Gregory S. Jones[1]
August 24, 2021

Constraints on Possible High Yield North Korean Nuclear Weapons: Weight and Nuclear Material Requirements

The low yield of North Korea's first nuclear test on October 9, 2006 led some to assert that it was a failure and that North Korea did not really have any nuclear weapons at all. However, its sixth nuclear test, on September 3, 2017, had a yield that could have been as high as 250 kilotons.[2] This high yield has led some to claim that North Korea has two-stage thermonuclear weapons (hydrogen bombs) and that these weapons could be lightweight enough to be carried by North Korean ballistic missiles to hit anywhere in the continental United States.

In fact, all that is known about the sixth North Korean nuclear test is its yield. In a paper written soon after this test, I explained that there were weapon types other than two-stage thermonuclear weapons that could produce a nuclear yield of this magnitude.[3] I concluded that this test was probably not a two-stage thermonuclear one and almost certainly not a lightweight thermonuclear weapon. Opinion continues to be divided on this issue. A recent article by Kristensen and Korda concluded that North Korea has "at most only a few thermonuclear warheads," whereas Fedchenko and Kelly believe that it is very likely that North Korea's 2017 nuclear test was an advanced two-stage thermonuclear weapon.[4]

However, there are two important issues regarding North Korean nuclear weapons that recent analyses have ignored. First, North Korea's substantial reliance on highly enriched uranium (HEU) as the nuclear material for its nuclear weapons means that it will be very difficult for North Korea to develop lightweight two-stage thermonuclear weapons. The heavier the North Korean nuclear weapons, the less range North Korean ballistic missiles will have. Second, high yield North Korean nuclear weapons will require more nuclear material than do lower yield fission weapons, which in turn would reduce the size of North Korea's nuclear arsenal.

---

[1] This paper is the product of the author's personal research and the analysis and views contained in it are solely his responsibility. Though the author is also a part-time adjunct staff member at the RAND Corporation, this paper is not related to any RAND project and therefore RAND should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com

[2] Dimitri P. Voytan, Thorne Lay, Esteban J. Chaves and John T. Ohman, "Yield Estimates for the Six North Korean Nuclear Tests From Teleseismic P Wave Modeling and Intercorrelation of P and Pn Recordings," *Journal of Geophysical Research: Solid Earth*," May 23, 2019. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019JB017418

[3] Gregory S. Jones, "North Korea's Sixth Nuclear Test: Was It a Hydrogen Bomb?" September 18, 2017. https://nebula.wsimg.com/871aa9ff0e83997abb8e714bb3b0d2be?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[4] Hans M. Kristensen and Matt Korda, "North Korean nuclear weapons, 2021," *Bulletin of the Atomic Scientists*, Vol. 77, No. 4, 2021, p. 224 https://www.tandfonline.com/doi/pdf/10.1080/00963402.2021.1940803 and Vitaly Fedchenko and Robert E. Kelly, "New methodology offers estimates for North Korean thermonuclear stockpile," *Jane's Intelligence Review*, July 30, 2020. https://www.janes.com/new-methodology-offers-estimates-for-north-korean-thermonuclear-stockpile

Two-Stage Thermonuclear Weapon Basics

Two-stage thermonuclear weapons, as the name implies, consist of two components: a primary which is a relatively low yield fission trigger and a thermonuclear burning secondary where most of the yield is produced. As originally conceived, the secondary consisted of a fissile material core (plutonium or enriched uranium) surrounded by alternating layers of thermonuclear fuel and natural uranium. The thermonuclear fuel is lithium deuteride (LiD). In a two-stage thermonuclear weapon about half of the yield is from fission reactions and half from fusion reactions.[5] The fusion reactions release high energy neutrons which can fission the U-238 in the secondary.

The two-stage thermonuclear device for which there is the best description is the British Grapple X device tested in November 1957.[6] The primary for this device was a Red Beard tactical pure fission implosion weapon which had a composite core (containing both plutonium and HEU) and a yield of 45 kilotons. The spherical secondary had only three layers, a central core of enriched uranium, a middle layer of LiD and an outer natural uranium layer. The masses of the materials in the secondary are unknown. The British used only three layers not because they thought it was necessarily superior to a multilayer design but rather for analytical simplicity. Nevertheless, the device performed quite well, producing a yield of 1.8 megatons instead of the expected 1.0 megaton.

