Assessment of DPRK 'Hwasan-31' Standardized Nuclear Warhead

Robert E. Kelley
Consultant
Korea Institute of Nuclear Nonproliferation and Control, KINAC[1]
June 2023

Executive Summary

- DPRK has announced standardization of the warhead used in many short-range nuclear weapons systems
- Standardization is a very reasonable logistical approach to a small stockpile
- Kim Jong Un has exhorted scientists to expand nuclear material production
- Examination of nuclear material production progress suggests this will mostly depend on more uranium enrichment
- The Hwasan-31 is probably based upon highly enriched uranium as a main fuel
- The Hwasan-31 has a likely yield of about 15 kt
- The DPRK program is becoming advanced and robust enough to become a proliferation supplier much as Pakistan did

Organization of this report

The announcement of the standardized warhead is an excellent opportunity to review what is known about the DPRK nuclear weapons program, stockpile and likely future direction.

In Part 1 of this report we review the history of nuclear testing and what it reveals about the evolution of the warhead itself.

In Part 2 we review the history of nuclear materials production, constraints, milestones and the impact of external help from Pakistan.

In Part 3 we look at the concept of miniaturization and the evolution of the standard warhead for a design and engineering point-of-view.

---

[1] Report prepared with the sponsorship and support of KINAC. The views are those of the author and not necessarily KINAC

Table of Contents

These are the warhead systems mentioned in open source

The Democratic Peoples Republic of Korea has recently announced that it is moving to standardize its nuclear warheads. The new standard warhead will be designated as Hwasan-31. In this mode the same nuclear explosive component will be used in ballistic and cruise missiles and a new robot torpedo. Posters visible at a Kim Jong Un site visit suggest the following military systems to include:

- 600 mm KN-25 MLRS rocket
- Hwasong-12
- KN-23 SRBM
- KN-24 SRBM
- Haeil-1 Underwater Drone
- Hwasal-1 strategic cruise missile
- Hwasal-2 strategic cruise missile

It is unlikely that the Hwasan-31 would be appropriate for the solid fueled strategic deterrent that may have a much higher yield, possibly 250 kt:

- Hwasongpho-18

Standardized nuclear explosive device given DPRK's limited test series

A standardized nuclear device is a very reasonable step for DPRK to take. It reduces logistical and manufacturing complexity. It makes military planning much easier. The only truly negative aspect is if a common mode failure is discovered later, the entire stockpile could be unreliable.

From DPRK pronouncements it appears that the Hwasan-31 is only appropriate for the shorter-range lower yield "tactical" nuclear explosives and not the long-range ICBM-carried large strategic deterrent, Hwasongpho-18. (See Part 3 for a discussion on the designation tactical versus strategic.)

DPRK really has only three nuclear tests likely to have been the quality control and proof standard for the Hwasan-31, Tests Kim-3,4,5. This was the occasion for the weapons designers to convince the political masters that they had a reliable and consistent product for the existential deterrence of the nuclear arsenal.

The standard warhead is useful for our analysis because we only have one system to study and to model. Yield and effects are therefore known and this reduces analytical uncertainty.

The sixth nuclear test was substantially larger and is not considered to be part of the Hwasan-31 standardization. It is considered later in this report.

Standardized nuclear explosive device in the case of virtually unlimited testing

The Soviet Union carried out about 715 nuclear tests and the US about 1054. This huge number of tests allowed evolution of many explosive package designs. Underground nuclear tests are usually designed largely to test the explosive package of fissile materials and high explosives. Electronic systems, safety systems and other auxiliary items can be tested under laboratory conditions and do not require a full nuclear test. Nevertheless, in the case of the United States there can be seen a trend to make weapons more and more similar in the years since new designs were introduced, largely in the 1970s and even more constrained since nuclear testing ceased in 1992. Warheads that seem to be very similar from their development history have been used or proposed for use in several cruise missiles, the discontinued Pershing IRBM and versions of gravity bombs. There have even been proposals to adapt warheads designed for different systems, by different nuclear weapons laboratories, to be substituted for each other. DPRK clearly does not have this luxury with only three likely weaponization tests.

