North Korea's Oct. 9 Nuclear Test: Successful or Failed?

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ABSTRACT

On Oct.9, 2006, North Korea announced that it had successfully conducted an underground nuclear test. On Oct.16, the U.S. Director of National Intelligence confirmed "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." Because the reported explosive yield is much smaller than other nuclear states' first tests (about 10-20 kt), the North Korean statement about a successful test has been questioned from the beginning. In this paper, I examined if the test was successful. Based on a technical analysis, I concluded that: whether North Korea's Oct.9 nuclear test was successful or failed would be dependent on North Korea's designed yield. If North Korea planned a yield of 4 kt (as told to China), it would be not a failed test. It could show that North Korea already had confidence to explode a nuclear device and pursued a much more compact warhead for its missiles. Thus, it is urgent to negotiate for dismantling North Korean nuclear and long-range missile programs.

Introduction

On October 9, 2006, North Korea conducted its first nuclear test. The Korean Central News Agency, the state's news agency, issued the following statement,"The field of scientific research in the DPRK [North Korea] successfully conducted an underground nuclear test under secure conditions on October 9, Juche95 (2006), at a stirring time when all the people of the country are making a great leap forward in the building of a great, prosperous, powerful socialist nation. It has been confirmed that there was no such danger as radioactive emission in the course of the nuclear test as it was carried out under scientific consideration and careful calculation."[1] While a number of seismic stations around the world detected this seismic activity, given the low yield of the test, many raised questions about whether the seismic signal was caused from a nuclear explosion or if a test had failed. On October 16, 2006, the US Director of National Intelligence stated decisively, "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."[2] However, many are still raising the question about whether North Korean test was successful or failed, because the reported explosive yield (around 1kt) is much smaller than other nuclear states' first tests (about 10—20 kt). Many experts are interpreting North Korean test as a failure, or a fizzle. Thus, they argue North Korea should not be recognized as a nuclear-weapon state.

In this paper, based on a technical analysis, I examine if the North Korean test was successful or failed. To judge if the test was failed or successful, one needs to know well the actual yield of the explosion and design yield of the device. In the following, I will first estimate what the actual yield of the test could be. I will then examine what a fizzle test is.

What was the real yield of the North Korean nuclear test?

Without on-site measurements, the better way for outsiders to estimate the explosive yield would apply sesmic approach, in which the explosion yield would be estimated through using the relationship between seismic magnitude and yield. Just after the test, reports of seismic body wave magnitude around the world ranged from a magnitude of 3.5 to 4.9 on the Richter scale (see table1); and the reported and estimated yields ranged from 0.25 kt to 15 kt. Based on the recorded seismic signals by the seismic observatories (as shown in thable1), it could be estimated that the North Korean nuclear test has an average seismic body wave magnitude of 4.2 ± 0.2.

Moreover, there is uncertainty in converting seismic magnitude to explosive yield. Even the same seismic magnitude value can correspond to yields that range over a factor of about 10 [3]. For example, the relationship between seismic magnitude and yield would depend upon variations in the structure of the Earth in the vicinity of the test site (low signal attenuation versus high signal attenuation areas), the material in which the explosion is emplaced (hard, water-saturated rock versus dry, porous materials), and the way in which the explosion is emplaced (tamped versus detonated in a large cavity designed to muffle the signal).

For known test sites (such as Russian nuclear test sites), the seismic approach would get a "factor of 2" uncertainty. The factor of uncertainty for a given measurement is defined as that number which, when multiplied by or divided into an observed yield, bounds the range which has a 95 percent chance of including the actual (but unknown) value of the yield. If combined Mb (body wave) and Ms (surface wave) approach, it could get better (e.g. factor 1.3). But, for the case of very low yield (say around 1 kt), and not known-well test site (as North Korea case), it would be difficult to narrow the uncertainty. For example, for explosions below 10 kt, the uncertainty increases because small explosions do not always transmit their signals efficiently to the surrounding rock.[4] Thus, as a better estimation, we could get a "factor of 2" uncertainty for North Korea case.

For different yield, the relationship between explosive yield Y [in kt] and magnitude (mb) could be different. And there is no formula for very low yield (say less than 5 kt). If we apply relation for 5.3kt <Y<120kt: mb = 4.262+0.973 logY,[5] then for a central value of mb of 4.2, we can get explosive yield Y approximately1 kt. Moreover, we assume: as a better estimation, we could get a "factor of 2" uncertainty for North Korea case. Eventually, we could estimate a yield of North Koran's test between 0.5 and 2 kilotons with 95 percent confidence.

