological release pathways, it would be possible from the measured concentrations to calculate ranges of estimated yield to compare with the estimates obtained from the seismic signature. However, given the large uncertainties in all these variables, especially the geology and nature of the test site, this latter backcasting would likely result in a very large range of estimates and add little useful extra information to the seismic signature method of estimating yield. Monitoring these gases, therefore, would provide a simple binary yes/no confirmation of the fact of a *nuclear* test rather than a reliable way to estimate the yield of the North Korean test.

3. Confirmation of yield of nuclear explosion using plutonium debris

The seismic magnitude resulted from the DPRK underground nuclear test gives a rough estimate of the yield of the explosion. The precise yield of the DPRK nuclear explosion can be confirmed by measurements of some isotopic compositions of plutonium debris released from the explosion.

Table 3 shows estimated the likely isotopic compositions of plutonium debris from the DPRK nuclear test of Oct. 9, 2006, calculated by one of the authors (Kang) using ORIGEN2.

Table 3. Estimated isotopic compositions of plutonium debris from the DPRK nuclear test of Oct. 9, 2006

Burnup of spent fuel containing the plutonium (MWd/tHM)	Explosive yield (kt TNT)	Pu-239/Pu (%)	Pu-240/ Pu-239 (%)
100	0	98.9	1.1
	1	98.7	1.3
	2	98.4	1.6
	5	97.7	2.4

10

96.3

3.7

20

93.3

7.0

200

0

98.0

2.0

1

97.8

2.2

2

97.5

2.5

5

96.7

3.3

10

95.4

4.7

20

92.3

8.0

300

0

97.1

2.9

1

96.9

3.1

2

96.6

3.4

5

95.8

4.2

10

94.4

5.7

20

91.3

9.1

400

0

96.3

3.7

1

96.0

4.0

2

95.8

4.3

5

95.0

5.1

10

93.5

6.6

20

90.4

10.2

500

0

95.4

4.6

1

95.2

4.8

2

94.9

5.1

5

94.1

6.0

10

92.7

7.6

20

89.4

11.2

600

0

94.6

5.4

1

94.4

5.7

2

94.1

6.0

5

93.3

6.9

10

91.8

8.5

20

88.5

12.2

700

0

93.8

6.2

1

93.6

6.5

2

93.3

6.8

5

92.5

7.7

10

91.0

9.4

20

87.7

13.2

Assuming that the plutonium used in the test was obtained from spent fuel from past operation of the Yongbyon 5 MWe graphite reactor, then we judge that the average burnup rate would have been about 100-150 MWd/tHM for one year operation of the reactor; and about 300-600 MWd/tHM for 3-4 years operation. Depending on the observed ratios and given the seismic signature, one could thereby determine either the "age" of the source plutonium (that is, which period of operation of the reactor the plutonium was made based on knowledge of its operating history); or, the yield given knowledge of the other variables.

In principle, by measuring the ratio of Pu-239 to plutonium total and ratio of Pu-240 to Pu-239, calculated by the explosive yield estimated by from the seismic magnitude due to the nuclear explosion, it is possible to calculate the exact yield of the nuclear explosion. In reality, we do not expect that this method has been useful to date due to the improbability that the United States has collected plutonium debris from such a small, underground test. (12)

Conclusions

We know from the seismic analysis that the explosive yield of the announced DPRK nuclear test is 1 kiloton or less of TNT equivalent. The US Director of National Intelligence confirms that the analysis of air samples that appears contain radioactive xenon of greater than minimum detectable concentration was collected and that the test was indeed a nuclear explosion. If we knew the isotopic ratios of the plutonium debris resulted from the DPRK nuclear test, we could calculate the exact yield of the DPRK nuclear explosion, as analyzed in this study. We speculate that at this stage, it is unlikely that such information has been collected outside of the DPRK; but if it is available, that it would likely simply confirm that the range was between 0.5 and 1 kilotonne of TNT equivalent.

There are many possible reasons why the DPRK nuclear test yielded less than 1 kilotonne of TNT equivalent. The pre-detonation of the DPRK nuclear explosion could be caused by poor machining of the device, the non-simultaneity of the detonation of the explosive charges used to compress the plutonium mass, the poor shaping of these charges, the small amount of plutonium used and/or mixture of non-pure-plutonium nuclides that might lead to pre-detonation, difficulties with the neutron initiator, and other environmental factors such as the performance of a neutron reflector. (13)

Whatever the explanation, we conclude that the DPRK test was more a failure than a success in physical terms defined with respect to a usable nuclear device configured as a warhead. However, it was also a technical success in four possible respects. The first and most important is that nuclear criticality was achieved. The DPRK has likely been designing nuclear explosives of various scales for many years. The DPRK scientists and engineers working on the test program will have learned a great deal from this first exercise, and will use this knowledge to improve their design for a second test. Achieving any level of nuclear explosion is a significant technical achievement and a pre-detonated critical mass is simply one event along a spectrum of possible outcomes, all of which offer substantial learning opportunities and a basis for on-going design work.

The second is that the DPRK may be confident that it can explode larger nuclear weapons and decided to tackle small warheads at the start of its test program in order to increase the speed with which it has a deployable long-range weapon on a missile or other delivery system. This is more challenging technically and this first test would assist them in this objective even if it did not yield the desired explosive power.

The third is that the DPRK may not have much plutonium due to difficulties with operating their reactors in the last two decades and with separating it from the spent fuel, and was economizing on their use of this scarce resource.

The fourth is that the DPRK may have been trying to minimize the risk of radioactive emissions and the political reaction to its test by keeping the test very small. A combination of these four and other factors may also be at play.