Part 1

DPRK nuclear test series

The DPRK has conducted only 6 nuclear tests. For a small country basing its existential deterrent on nuclear weapons there should not be great deal of variety in its nuclear warheads if there have not been a number of tests. There *could be* many possible devices: uranium, plutonium, composites of both, boosted and unboosted, different sizes for different systems. But the record shows DPRK conducted only six nuclear tests and that 3 of the tests were quite similar in their test output. Those three are the tests of interest, the ones on which DPRK might base a reliable stockpile. It is unlikely that there are a great number of different warheads without appropriate testing.

Analysis of these tests shows that the most likely yield for a standard warhead yield is about 16 kilotons of high explosive yield. There is uncertainty in this value, but an analysis of the tests gives some idea of the targeted yield range. It is important at this point to note that there is considerable scientific uncertainty in the DPRK test yields. For our purposes we can choose similar conclusions by scientific experts to compare each test to another. While that leaves uncertainty in the final yield, the pattern of comparing several tests with similar yields to each other is very useful.

Consider the testing history:[2]

Date	Test Sequence Number	Yield range Kilotons	Comments
2006 10 09	Kim-1	0.7 -2	First test. Learning experience. Some sources reported attempt to use very small amount of fissile material
2009 05 25	Kim-2	2 – 5.4	Three-year gap in development. Consistent with a small plutonium device
2013 02 12	Kim-3	6-16	Another 3-year gap resulting in a very respectable military yield, likely VHEU.[3] First test after beginning centrifuge enrichment of uranium
2016 01 06	Kim-4	7 – 16.5	Very similar result, Likely VHEU
2016 09 09	Kim-5	15-25	Uncertainties barely overlap with tests Kim-3 and Kim-4 at about 16 kilotons, Likely VHEU
2017 09 03	Kim-6	70 - 280	Clearly a much larger device. Probably thermonuclear but could be a deception. Several reputable sources have given approximately the same yield estimate -250 kt. The primary fission stage in this device could be the Hwasan-31. Likely that the two-stage nuclear device uses both plutonium and VHEU.

Table 1. Summary of DPRK Nuclear Tests

Leakage of nuclear materials from test tunnels

DPRK has been very successful in containing any leakage whatsoever of radioactive materials from its underground nuclear tests. This is important for health and safety reasons. Leaked nuclides can present a local problem for the health of people nearby if they are exposed to leaked radioactive debris. It is unfortunate that the tests are so very well contained from an intelligence point of view. Leaked radionuclides provide a huge amount of information about the components of a nuclear device being tested. For example, it would be clear if DPRK was using plutonium, HEU, or a combination of both. It would be immediately obvious if they were "boosting" the yield with tritium and any success with thermonuclear design would be clear. Ignoring health and safety issues it is a shame that DPRK has been so very successful in underground debris containment!

Physical damage to an underground test site

[2] Wikipedia has collected 38 reputable sources in one summary table. https://en.wikipedia.org/wiki/List_of_nuclear_weapons_tests_of_North_Korea

[3] VHEU is Very Highly Enriched Uranium enriched to greater than 80% in the uranium-235 isotope.

DPRK has conducted 6 nuclear tests in a relatively small geographical area. Especially the final test, of about 250 kt will have done substantial damage to the structure of the mountain and will increase the possibility that some radioactive debris will leak out of future nuclear tests through cracks in the earth from previous nuclear explosions.

It is possible to reuse underground test tunnels called adits[4] for subsequent nuclear tests. The main tunnel would normally go straight into the mountain, and side adits are used for subsequent nuclear tests. The side adits are not straight but are roughly shaped like a hook so that they can seal themselves off from blast and debris leakage. There will also be massive containment using concrete and earth to contain the blast, so it does not leak into the main straight tunnel. A particular problem is the electrical cables that penetrate the concrete plugs that seal the adit. Preventing leakage of radiation between the insulation and copper conducting wires is a difficult task. If the containment is good enough, it is safe for humans to enter the original straight adit and construct new adits at new side locations. If the blast does significant geological damage, then a new location must be found. It is likely that the tunnel complex for the 250 kt test is damaged beyond re-use.

Note that if the tunnel were left open to the environment there would be a huge radioactive release signature. But the blast coupling of the test occurs almost entirely in the earth surrounding the detonation point by x-ray absorption. A small fraction of the energy of the blast escapes outside the mountain even if a tunnel is unsealed. If a tunnel were left unsealed, the measured blast yield would not change substantially.