A more recent depiction of the W87, an advanced U.S. two-stage thermonuclear weapon, in the "Cox report" shows a three layer spherical secondary similar to that of the Grapple X device.[7] However, it shows that the outer layer could be either U-238 or U-235.

Implications of North Korea's Heavy Reliance on HEU

Recently there have been a number of different estimates of the size of North Korea's HEU stockpile, which illustrates the large uncertainties surrounding North Korea's nuclear program. Heinonen has an estimate of only 540 kilograms as of the end of 2020.[8] Bennett et al., have a rather different estimate of about 1,100 to 2,100 kilograms.[9] Hecker has estimated an intermediate 600 to 950 kilograms.[10] Kristensen and Korda do not explicitly estimate the size of North Korea's HEU stockpile. However, since their estimate of the number of weapons in North

---

[5] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, Third Edition, United States Department of Defense and United States Department of Energy, 1977. p. 22.

[6] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, pp. 155-160.

[7] U.S. National Security and Military/Commercial Concerns With The People's Republic of China, Volume I, Select Committee, United States House of Representatives, January 3, 1999, p. 78. https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851.pdf

[8] Olli Heinonen, "Development of the Yongbyon Uranium Enrichment Plant Between 2009 and 2021," *38North*, July 16, 2021. https://www.38north.org/2021/07/development-of-the-yongbyon-uranium-enrichment-plant-between-2009-and-2021/

[9] Bruce W. Bennett, Kang Choi, Myong-Hyun Go, Bruce E. Bechtol, Jr., Jiyoung Park, Bruce Klingner, and Du-Hyeogn Cha, *Countering the Risks of North Korean Nuclear Weapons*, RAND and Asan Institute for Policy Studies, April 2021. https://www.rand.org/pubs/perspectives/PEA1015-1.html

[10] Siegfried Hecker, "Estimating North Korea's Nuclear Stockpiles: An Interview With Siegfried Hecker," *38North*, April 30, 2021. https://www.38north.org/2021/04/estimating-north-koreas-nuclear-stockpiles-an-interview-with-siegfried-hecker/

Korea's nuclear stockpile is similar to that of Hecker, it is likely that their estimate of North Korea's HEU stockpile is also similar to that of Hecker. Given the large uncertainties regarding North Korea's enrichment program, I believe that the entire range, from 540 kilograms to 2,100 kilograms is plausible.

There is much more agreement among these analysts as to North Korea's stocks of plutonium and tritium. Both of these materials would have been produced in the 25 MWt plutonium production reactor at Yongbyon. This reactor started operating in the latter part of the 1980s but has been shut down for lengthy intervals. As a result, it is estimated that North Korea today has only about 25 to 60 kilograms of plutonium and little to no tritium. Without tritium, North Korea will not be able to boost its nuclear weapons.[11]

The lack of tritium is a consequence of tritium's relatively short half-life of 12.3 years. As a result, 5.5% decays away each year. Maintaining a tritium stockpile requires continuing production. The last time the reactor at Yongbyon operated was between 2013 and the end of 2018. It has been idle for the last two and one half years. Any tritium that the reactor might have produced during its intermittent operations during 2013-2018 is decaying away. North Korea appears to be in no hurry to restart this reactor (or to start the nearby experimental light water reactor) and regardless of how much tritium North Korea may currently have, it clearly is not relying on this material for its weapons.

The lack of tritium impacts the utility of North Korea's plutonium stocks. Without tritium for boosting, it would take about 5 kilograms of plutonium to produce a weapon with a yield in the 10 to 20 kiloton range. Given the small size of North Korea's plutonium stockpile, it could produce about 5 to 12 nuclear weapons, which is only a small fraction of North Korea's estimated nuclear weapon stockpile. It appears that most if not all of North Korea's weapons will rely on HEU exclusively.

How might the lack of plutonium and tritium affect any potential North Korean two-stage thermonuclear weapons? It is certainly possible to build a two-stage thermonuclear weapon using just HEU without boosting. China's first two-stage thermonuclear weapon test on June 17, 1967 involved such a weapon. Even so, China later acquired both plutonium and tritium, highlighting the importance of these materials.