Nonetheless, the fact is that the DPRK is now a self-declared nuclear weapon state, but not an actual or demonstrated nuclear weapons state. This is not a domestic political problem for Kim Jong Il at this time. Indeed, on October 20, 2006, the leadership staged a “mass rally” in central Pyongyang to "welcome the historical successful nuclear test” and, as one gigantic placard stated, to” ardently congratulate the scientists, technicians, and workers who succeeded in a nuclear test.”

But for the reasons outlined above, the other nuclear weapons states know the true state of affairs. Until the test, it was possible for the DPRK to employ the “Israeli model” of nuclear opacity as the basis for nuclear threat, whatever the purpose of having such a threat capacity, and to keep everyone guessing.

Having tested and failed, the DPRK can no longer rely on opacity as the basis for having a credible nuclear force, at least sufficiently credible to threaten its adversaries with a nuclear explosion. The DPRK might believe that a half kilotonne “mininuke” still provides it with a measure of nuclear deterrence and compellence; but it could not rely on other nuclear weapons states to perceive it to have anything more than an unusable, unreliable and relatively small nuclear explosive device.

In short, the DPRK has now demonstrated that it does not yet have a nuclear capacity that enables it to threaten nuclear Armageddon against anyone but itself.

Therefore, although it could exploit the residual ambiguity that still shrouds its remaining capacity to deploy nuclear weapons and not test again, we judge it to be more likely that the DPRK will test again to assert the credibility of its nuclear arsenal and thereby, to truly join the ranks of the nuclear weapon states.

The exact timing of the next test will determined by how non-technical factors such as “managing China’s response” and “picking up food aid from South Korea for the next winter” interact with the DPRK leadership’s perception of the need to “fix” the demonstrated non-capability from the first test. (14) This latter factor is also political and will be primarily a function of the DPRK leadership’s view on how to (not) use nuclear threat to compel the United States to engage it on terms that it finds acceptable, whether bilaterally, at resumed six-party talks, or at some other venue and time.

Thus, via this last factor, the United States has continuing and unique ability to influence Pyongyang's decision on when and if the DPRK conducts more nuclear tests.

III. Citations

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(2) A kilotonne or kt is a 1000 metric tones. The nuclear bomb that destroyed Hiroshima on August 6, 1945 was roughly 15 kt.
(3) Lynn R. Syres and Goran Ekstrom, "Comparison of seismic and hydrodynamic yield determination for the Soviet joint verification experiment of 1988," *Proc. Natl. Acad. Sci. USA*, Vol. 86, pp. 3456-3460, May 1989.
(4) see also "NORK DATA: It was a DUD," at: http://www.armscontrolwonk.com ;
(5) As given by D. McKinzie "NRDC RELEASES NEW SATELLITE PHOTO OF NORTH KOREAN NUCLEAR TEST SITE," October 13, 2006, at: http://www.nrdc.org/media/#1013
(6) ODNI News Release No. 19-06, "Statement by the Office of the Director of National Intelligence on the North Korea Nuclear Test," October 16, 2006.
(7) Officials associated with that office reportedly did confirm that the weapon was plutonium-based, however. See T. Shanker and D. Sanger, "North Korean Fuel Identified as Plutonium," *New York Times,* October 17, 2006, at: http://www.nytimes.com/2006/10/17/world/asia/17diplo.html?_r=1&n=Top%2fReference%2fTimes-Topics%2fPeople%2fS%2fSanger%2c-David-E%2e&oref=login
(8) A Bq is the unit of radioactivity being the activity of a quantity of radioactive material in which one nucleus decays per second . 1mBq = 0.001 Bq.
(9) Private communication with Martin B. Kalinowski on October 13, 2006. Air concentration of Kr-85 in northern hemisphere is about 1.3Bq/m3 air.
(10) Martin B. Kalinowski, Lawrence H. Erickson and Gregory J. Gugle, "Preparation of a Global Radioxenon Emission Inventory: Understanding Sources of Radioactive Xenon Routinely Found in the Atmosphere by the International Monitoring System for the Comprehensive Nuclear-Test-Ban Treaty," *Presented at Understanding Complex Systems 2006,* Urbana, Illinois, USA.
(11) *ORIGEN2.1: Isotope Generation and Depletion Code Matrix Exponential Method,* CCC-371 ORIGEN 2.1 (Oak Ridge National Laboratory, Radiation Safety Information Computational Center, August 1996). The AMOPUUUC.LIB fast reactor cross-section files were used to calculate the production rates of actinides and fission products.
(12) Some journalists reported that the United States has collected plutonium, but this seems more likely a journalistic assumption than the result of informed investigative journalism. See, for example, P. Grier, "Pyongyang's nukes: How dangerous are they? North Korea's recent blast was tiny, but its commitment to nuclear weapons is long," *The Christian Science Monitor*, October 19, 2006, at: http://www.csmonitor.com/2006/1019/p01s01-woap.html

(13) See R. Garwin, F. von Hippel, "A Technical Analysis of North Korea's Oct. 9 Nuclear Test," Arms Control Today, November 2006, at: http://www.armscontrol.org/act/2006_11/NKTestAnalysis.asp ; and J. Holdren, M. Bunn, "Tutorial on Nuclear Weapons and Nuclear-Explosive Materials: Nuclear Basics," at: http://www.nti.org/e_research/cnwm/overview/technical1.asp

(14) If statements attributed to Kim Jong Il that he promises to not test again are accurately reported, then we appraise such assurances to be strictly tactical: *Yonhap* (Seoul), "N. Korean Leader Said To Have Promised No More Nuclear Test," October 20, 2006.

IV. Nautilus Invites Your Responses

The Northeast Asia Peace and Security Network invites your responses to this essay. Please send responses to: napsnet-reply@nautilus.org . Responses will be considered for redistribution to the network only if they include the author's name, affiliation, and explicit consent.

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