Possible disinformation option for the very large nuclear test

It is almost a certainty that the very large nuclear explosion in September 2017 was a true thermonuclear test. There are many reasons we have stated that it is probably true. It is important, however, to realize there is a small possibility that it was disinformation designed to impress the world with a non-existent thermonuclear capability.

Such a large explosion is possible with a simple, very large fission bomb. Such a bomb would be too large for any DPRK missile to deliver. But it could be designed as a very large one stage fission-only device and then assembled inside a nuclear test tunnel and detonated. Take, for example, the first US thermonuclear device test. It was truly thermonuclear, but it was the size of a large building, and it could not have been moved from its location by any means whatsoever.

A large fission-only device could be modeled on a device like the US Ivy-King experiment in Polynesia in 1952. That device used a very large amount of VHEU – probably several critical masses - and produced a reported 500 kilotons without tritium boosting.[5] It was small enough to fit in a large bomber and was detonated in the atmosphere, but it was far bigger than any device the DPRK could deliver except possibly in a ship. It could have been built piece-by-piece inside a nuclear testing tunnel.

---

[4] Technically, an adit is a horizontal tunnel into the earth that only has one opening. A tunnel normally has two openings, passing through a mountain. Popular language is used in describing these underground nuclear tests as "Tunnel Tests."

[5] https://www.radiochemistry.org/history/nuke_tests/ivy/index.html

This is a remote possibility, but one that policy makers should consider as possible disinformation. If there is not another large DPRK thermonuclear test it will be an indication either way, that the event was to impress and less to be an actual threat.

Choosing a tunnel instead of a vertical shaft

There are several reasons to choose a horizontal tunnel for a test versus a vertical shaft. Developing countries are likely to have tunnel engineers and digging capability

- A tunnel can even be dug by hand
- Drilling a deep shaft possibly a meter in diameter is not easy for a developing country
- A tunnel allows easy access for humans to set up a test
- A vertical shaft does not allow easy access once a device is placed in the ground
- It is relatively easy to set up diagnostic instruments in a room mined at the end of a tunnel
- It is probably easier to seal a tunnel against debris than a shaft

It is easy to see that tunnels are much more applicable to DPRK than drilling deep holes.

Part 2

Nuclear Material Production

There is a general consensus that the material used in the first and second DPRK tests was probably plutonium from the 25 MW (thermal) graphite moderated reactor at Yongbyon.[6] This reactor was the only known source of bomb-grade nuclear material until about 2010. Foreign estimates of DPRK fissile material usually considered that DPRK had an unknown hidden source of uranium enrichment but not until about 2010. This was not confirmed in open-source reporting until a group of scientists led by Dr. Siegfried Hecker were shown an enrichment cascade. That cascade was considered to be producing Very Highly Enriched Uranium (VHEU) for weapons.[7]

If we compare the timeline of DPRK nuclear tests to a timeline of DPRK nuclear material production, it becomes obvious that there was a major shift in priority from continuing to produce small amounts of plutonium to enriching uranium.

[6] This reactor is often referred to in the literature as the 5MW(e) reactor. This is a confusing misnomer. The reactor was never realistically built to produce electricity. When estimating plutonium production among small military plutonium production reactors the correct figure of merit is the *thermal power rating* and not an arbitrary electrical generating capacity.

[7] This report uses the term Very Highly Enriched Uranium to designate uranium enriched to about 80% uranium 235. The legal definition of Highly Enriched Uranium (HEU) greater than 20% is quite useless for serious consideration of enriched uranium suitable for nuclear explosives.

Evolution of the growing uranium enrichment program

1980s and 1990s	Program entirely focused on plutonium production
1998	Some centrifuges flown to DPRK from Pakistan[8]
2002	DPRK admits a U enrichment program[9]
2003	Casings for P-2 machines stopped at Suez
2006	Kim-1 nuclear test
2008	US Finds HEU on papers
2009	Kim-2 nuclear test Construction started on centrifuge plant at Yongbyon
2010	Hecker observes brand new plant
2013	Kim-3 nuclear test Centrifuge plant doubles floor space[10]
2016	Kim-4 and 5 nuclear test Pictures of single stage nuclear warhead model
2017	Kim-6 nuclear test Pictures of two-stage thermonuclear warhead model
2023	Pictures of standardized Hwasan-31