Today, the U.S. relies on boosted plutonium primaries in its two-stage thermonuclear weapons.[12] The use of plutonium/tritium primaries presumably allows the production of the small, lightweight, primaries that are needed to produce the lightweight, compact, high yield nuclear weapons that comprise the U.S. nuclear arsenal.

---

[11] For the role tritium plays in boosting see: Gregory S. Jones, "U.S. Increased Tritium Production Driven by Plan to Increase the Quantity of Tritium per Nuclear Weapon," June 2, 2016. https://nebula.wsimg.com/08a60104185a91e6db9008fb929a0873?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[12] "Stockpile Stewardship and Management Plan: Fiscal Year 2020," National Nuclear Security Administration and United States Department of Energy, July 2019, p. 2-21 and p. 2-28. https://www.energy.gov/sites/default/files/2019/08/f65/FY2020__SSMP.pdf

Unboosted HEU primaries would be significantly larger and heavier, making the resulting two-stage thermonuclear weapons larger and heavier as well. It is hard to know just how much larger and heavier such weapons would be but a reasonable surmise is that such weapons would be similar to earlier generations of two-stage thermonuclear weapons. A reasonable guess is that such weapons might be similar to the Chinese warhead for the DF-21, with a yield of 200 to 300 kilotons and a weight of about 600 kilograms.[13] This is in contrast to the TN 71, a more advanced boosted French ballistic missile MIRV warhead, which could produce 150 kilotons while weighing only 175 kilograms (385 lb.).[14]

If North Korea were to employ high yield pure fission warheads, they might weigh even more than 600 kilograms. Unboosted fission weapons can achieve high yield by using large amounts of HEU. In May 1957 the British tested a pure fission device[15] known as Orange Herald (Small) which was 30 inches (0.8 meters) in diameter and weighed about 2,000 lb. (900 kilograms).[16] It had a yield of 720 kilotons and was the largest yield pure fission weapon ever tested.

This device was never deployed as a weapon. Rather, between 1958 and 1962, the British deployed a reduced yield version of this type of weapon as a gravity bomb with the designations Violet Club and Yellow Sun Mk. 1.[17] The device was never tested but was estimated to have a yield of 400 kilotons. However, it was significantly larger and heavier than Orange Herald with a diameter of 45 inches (1.1 meters) and a weight of 7,000 lb. (3,200 kilograms).[18] It is not clear why the deployed version was so much heavier.

Nor can the warhead weight issue be avoided by reducing the weapon's yield. Even 10 to 20 kiloton pure fission weapons would weigh at least 500 to 900 kilograms.[19]

These relatively heavy warheads would significantly reduce the range of North Korean ballistic missiles. A detailed analysis of North Korea's Hwasong 14 by Postol, Schiller and Schmucker showed that with a 200 kg warhead the missile would have a range of about 10,000 kilometers which would be sufficient to reach Chicago.[20] However with a 600 kilogram warhead the missile's range would be reduced to only about 6,000 kilometers, which is 2,000 kilometers short

[13] Robert S. Norris, Andrew S. Burrows and Richard W. Fieldhouse, *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*, Westview Press, Boulder, CO, 1994, p. 388.
[14] *Ibid.*, p. 218.
[15] The British attempted to boost this device using a small amount of thermonuclear material but concluded that the boosting was unsuccessful. Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001, p. 147.
[16] Richard Moore, "The Real Meaning of the Words: a Pedantic Glossary of British Nuclear Weapons," UK Nuclear History Working Paper, Mountbatten Centre for International Studies, March 2004. https://www.nuclearinfo.org/wp-content/uploads/2020/09/The-Real-Meaning-of-the-Words-A-Pedantic-Glossary-of-British-Nuclear-Weapons.pdf
[17] John Walker, "British Nuclear Weapon Stockpiles, 1953-78," *RUSI Journal*, Vol. 156, No. 5, October/November 2011. https://www.tandfonline.com/toc/rusi20/156/5?nav=tocList
[18] John Simpson, "British Nuclear Weapon Stockpiles, 1953-78, A Commentary on Technical and Political Drivers," *RUSI Journal*, Vol. 156, No.5, October/November 2011.
[19] Gregory S. Jones, "North Korea's Sixth Nuclear Test: Was It a Hydrogen Bomb?" September 18, 2017, p. 4.
[20] Theodore A. Postol, Markus Schiller and Robert Schmucker, "North Korea's 'not quite' ICBM can't hit the lower 48 states," *Bulletin of the Atomic Scientists*, August 11, 2017. https://thebulletin.org/2017/08/north-koreas-not-quite-icbm-cant-hit-the-lower-48-states/

of even Seattle. A 900 kilogram warhead would reduce the range to only about 4,000 kilometers.

