Nuclear Test

By Richard L. Garwin and Frank N. von Hippel

A Technical Analysis: Deconstructing North Korea's October 9 Nuclear Test

On October 9, North Korea announced that it had carried out an underground nuclear test. In subsequent days, the apparent low yield of the device and initial lack of reports of detection of radioactivity from the test raised questions about whether North Korea had actually tested a nuclear device or if a test had failed.

One week later, the Office of the Director of National Intelligence issued a statement confirming the detection of radioactive debris and stating that North Korea had conducted a nuclear explosion with a yield of less than 1 kiloton (1,000-ton TNT equivalent).[1] Our analysis of the available public information is consistant with this conclusion. We also judge that, although the test did not succeed as planned, North Korea might have been testing a lower-yield design than many commentators have assumed. This imperfect test may well lead North Korea to test again.

Our analysis concerns three questions: How powerful was the explosion? Was it a nuclear test? If nuclear, was the test successful?

How Powerful Was It?

North Korea reportedly informed China that it would be conducting a nuclear test, with a yield in the range of 4 kilotons.[2] Such an explosion in hard rock would produce a seismic event with a magnitude of about 4.9 on the Richter scale.[3] By contrast, the U.S. Geological Survey reported the explosion to have a seismic magnitude of 4.2.[4] South Korea's state geology research center reported the magnitude as lower, between 3.58 and 3.7, and estimated a yield equivalent to 550 tons of TNT.[5] An uncertainty in seismic magnitude of 0.5 translates into a shift in yield of about a factor of 4.6. Compounding this uncertainty is that the relationship between seismic magnitude and yield depends on the hardness of the rock in which the explosive is buried.[6]

Given all these uncertainties, it is not surprising that a range of yields has been reported. Terry Wallace, a seismologist at Los Alamos National Laboratory, based on an unclassified analysis of open data, estimates a yield of between 0.5 and 2 kilotons, with 90 percent confidence that the yield is less than 1 kiloton.[7] Lynn R. Sykes of Columbia University estimates a yield of 0.4 kilotons, with 68 percent confidence that the yield is between 0.2 and 0.7 kilotons and a 95 percent probability that the yield is less than 1 kiloton.[8] One notable by-product of the test is that it has demonstrated that university and other independent seismic detection systems, as well as those of governments and the International Monitoring System of the Vienna-based Comprehensive Test Ban Treaty Organization, very effectively detect underground explosions in the subkiloton range.

Was It a Nuclear Test?

From the seismic data alone, the source might have been an explosion of a mixture of ammonium nitrate and fuel oil (ANFO), an inexpensive explosive used in mining all over the world. Five hundred tons of ANFO would fill the last 60 meters of a tunnel with a height and width of about 3 meters.

The radioactivity detected in the atmosphere of the region two days after the

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explosion could strengthen the evidence that it was indeed a nuclear test. No information has been made public about the nature of the radioactivity that has been detected. If a nuclear test occurred, however, particulate matter and gases might have been vented at the time of the test, or radioactive gases might subsequently have seeped out through the cracks in the rocks above the explosion.

We focus here on two radioactive xenon isotopes, Xe-133 and Xe-135, with half-lives of about five days and 0.4 days, respectively, that are often detected after underground tests. Xenon is chemically unreactive, like helium, and therefore does not plate out on the surfaces of cracks in the rock or get scrubbed out of the atmosphere by rain. We assume that the weapon was made of plutonium. North Korea is known to have enough plutonium to make at least several Nagasaki-type weapons, although it is alleged also to have a clandestine uranium-enrichment program.[9] The ratio of the production of Xe-135 and Xe-133 in plutonium fission is known. Because the Xe-135 decays much more rapidly, the ratio of their concentrations in the plume provides a rough measure of the number of Xe-135 half-lives and therefore the time since the test.[10]

It would require the fission of about 60 grams of plutonium to produce a yield of 1 kiloton. That much fission would produce about 2 grams each of Xe-133 and Xe-135. Because of their radioactivity, these xenon isotopes can be detected at levels of about 1,000 and 100 atoms per cubic meter of air respectively.