Table 2. Evolution of DPRK fissile material production from plutonium-based to VHEU

Reports of clandestine activity by the Pakistani metallurgist A. Q. Khan became ubiquitous around 2002 and the CIA estimated that DPRK might have an operational centrifuge plant by 2005.[11] Hecker very clearly defines the time scale he was given:

> *At Yongbyon, we were told that construction of the centrifuge facility began in April 2009 and that it was completed days before we arrived. But what we saw demonstrates without a doubt that Pyongyang has pursued enrichment for many years. The claim that they just started the centrifuge program for their new LWR program is not credible. In retrospect, over the years there has been plenty of evidence, but no smoking gun, of Pyongyang's uranium enrichment efforts. Former Pakistani President Pervez Musharraf claimed in his memoir that A.Q. Khan, the father of the Pakistani bomb, delivered 20 P1 and four P2 centrifuges to North Korea about 10 years ago.*

There are reasons to believe this is an accurate estimate. There is a wealth of reporting that this was the period when A. Q. Khan was actively trading technical knowledge with DPRK about missiles and nuclear activities. It also shows it was likely at the time of the first DPRK test in 2006 it would not have enough VHEU for a device test and that the only fissile material would have been plutonium from the 25 MW(th) reactor. This might still have been

[8] "Shopping for Bombs," Gordon Corera, 2009, ISBN 978-0-19-537523-7

[9] https://www.armscontrol.org/factsheets/dprkchron

[10] https://www.38north.org/2021/07/development-of-the-yongbyon-uranium-enrichment-plant-between-2009-and-2021/

[11] "Shopping for Bombs," Gordon Corera, 2009, ISBN 978-0-19-537523-7, page 100

true in 2009 for the test Kim-2. In the years between 2005 and 2023 the production of weapons grade plutonium has been severely limited by the fact there is only one small reactor in operation and one reprocessing plant as far as we know.

Kim calls for greater nuclear material production

In 2023 Kim Jong Un exhorts the party to increase nuclear material production:

> *Noting that the institute and the field of atomic energy should expand on a far-sighted way the production of weapon-grade nuclear materials for thoroughly implementing the plan of the Party Central Committee on increasing nuclear arsenals exponentially and put spurs to continuing to produce powerful nuclear weapons, he set forth important tasks facing the institute and the field of atomic energy.*[12]

DPRK's limited options for more nuclear material

There is very little likelihood that plutonium production can be easily increased without operating a new clandestine reactor and reprocessing plant. These activities have signatures that are more likely to be detected by intelligence surveillance. But centrifuge plants (and their feed material plants) are much easier to conceal and have fewer external signatures than plutonium production. The original discovery of the small plant at Yongbyon came as a surprise. There was strong suspicion that the efforts of A.Q. Khan to supply centrifuges and centrifuge technology was being exercised somewhere. An expansion of the plant in 2013 is the only other publicly confirmed enrichment activity. Some amateur sources identified a plant near Kangson as a possible enrichment site. The satellite imagery is not at all compelling and there is no other reputable information to support this claim. This claim is no longer prominent in open-source information.

If there are other plants elsewhere in DPRK they are easy to expand from an industrial point of view. The best example of this is to look at Urenco plants in Europe and in New Mexico, USA. As demand increases, additional centrifuge cascades are easily added to an existing plant and they can draw upon existing supplemental industrial processes for feeding and withdrawing uranium.

[12] The Rodong Sinmun, 28 March 2023, Respected Comrade Kim Jong Un Guides Work for Mounting Nuclear Warheads on Ballistic Missiles, https://kcnawatch.org/newstream/1679988837-154013295/respected-comrade-kim-jong-un-guides-work-for-mounting-nuclear-warheads-on-ballistic-missiles/

2011 2021

Figure 1. The addition of similar plant modules to increase plant capacity is clear in the evolution of the Urenco centrifuge separation plant at Eunice, New Mexico, USA

Pakistan's Nuclear Program as an Example

Pakistan has a robust uranium enrichment program that has been known for decades. The main site at Kahuta has been identified but the details of the internals are unknown. There have been upgrades of the plant especially in response to two earthquakes that reportedly caused considerable damage but the degree of upgrades in each case is unknown. There are a number of reports in open literature about additional enrichment plants in Pakistan. Very general geographic locations are specified but there are no specific site identifications. Centrifuge buildings can be very plain in their outside characteristics and are largely indistinguishable from other industrial activity – even warehouses – in satellite imagery. Despite years of observation, the uncertainty in how many enrichment plants Pakistan has is huge and the knowledge of actual HEU production is equally uncertain.