In addition, one needs to consider whether the test had a decoupling effect, that is, if the test was conducted in an excavated cavity, the shock wave could be decoupled from the ground, thus resulting in a lower yield to seismic monitors. It is reported the test was conducted in an old mine. Thus, while Pyongyang could have no intention for decoupling (because it wanted to demonstrate its nuclear capacity, and it had already declared its intention for such a test six days before the test. In addition, there was no evidence of evacuation activities for decoupling), one argument could be whether the mine itself has decoupling effect. The minimum cavity radius required for full decoupling (a factor of 70) is proportional to the cube root of the explosion yield and inversely proportional to the cube root of the maximum pressure which the overlying rock can sustain without blowing out or collapsing.[6] As an estimation, assuming North Korea's test site is as the granite case, thus the minimum cavity size for a full decoupling is: $R \sim 20\ Y^{1/3}$; (where R: the minimum cavity radius (m); Y: the explosive yield (kt). Consequently, for full decoupling a yield of 4 kt, the minimum cavity radius would be about 32 m. Moreover, the cavity size for a partial decoupling (to obtain reduction by more than a factor of 2) is: $R \sim 6\ Y^{1/3}$. Thus, for a partial decoupling of a yield of 4 kt, the cavity radius would be about 10 m; for the case of a yield of 1 kt, the cavity radius would be about 6 m. Eventually, we can conclude that : If North Korea did not build a bigger cavity, and if assuming that the size of the tunnel across R would be around 2m. Then it would be much smaller than the required minimum size for even partial decoupling. Thus, the old mine could have no decoupling effect.

Finally, beyond the seismic approach, can off-site air sampling be used to estimate the test yield for North Korea case? If we could collect and estimate the total inventory of one specific or some of the released gaseous fission products, then we could narrow the yield estimation. In practice, it is impossible, however. In addition, the explosive yield would not be estimated by the ratios of those fission products. To further narrow the yield estimate, it would depend on on-site approaches, such as CORRTEX (Continuous Reflectometry for Radius versus Time Experiments)[7] and Radiochemical analysis. CORRTEX measurements could be accurate within a factor-of-1.3 uncertainty. Radiochemical analysis is believed to be the most accurate means of yield determination. E.g. estimating the total inventory of some fission products (e.g. the non-volatile products contained in the collapsed blast cavity which would need on-site drill, etc.) However, both CORRTEX and Radiochemical analysis would require the host country's cooperation. It is not possible for North Korean current case.

Table1: Reported seismic magnitudes of North Korea's Oct.9 nuclear test

Nation/Organization, etc	Mb
U.S.	U.S. Geological Service: 4.2
South Korea	Initial 3.58-3.7; later revised to 3.9
Japan	The Japan Meteorological Agency: 4.9 Inst. of Seismology and Volcanology at Kyushu University: 4.4
Russia	Information Processing Center, Geophysical Survey, Russian Academy of Science: 4.0
China	4.1--4.2
Norway	Norwegian institute of seismology: 4.2
CTBTO	IDC, Provisional Technical Secretariat of the Preparatory Commission for the CTBTO: 4.0

Was the North Korea's nuclear test fizzled?

Given the fact that the yield of the North Korean test (around 1kt) is much smaller than other nuclear states' first tests (ranged around 10-20 kt, the easier size of building weapons), many experts and scholars around the world have suggested that the October 9 test was a failure, or a fizzle. Then, what is a fizzle test?

We assume that North Korea tested a plutonium device. In fact, North Korea already has enough separated plutonium for at least several weapons. However, it would be several years away from producing HEU enough for one or two bombs.[8] Because of the problem of spontaneous neutrons, a plutonium weapon would had to use implosion design as used in "Trinity" test and the "Fat Man" bomb. If the nuclear chain is not sustained long enough to cause an explosion, a fizzle will occur. This can happen, for example, if the detonators do not explode at the right time or if the neutron initiator is misfired.[9]

The smallest possible yield resulting from preinitiation has been referred to as the "fizzle yield." Some scientists have provided the definition of a fizzle yield. For example, nuclear expert J. Carson Mark provided a criterion for predetonation that the chain-reaction be initiated at a time early enough so that approximately e^{45} fissions have occurred before maximum criticality is achieved.[10] Based on his simplified model of the assemble system as Trinity's, if a test yield is 2.7 percent of design yield, then it would be called a fizzle yield. For an assembly system twice as Trinity's (which could be not the typical case), the fizzle yield could be up to 7.6% of design yield. Mark further estimated how Robert Oppenheimer defined a fizzle yield. One week after the first fission explosion on 16 July 1945, Robert Oppenheimer wrote to General Leslie R. Groves' deputy and described the expected performance of the Trinity device in combat, as Mark rephrased, "With the Trinity Implosion assembly system and the grade of plutonium employed, the probability was 88 percent that the device would survive long enough without a chain being initiated that it would provide the nominal yield of 20 kilotons; about 94 percent that it would survive long enough that the yield would be greater than 5 kilotons (one quarter of the nominal yield); about 98 percent that it would provide a yield in excess of one kiloton. Only in two percent of all firings would the chain be initiated so early that the energy release would be between the fizzle yield and one kiloton."[11] Mark presumed the fizzle yield of this known device (of yield of 20kt) by Oppenheimer was around 700 t, which is a yield of 3.5% design yield.