Martin Kalinowski has provided us with a calculated trajectory of the first gas that might have been released by the test. By the end of the third day, he estimates that the plume would have traveled about 1,000 kilometers in a zig-zag track over the Sea of Japan.[11] At that point, the plume might be 1 kilometer high by 200 kilometers wide. If the radioactive xenon produced by a 1-kiloton underground explosion were released into the atmosphere at a typical rate of 0.1 percent per day of the undecayed xenon, the concentration of Xe-133 and Xe-135 in the plume would still be 100 and 10 times above the detection limit respectively. If the ratio of Xe-133 and Xe-135 concentrations was consistent with the time of the explosion, that would verify that it was nuclear.

Indeed, detection of Xe-133 alone after even a week or more could in itself confirm the nuclear nature of the explosion, but its trajectory would have to be "backcast" to make sure that it was not due to leakage from reactors in South Korea or Japan. Much more could be learned if particles as well as gas leaked from the explosion, including its yield and whether it truly was a plutonium device.[12]

Was It a Successful Test?

Much has been made of the apparently low yield of the North Korean test in comparison to the first U.S. plutonium explosive, the Nagasaki bomb, which had a yield of about 20 kilotons. In the Nagasaki bomb, tons of high explosive served to implode a solid subcritical sphere of plutonium to a higher density to make it supercritical. If Pyongyang tried to replicate the Nagasaki design, it is indeed likely that something went wrong.

Before the Nagasaki bomb was used in August 1945, J. Robert Oppenheimer, who directed the bomb-design effort at Los Alamos, wrote to General Leslie Groves, the overall head of the U.S. nuclear-weapon effort, that there was a 2 percent chance that the yield could be lower than 1 kiloton.[13] This would happen if a neutron started the chain reaction just when the plutonium first became critical, 10 millionths of a second before it reached its maximum supercriticality. The reason was that there was a 2 percent probability that the plutonium

Nuclear Forensics and the North Korean Test

The power and versatility of nuclear forensics, particularly radio-chemical techniques, could not have been better demonstrated than by its application to the recent underground test in North Korea.[1] Some might have thought that all the debris from the explosion would have been contained in the underground cavity. After all, that was the original purpose of testing underground.

In fact, any nuclear explosion creates radioactive noble gases, notably xenon and krypton, that do not combine with other elements in the geologic structure. Therefore, they can more easily leak to the surface and into the atmosphere where they can be detected beyond national boundaries. Because at least two different gases escape, it is possible for radiochemists to determine if the fissile material was plutonium or uranium, which of course is exactly what happened. (Press reports said the material was plutonium.)[2] Unfortunately, the chemists cannot determine much more. If there has not been direct venting to the atmosphere, they will not be able to answer the mystery of why Pyongyang's device seems to have produced such a low nuclear yield, reportedly less than one kiloton, or less than 5 percent of the yield of the Hiroshima and Nagasaki bombs.

The same would not be true if a nuclear weapon were exploded above ground. Then, the debris would be unfiltered, and much more critical information could be obtained, such as the sophistication of its design and whether there exists a stockpile containing fissile material with similar isotopes. The last should be a key consideration for North Korea or any other government that might contemplate providing nuclear materials to terrorists.

Thanks to the inspections associated with implementation of the 1994 Agreed Framework, the International Atomic Energy Agency (IAEA) and/or the United States may possess the isotopic data of the North Korean plutonium. North Korea must be made aware that use of its fissile material can be traced to Pyongyang and that it must anticipate the retribution that would follow if any of its weapons or fissile material should be used by any of its accomplices or customers. Perhaps, this is the time for the Bush administration to speak directly to the North Korean government and make this clear.