Pakistan has embarked on a program of building 4 military nuclear reactors for producing plutonium. Earth Observation Satellites have followed the construction. The sites are well known. Cooling systems and other external characteristics give many clues about technology, power levels and operational status. Reactors and their attendant support facilities such as fuel reprocessing are much harder to hide than centrifuge plants and analysts have a good chance of making high quality estimates of output.

From this example we can see that DPRK's two small reactors at Yongbyon are well known and there is no indication despite years of observation that there are more. On the other hand, the enrichment plant at Yongbyon came as a surprise and would not be known if it had not been disclosed to the American visitors. Other centrifuge plants are suspected in DPRK but will be very hard to identify and quantify, if they exist at all. This is another reason why DPRK is likely to dedicate its fissionable materials effort largely to enriching uranium.

External features of a gas centrifuge do not identify internals

Western intelligence scored a coup when the group of US scientists observed DPRK gas centrifuges that are used to enrich uranium.[13] They observed that the external machines were likely copies of Pakistani P-2 centrifuges, or even in some cases, old Pakistani machines sold by A. Q. Khan.[14] This is a vital observation and can be used to *predict a lower bound* on DPRK enrichment in individual centrifuges based upon Pakistani machines using 350 Grade flow-formed maraging steel spinning rotors.

Maraging steel is a very complicated and difficult material to work with. Parts are formed using an unusual technology called flow forming that uses special machinery and is difficult to master. Maraging steel was used as a temporary alternative by Pakistan between primitive aluminum rotors in the P-1 centrifuges (also shared with DPRK) and later composite rotors using epoxy reinforced carbon fiber. This is because Pakistan was copying a temporary design stolen from the Netherlands. The substitution of improved rotor materials

[13] https://www.aps.org/publications/apsnews/201103/backpage.cfm
[14] "Shopping for Bombs," Gordon Corera, 2009, ISBN 978-0-19-537523-7, page 100

is not obvious from the outside of the machines. Although it is possible, even likely that the machines observed by the Americans used maraging steel rotors, it is likely that DPRK has advanced to far superior epoxy-reinforced composites.

This observation is reinforced by the experience of the Soviet Union centrifuge program. The external configurations of the outside of its centrifuges did not change for many decades. The internals were upgraded, however, from old aluminum rotors to advanced composite rotors during that time. It is only the European Urenco consortium that adopted maraging steel as an improvement over aluminum spinning rotors. In turn, Pakistan stole the European technology at the point where maraging steel was the latest choice. Maraging steel was a digression from improving centrifuge performance, influenced by a 1960s engineering decision that was a mistake, in retrospect.

Urenco moved on to epoxy-reinforced composites quickly and Pakistan appeared to have switched to fiber composites by about 1999.[15, 16, 17] The Soviet Union skipped the unnecessary evolution through maraging steel as a waste of time and moved on to composites directly. There is no public evidence that the US ever used maraging steel as a bridging technology.[18]

Lessons from the DPRK testing series

Availability of nuclear materials during test series

The nuclear weapons program of DPRK was initially focused on plutonium from its inception until the possibility of centrifuge enrichment was provided by A.Q. Khan of Pakistan. DPRK's troubles with the IAEA safeguards on its reactor and reprocessing always concerned plutonium production. There was no uranium enrichment program, declared or undeclared.

But by the early 2000s DPRK had acquired centrifuges and centrifuge design technology from Pakistan and its long-term vision would have begun to see uranium enrichment as the main source of fissile materials. The tests Kim-1 in 2006 and Kim-2 in 2009 were in a period where Very Highly Enriched Uranium, VHEU, was just becoming available. Those tests almost certainly used plutonium. As noted earlier, Siegfried Hecker and colleagues observed an operational small centrifuge plant in 2010.

Assessment of nuclear material in the standardized Hwasan-31

This analysis concludes that Kim Jong Un is urging greater VHEU production. If so, it is likely that the standardized Hwasan-31 will be based upon VHEU fissile fuel.