A similar detailed analysis is not available for North Korea's longer-ranged Hwasong-15 but it is clear that with a heavy enough warhead even this missile will not be able to reach the continental United States. North Korea's lack of tritium and its small plutonium stockpile must be factored into any analysis of the ballistic missile threat from North Korea to the continental United States.

Nuclear Material Requirements for High Yield North Korean Nuclear Warheads

If North Korea has deployed high yield nuclear warheads, they are most likely simple fission weapons using large amounts of HEU similar to the British Orange Herald device. The U.S. first tested such a weapon in 1952 as the King shot in the Ivy test series. It had a yield of 500 kilotons. This weapon was large and heavy, being about the size of the Nagasaki weapon, 60 inches (1.5 meters), in diameter, weighing about 8,800 lb. (4,000 kilograms) but as the British demonstrated smaller, lighter versions are possible. The U.S. deployed this device as the Mark 18 bomb between 1953 and 1956.

One source says that the Orange Herald device used 117 kilograms of HEU.[21] To produce 720 kilotons would require the complete fissioning of the U-235 contained in about 46 kilograms of 90% enriched uranium. The reported HEU content of the device would imply an efficiency of about 39%. If the King device had the same efficiency, then it contained about 81 kilograms of 90% HEU. A lower yield device would probably need less HEU but to get a 250 kiloton yield would likely require between 40 kilograms and 60 kilograms of HEU.[22]

Fedchenko and Kelly have strongly argued that North Korea's September 3, 2017 nuclear test was that of an advanced two-stage thermonuclear device.[23] They invoke the authority of "*Janes*" to dismiss the possibility that this test was a device similar to Orange Herald. They argue that since the North Koreans have shown illustrations of two-stage devices, North Korea testing a large yield Orange Herald type device in order to fool the West would be "extremely sophisticated disinformation."

However, the North Koreans have previously attempted to mislead the West. In 2012 North Korea paraded "ICBMs" to make the U.S. believe that it was vulnerable to a missile attack. However, they were nothing but poorly made mockups.[24] It would not require "extreme sophistication" for North Korea to attempt to make the West believe that it had two-stage thermonuclear weapons when it did not.

---

[21] Nuclear Weapon Archive. Britain's Nuclear Weapons - British Nuclear Testing (nuclearweaponarchive.org) Walker describes Orange Herald (Small) a little differently. He says that it was 45 inches (1.1 meters) in diameter, 2,500 lb. (1,100 kilograms) and used "up to" 120 kilograms of HEU. See: John Walker, *British Nuclear Weapons and the Test Ban 1954-1973*, Ashgate, 2010, p. 25 & p. 8.
[22] With a 39% efficiency about 40 kilograms would be required. However, the efficiency might be less if North Korea tried to lighten the weapon, resulting in a need for a larger amount of HEU.
[23] Vitaly Fedchenko and Robert E. Kelly, "New methodology offers estimates for North Korean thermonuclear stockpile," *Jane's Intelligence Review*, July 30, 2020.
[24] Markus Schiller and Robert H. Schmucker, "A Dog and Pony Show: North Korea's New ICBM," April 18, 2012. https://www.armscontrolwonk.com/files/2012/04/KN-08_Analysis_Schiller_Schmucker.pdf

At any rate, any potential North Korean two-stage thermonuclear weapon would require increased amounts of HEU compared to the 20 kilograms that are required to produce a 10 to 20 kiloton yield simple fission weapon. Fedchenko and Kelly have estimated the amount of HEU needed. They assume that the North Koreans use a boosted plutonium primary. Otherwise, they base their analysis on unofficial open-source information regarding one of the most advanced U.S. warheads, the W88. They assume that the secondary is three layered, similar to the British Grapple X device, except that the inner and outermost layers are U-235 and the middle layer LiD. They assume that no significant yield is produced by the LiD layer and that all of the yield is produced by the U-235 in the secondary. They calculate that to produce the 475 kiloton yield of the W88 would require the complete fissioning of about 28 kilograms of U-235 (which they incorrectly term "HEU"). They assume a fission efficiency of 40% and a yield for the North Korean weapon of between 250 and 270 kilotons. They calculate that the North Korean secondary would require between 37 and 40 kilograms of U-235 (which again they incorrectly call HEU), this would be 41 to 44 kilograms of 90% enriched HEU.