Pyongyang might conclude that President George W. Bush was not making an idle boast when he said October 9 that "the transfer of nuclear weapons or material by North Korea to states or non-state entities would be considered a grave threat to the United States, and we would hold North Korea fully accountable of the consequences of such action" One can hope, therefore, that forensic science combined with strong and credible diplomacy can deter North Korea from passing plutonium to terrorists or to other countries. —***Harold Smith***

ENDNOTES

1. For more information on nuclear forensics, see William Dunlop and Harold Smith, "Who Did It? Using International Forensics to Detect and Deter Nuclear Terrorism," *Arms Control Today*, October 2006, pp. 6-10.
2. David Sanger, "North Korean Fuel Identified as Plutonium," *The New York Times*, October 17, 2006, p. A-11.

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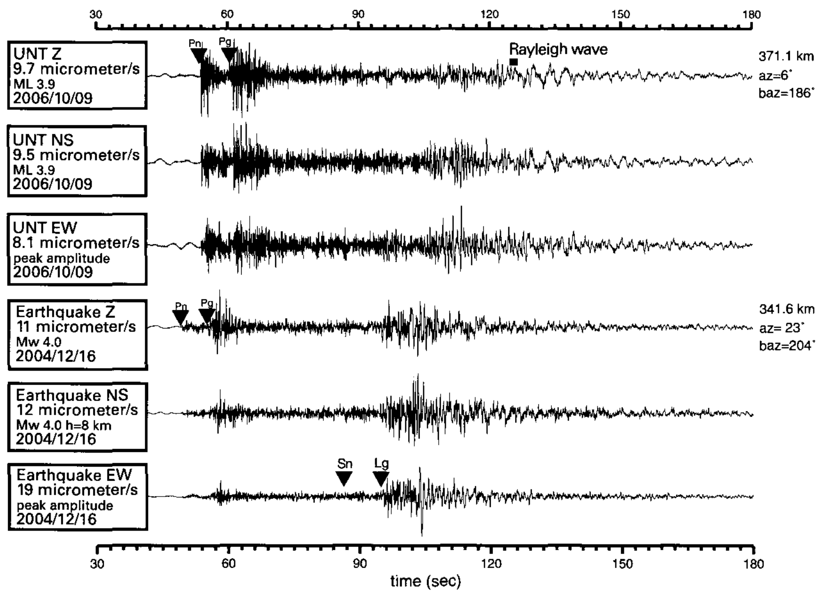
Figure 1: Seismic Signature of North Korean Test vs. Earthquake

Seismic monitoring stations in Asia, such as Mudanjiang in northeast China, detected the Oct. 9 event. The three top seismograms (below) clearly show how the seismic waves from the nuclear explosion build up suddenly, while the three bottom seismograms indicate the slower buildup of such waves from an earthquake of similar seismic magnitude in the region in 2004.

Three-component Records at MDJ (Mudanjiang, NE China) from the Presumed North Korean Nuclear Test on 9 October 2006 (ML 3.9, Shallow) and a nearby Earthquake on 16 December 2004 (Nw 4.0; h= 8 km)



Source: Lamont-Doherty Earth Observatory of Columbia University

would produce a neutron spontaneously and start the chain reaction early. Other possibilities in the North Korean test are that extra neutrons might have been generated by the alpha particles from plutonium decays interacting with light-element impurities or the neutron initiator might have been mistimed and fired too early or too late.

The fact that the weapon designers predicted a 4-kiloton yield suggests, however, that they were not aiming for the Nagasaki design. The Nagasaki bomb weighed about 4 tons, much more than could be lifted by any North Korean missile. Perhaps North Korea's weapon designers tried to go directly to a weapon in the 500-1,000-kilogram class that could reach South Korea on a Scud missile, Japan on a Nodong missile, or the United States on a Scud launched from an offshore merchant ship.

A 4-kiloton or even a 1-kiloton explosive would still be a terrifying weapon. Recall that the 1995 Oklahoma City explosion involved only a few tons of ANFO. A 1-kiloton bomb could kill people in an area of about one square mile and partially destroy a much larger area.[14] Most of these deaths would be from fire or from the prompt nuclear radiation.