---

[15] https://eprints.nottingham.ac.uk/14216/1/239903.pdf
[16] See Annex for detailed description of Pakistani composite centrifuge rotor activity
[17] Shaiq.com, accessible through the Wayback Machine

[18] The American Gas Centrifuge Past, Present, and Future, October 13, 2003, Dean A. Waters, Chief Scientist and Technical Manager, USEC, Inc , https://www.osti.gov/servlets/purl/912770

Part 3

Assessment of North Korea's claims regarding the "miniaturized" tactical nuclear weapon and its implications

Introduction

In the first part of this report, we have established that it is quite reasonable for DPRK to standardize its smaller nuclear warhead. There are sufficient reasons to believe that the continuous supply of Very Highly Enriched Uranium (VHEU) and tight constraints on plutonium mean that VHEU is likely the main fissile material in the standardized Hwasan-31. Now we will analyze what design information we can gather from these assumptions.

What is miniaturization

Open literature often refers to "miniaturization" of a nuclear explosive device. "Miniaturization" is not a term-of-art in the nuclear weapons community. It is a popular media term and can mean many different things to different people. The first nuclear explosives were over a meter in diameter and used many hundreds of kilograms of high explosive to compress nuclear materials to a highly critical, explosive state. The expediency of World War II design led to a high explosive system that was very large and could only be delivered by the heaviest bombers of the era.

The high explosive is used to compress a subcritical fissile sphere into super criticality so it will fission and explode. It is important that the fissile materials be as small and as perfectly spherical as possible. In early bombs the explosive was very large and thick so that the shock wave coming from many discrete points on the outside of the explosive converged into a smooth spherical shack wave.

The first step to reduce the size of a bomb was an optimization of the type of explosive lenses and the central physical core. These improvements were equally applicable to plutonium and uranium cores. In the 1950s the lens systems were radically redesigned to make the diameter of the bomb much smaller. This allowed countries to develop warheads small enough to be fired from a military cannon. One device was able to be fired from a bazooka and other models were small enough to be transported by one soldier in a backpack. Some of these devices were standardized, such as the US W-54 explosive that was used in the bazooka and an anti-aircraft missile.[19] There is evidence of a US artillery shell that was small enough to be fired from a 155mm cannon. These designs would probably be close to the limit of what would be called "miniaturized."

Miniaturizing simple fission warheads to reduce size

The first US nuclear device tested in the Trinity Test in 1945 had 32 detonation points and used on the order of 2400 kg of relatively primitive high explosives.[20] It had a huge explosive system so that the discrete ignition points on the explosive were smoothed out by the time the implosion reached the plutonium pit. The way to miniaturize the system is to increase

---

[19] https://en.wikipedia.org/wiki/W54

[20] https://ahf.nuclearmuseum.org/ahf/history/electronics-and-detonators/

the number of detonation points of the surface of the high explosive sphere to produce a smooth and symmetrical implosion. This can be done by greatly increasing the number of detonation points on a thin explosive sphere. A good example of this is a Chinese implosion system using 252 individual detonation points on a very small sphere.[21] Another way to accomplish this is to have only a few main detonation points that ignite other points in turn. This system was allegedly proposed for an untested Iranian concept. This is described in the reference.[22] The original 12 detonation points, in turn, ignite other detonation points.

In an image released by DPRK in 2016, there is a large spherical device that is probably a fission implosion bomb with 12 detonator cables visible. This is probably a 12-point implosion system based upon a symmetrical dodecahedron. It can be made smaller by increasing the number of detonation points, possibly using the Iranian concept. There may be a common design concept between Pakistan, Iran and DPRK given other areas of cooperation, for example missile technology.

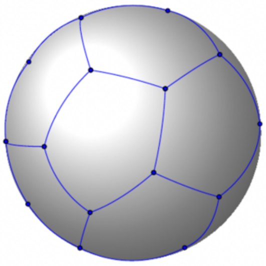

Figure 2 Geometric representation of 12 symmetric high explosive lenses surrounding a sphere

Figure 3 Examining a DPRK spherical probable fission device with only 12 cables entering the metal case around the high explosives

This device is assessed to use VHEU as the fissile fuel based upon the 2016 photo date and the production of VHEU by centrifuges. It could be about 2/3 this size if it used plutonium but that is in short supply for a standard warhead program.