There are a number of problems with this analysis. North Korea is not going to use boosted plutonium primaries but rather must use unboosted HEU ones. As was discussed above, the official *The Effects of Nuclear Weapons* states, "On the average, the energy released in the explosion of a thermonuclear weapon originates in roughly equal amounts from fission and fusion processes, although there may be variations in individual cases."[25] These "variations" may mean that the fusion fraction in a weapon like the W88 is less than 50% but it is very unlikely to be near zero. On a weight basis, LiD contains over three times as much energy as HEU (about 51 kilotons per kilogram vs 17.5 kilotons per kilogram U-235), so that the fusion of just a few kilograms of LiD would provide a substantial contribution to the yield. Further, as was illustrated by the Grapple X device, many two-stage thermonuclear weapons derive a significant part of their yield from U-238. The U-238 would only fission if there were substantial yield from LiD in order to produce high energy neutrons. For very large yield weapons (say 5 to 10 megatons) it would require implausibly large quantities of HEU to achieve the yield if there were no U-238 fission.[26]

If one assumes that half of the yield of a 250 kiloton weapon is produced by the LiD, then with a 40% efficiency, it would require only about 20 kilograms of 90% enriched uranium to produce 125 kilotons of yield. Even if only one quarter of the yield is produced by LiD, then with a 40% efficiency, it would require about 30 kilograms of 90% HEU to produce 188 kilotons of yield. However, it is possible that a significant fraction of the yield is produced by the fission of U-238. If, in these two cases, we assume that half of the fission yield is produced by U-238, then only 10 to 15 kilograms of 90% enriched HEU would be required in the secondary.

[25] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, Third Edition, United States Department of Defense and United States Department of Energy, 1977. p. 22.

[26] For a 10 megaton weapon, assuming a 50% fusion fraction, fission would need to supply 5,000 kilotons of yield. If this were all provided by U-235, this would require almost 800 kilograms of 90% enriched uranium, assuming a 40% fission efficiency. One hundred such weapons would require 80 metric tons of HEU.

In addition, one must add the 20 kilograms of HEU that would be in the primary, giving a total of 30 to 50 kilograms of HEU. This estimate is in the same general range as that of Fedchenko and Kelly even if the details are rather different.

In sum, an unboosted HEU pure fission device would require between 40 and 60 kilograms of HEU to produce a yield of 250 kilotons. An unboosted two-stage thermonuclear weapon using only HEU would require between 30 to 50 kilograms of HEU to produce a yield of 250 kilotons. Therefore, a given North Korean HEU stockpile would produce somewhere between one-third and two-thirds as many high yield weapons compared to 10 to 20 kiloton weapons each using 20 kilograms of HEU per weapon.

Conclusions

The 25 MWt plutonium production reactor at Yongbyon has only operated intermittently since the late 1980s and not at all for the last two and one half years. As a result, though North Korea's uranium enrichment program may have produced large amounts of HEU, its plutonium stock is small and whatever tritium it has is decaying away. North Korea's nuclear weapons will likely be based almost exclusively on HEU.

If North Korea produces high yield weapons, they will likely be unboosted pure fission weapons using large amounts of HEU. If North Korea produces two-stage thermonuclear weapons, they will have relatively large unboosted HEU primaries. Either type of weapon will be relatively heavy, with a weight of approximately 600 to 900 kilograms. These heavy weapons will significantly shorten the range of North Korea's ballistic missiles, limiting their ability to hit the continental U.S. These weapons would require somewhere between 30 and 60 kilograms of HEU. Therefore, a given North Korean HEU stockpile would produce somewhere between one-third and two-thirds as many high yield weapons compared to 10 to 20 kiloton weapons each using 20 kilograms of HEU.