If, as the seismologists have concluded, the yield of the explosion was much less than the design yield, North Korea can have little faith in its nuclear-weapon stockpile. It is likely that its weapons team will regroup. The North Korean government has already raised the possibility of a second test.[15] **ACT**

ENDNOTES

1. "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." Office of the Director of National Intelligence, "Statement by the Office of the Director of National Intelligence," press release, October 16, 2006, http://www.odni.gov/announcements/20061016_release.pdf.

2. Mark Mazzetti, "Preliminary Samples Hint at North Korean Nuclear Test," *The New York Times*, October 14, 2006.

3. For a stable tectonic setting such as Novaya Zemlya, the relationship between explosive yield Y (in kilotons) and magnitude (mb) is approximately mb = 4.45 + 0.75 log Y. See http://www.iris.edu/news/IRISnewsletter/fallnews/political.html. For other Mb-Y relationships, see Lynn R. Sykes and Göran Ekström, "Comparison of Seismic and Hydrodynamic Yield Determinations for the Soviet Joint Verification Experiment of 1988," Proceedings of the National Academy of Sciences of the USA, Vol. 86, May 1989, p. 3456. According to this paper, for a low-yield test in hard rock or below the water table, a 0.5 increase in Mb would translate into an increase in yield by a factor of about three.

4. The coordinates are given as 41.294 N, 129.094 E, and the depth is given as shallow. See U.S. Geological Survey, "Magnitude 4.2 – North Korea," http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/ustqab.php.

5. Lee Chi-dong, "N. Korea Claims Success in Nuclear Test," *Yonhap News*, October 9, 2006.

6. Lynn R. Sykes, "Dealing With Decoupled Nuclear Explosions Under a Comprehensive Test Ban Treaty," in *Monitoring a Comprehensive Test Ban Treaty*, eds. E. S. Husebye and A. M. Dainty (Kluwer Academic Publishers, 1995).

7. Terry Wallace, personal communication with authors, October 14, 2006.

8. Lynn R. Sykes, personal communication with authors, October 15, 2006.

9. North Korea produced an estimated 30-40 kilograms of plutonium prior to 1994. See David Albright and Kevin O'Neill, *Solving the North Korean Nuclear Puzzle* (Institute of Science and International Security Press, 2000). Siegfried Hecker, a former director of the Los Alamos National Laboratory, visited North Korea in January 2004 and August 2005. According to Hecker, he was told during his first visit that North Korea had reprocessed all the pre-1994 spent fuel stored at its Yongbyon plutonium-production reactor. During his second visit, he was told that reprocessing of fuel that had been irradiated from February 2003 through March 2005 was almost complete. (Between 1994 and 2003, the reactor was shut down by an agreement brokered by former President Jimmy Carter.) See Paul Kerr, "North Korea Increasing Weapons Capabilities," *Arms Control Today*, December 2005, pp. 33-34.

10. Martin Kalinowski, "Characterization of Prompt and Delayed Atmospheric Radioactivity Releases From Underground Nuclear Tests at Nevada as a Function of Release Time" (unpublished). See also Martin Kalinowski, et al., *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*, Arms Control Disarmament and International Security Research Report, University of Illinois, December 2005.

11. Martin Kalinowski, personal communication with authors, October 12, 2006.

12. Press reports suggest that such evidence has been obtained but give no specifics. Thom Shanker and David Sanger, "North Korean Fuel Identified as Plutonium," *The New York Times*, October 17, 2006. At press time, the South Korean government announced that it had detected radioactive xenon from the North Korean test, The Associated Press, October 25, 2006.

13. Albert Wohlstetter, "Spreading the Bomb Without Quite Breaking the Rules," *Foreign Policy 25*, (Winter 1976-77), p. 160.

14. Richard L. Garwin, "Nuclear and Biological Megaterrorsim," August 21, 2002, http://www.fas.org/rlg/020821-terrorism.htm.

15. "N. Korea Raises Threat of New Test," BBC, October 11, 2006, http://news.bbc.co.uk/2/hi/asia-pacific/6039438.stm.