---

[21] "Fusion Produced by Implosion of Spherical Explosive," Dong Qingdong, et.al., Shock Compression of Condensed Matter – 1989, Conference Proceedings.

[22] Iran's Work and Foreign Assistance on a Multipoint Initiation System for a Nuclear Weapon, David Albright, Paul Brannan, Mark Gorwitz and Andrea Stricker, November 13, 2011, https://isis-online.org/isis-reports/detail/irans-work-and-foreign-assistance-on-a-multipoint-initiation-system-for-a-n/

Miniaturizing thermonuclear warheads to reduce size

Miniaturization can also come from redesigning the warhead to be thermonuclear. One of the advantages of a thermonuclear warhead is that it can be smaller in diameter than a simple fission explosive of the same yield, possibly lower in mass and usually much longer along its axis. In this case miniaturization did not mean that the warhead was becoming tiny like a backpack bomb but rather that its weight and shape were adapted for a missile warhead reentry system.

Reentry vehicles need aerodynamic shape and mass to be stable as they enter the atmosphere. Much like a badminton shuttlecock needs mass at the tip and feathers to make it fly straight. Thermonuclear warheads need to have the weight as far possible to ensure they will fly straight and not tumble.

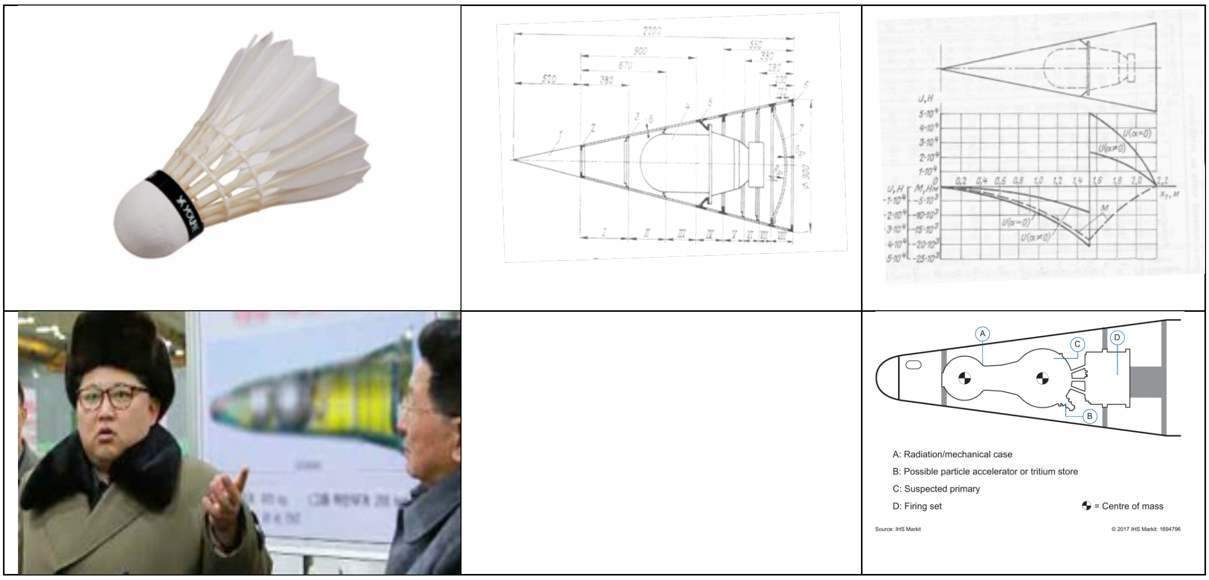

Figure 4. Several illustrations of the importance of having weight forward in the nose so an object will fly without tumbling

In the single stage fission weapon on the left the sphere is as far forward as it can be. The thermonuclear secondary in the vehicle on the right is very massive but smaller in diameter than the sphere as so it can be pushed further forward to remain stable with a somewhat greater yield than the sphere alone.

This was especially important for physically constrained systems like a Submarine Launched Ballistic Missile that had to be very small in diameter and weight to fit in a submarine and yet have a high enough yield value for destruction at its target.

Take one of the largest and significant warheads builds in the US stockpile, the W-68 Poseidon SLBM. Over 5000 were built and had far smaller yield than the other strategic bombs and missiles of the late 1950s and 1960s, only about 40 kt.[23]

---

[23] https://en.wikipedia.org/wiki/W68. Yield number is taken from open sources.