Consequently, a fizzle yield could be defined as a few percent of the design yield for an assembly system similar to Nasasagi type bomb. Thus, whether North Korean test was a failure would depend on its design yield. For example, if North Korea design yield was 20 kt as others usually did for their first tests, then a 0.5 kt could be a fizzle yield (because the ratio of the test yield to the design yield is 2.5% (0.5kt/20kt), which is less than the defined fizzle yield (say around 3%). However, if North Korea planned a yield of 4kt, even a test yield of 0.5 kt (12.5% of designed yield) would be not a fizzle yield. Indeed, Chinese officials have told American nuclear experts and diplomatic officials that Pyongyang had informed Beijing in advance an estimated explosion yield of approximately 4 kilotons.[12]

In theory, the probability of starting a chain reaction by neutrons generated from spontaneous fission in the plutonium always exists. Based on Mark's simplied model of the behavior of an implosion design, Frank von Hippel et al provided calculations on probabilities of different yields as follows,[13]

$$P\left(\frac{Y}{Y_0} < x\right) = \int_{x_{\min}}^{x} dx' \left(\frac{dP}{dx'}\right) = 1 - \exp\left[-\frac{1}{2}Nt_0x^{2/3} + 45N\tau\right]$$

Where P $(Y/Y_0<1)$: cumulative probability of predetonation; Y_0: design yield; Y: the reduced predetonation yield; x: Y/Y_0; N: spontaneous fissions rate. Thus, based on Mark's simplied model and using von Hippel's formula, we can estimate the cumulative probability to get above a certain yield for different yield fraction. For the case of North Korean Oct.9 nuclear test, assuming that: the device contained about 6kg WgPu (6% Pu-240); SF neutrons produced at rate of $3 * 10^5$ /sec; $t_0=10^{-5}$ s (t_0: the time interval through which the system is supercritical prior to completion of the assembly as the shock wave from the high explosive reaches the center); $\tau = 10^{-8}$s (τ : the lifetime of a fission neutron); and the designed yield is 4 kt. Then, it could be estimated as follows (see also figure 1) the North Korean implosion assembly system and the grade of plutonium employed (94%Pu239), the probability was 26 percent that it would get the design yield of 4 kt; about 44 percent that the yield would be greater than 2 kt (one half of the design yield); about 63 percent that it would provide a yield in excess of one kiloton; and about 78 percent that it would provide a yield in excess of 0.5kt.

In summary, if the design yielded was 4kt, then the actual explosion yield between 0.5-2kt would be not unusual. One the other hand, if the actual yield was the design yield, it could be "unusual". Thus, if North Korea planned a low yield test, its test on Oct.9 might be not a failure.

Conclusion

A better estimation of the yield of North Korean nuclear test for the outsiders could range between 0.5 kt and 2 kt. If North Korea planned the yield of 4 kt (as reported), the test could be not a failure. It could show that Pyongyang already has confidence to explode a larger nuclear device and is pursuing much more compact warhead for its missiles. If North Korea continues its nuclear tests for much more compact warheads and tests its long-range missile, its nuclear missile delivery capability would be expanded from its current coverage of South Korea and Japan to U.S. territory. Yet, since the current nuclear crisis broke out in October 2002, North Korea continues to be unhindered in its efforts to increase its nuclear capabilities including producing and separating more plutonium thus more warheads, its Feb.10, 2005 announcement of having manufactured nuclear weapons and its Oct. 9, 2006 nuclear test. The longer the crisis lasts, the greater North Korea's nuclear capability and the higher the stakes for that country. It is urgent to negotiate for dismantling North Korean nuclear and long-range missile programs. Now it is the time for the six-party talks to agree to a roadmap for faithful implementation of the Joint Statement issued in September 2005 and to start the first step as the Feb13 agreement demands. [14]

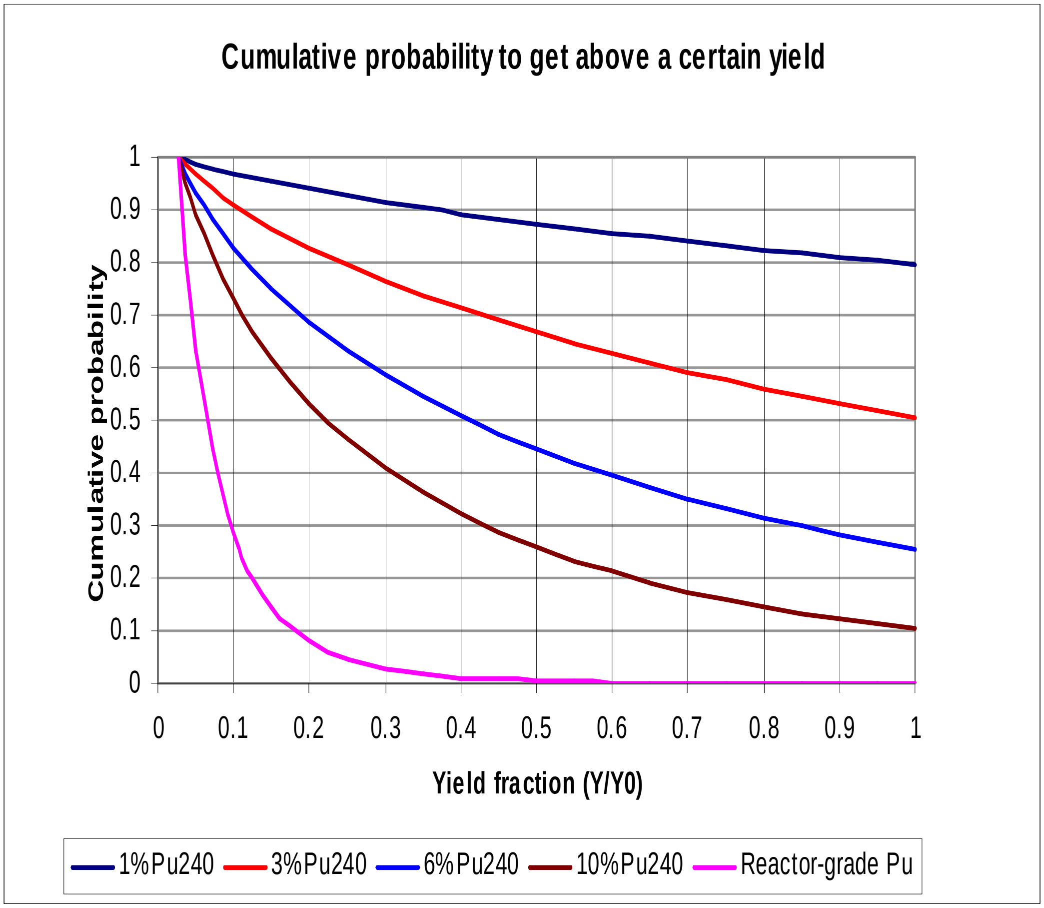

Figure 1: The cumulative probability to get above a certain yield as function of Y/Y_0 for plutonium cores with 1% Pu240; 3% Pu240; 6% Pu240; 10% Pu240; and reactor-grade Pu.

References and Notes

1 See, e.g. "DPRK Successfully Conducts Underground Nuclear Test," Korean Central News Agency (KCNA), October 9, 2006, http://www.kcna.co.jp.

2 See, e.g. 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. See: http://www.odni.gov.

3 Office of Technology Assessment, *Verification of Nuclear Testing Treaties*, OTA-ISC-361, May 1988.

4 OTA, *Verification of Nuclear Testing Treaties*, op. cit.

5 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.

6 OTA, Verification of Nuclear Testing Treaties, op. cit.

7 OTA, Verification of Nuclear Testing Treaties, op. cit.

8 Hui Zhang, "Chinese Perspectives on the North Korean Nuclear Issue," Proceedings *of INMM 46th Annual Meeting,* Phoenix, AZ, July 10-14, 2005.

9 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.

10 J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," Science *and Global Security,* 1993, Volume 4, pp.111-124.

11 Mark, "Explosive Properties of Reactor-Grade Plutonium," op.cit.

12 This author had confirmed this with Christopher Hill, chief US negotiator for Six Party Talks, when he delivered his talk at Harvard's Kennedy School of Government; see also Siegfried Hecker, Report on North Korean Nuclear Program, Policy Forum Online 06-97A: November 15th, 2006, Nautilus Institute, see: http://www.nautilus.org/fora/security/0697Hecker.html.

13 Frank von Hippel and Edwin Lyman, " Appendix: Probabilities of Different Yields," *Science and Global Security*, 1993, Volume 4, pp.125-128

14 Hui Zhang, " North Korean Denuclearisation: A Chinese View of the Way Forward," *Disarmament Diplomacy* no. 82 (Spring 2006).