If this very small reentry vehicle was fitted with a single stage fission warhead the diameter of that simple warhead would limit the yield to a smaller number. But the thermonuclear design allowed the mass to be pushed forward into the nose giving a stable shuttlecock configuration with the maximum yield.[24]

The Hwasan-31 standard warhead

Open-source images of the Hwasan-31 show a short device in a military hardened container. Images on wall posters show the package placed in several delivery vehicles with different mounting schemes for an object roughly the same size. Cruise missiles and the torpedo can adapt a package of this size and weight easily in terms of weight and balance. Ballistic missile systems, however, are very sensitive to aerodynamic stability. In general, the mass should be as forward as possible in the reentry vehicle so that it will not tumble on atmospheric reentry. The Hwasan-31 is very small in diameter, especially when compared to the 2017 sphere Kim is examining in Figure 2. It should be small enough to mount far enough forward to be stable.

Figure 5. Kin Jong Un examining a model of a standardized Hwasan-31 casing with illustrations of deployment in vehicles on the wall behind him

From features in this photo, we estimate the yield of the outside military case as between 40 and 45 cm in diameter. Allowing for mounting hardware inside the diameter of the high explosive system might be 35 to 40 cm in diameter. This corresponds to a nuclear explosive system weight on the order of 45 kg. From the image and the very short length of the device it is clear that it is not thermonuclear.

Engineering choice of plutonium, VHEU or both in a fission device

---

[24] North Korea bargains with nuclear diplomacy,18-Oct-2017, Alison Evans, Karl Dewey, Markus Schiller, Robert E. Kelley, Jane's Intelligence Review

From an engineering point of view, plutonium is always the material of choice for an implosion fission bomb. The critical mass is about 1/3 that of VHEU making it much lighter, smaller in diameter and easier to compress.

Why would a country choose anything other than plutonium:

- The reactor and reprocessing infrastructure to make weapons grade plutonium is huge compared to enriching uranium to VHEU
- The plutonium production infrastructure is much more visible to intelligence than uranium
- Plutonium is a highly toxic material, much more so than VHEU
- Manufacturing of plutonium metal parts is far more difficult than uranium due to toxicity and very unfavorable metallurgy

Therefore, if VHEU is readily available, and its future increased production is ensured, uranium can be the logistical choice.

Composite cores of VHEU and plutonium

As with many engineering decisions, there can be alternative paths. If there is an inventory of plutonium insufficient for a stockpile but significant in size, plutonium could be used to stretch uranium reserves and build smaller devices due to its smaller critical mass. This is clearly an engineering decision, unique to any state and its perception of its nuclear weapons program now and into the future.

Plutonium-VHEU cores (called composite cores) made of both VHEU and plutonium are possible with an important caveat. Plutonium and uranium mixtures do not form an alloy. They form a brittle material called an intermetallic mixture that is highly pyrophoric and impossible to manufacture into reliable parts. Therefore, a composite device will suffer from additional manufacturing and physics problems caused by layered and separate parts of plutonium and VHEU. Add to this the timeline uncertainty of past and future material supplies. The engineering decisions and compromises are challenging logistically and subject to change over time.

Tritium and boosting

It is certainly possible that DPRK has succeeded in "boosting" simple fission primary yields by adding a burst of neutrons at the instant of maximum criticality of the imploding primary. This would be accomplished by causing the extreme heat of an exploding fission device to cause thermonuclear reactions in deuterium and tritium resulting in a huge burst of neutrons that in turn cause a doubling, quadrupling or even more of the unboosted yield of the fission device.

This is good physics for many reasons, not the least of which is increasing the yield.

It is questionable whether this boosting makes sense in the political and diplomatic space of DPRK. Tritium for boosting requires a few grams of tritium for each nuclear explosive.

Tritium is radioactive with a very short 12-year half-life. It must be produced continuously in military reactors in DPRK to replace that which is decaying. If the functionality of the DPRK stockpile is dependent on military nuclear reactors, like the small reactor at Yongbyon or the future ELWR, there is a huge danger that an essential ingredient might become unavailable if arms control or other measures such as a single military strike eliminates the production of replacement tritium.

It would be foolish to make the DPRK stockpile completely dependent on an unstable material that can be suddenly and totally cut off. Hence, although boosted weapons are more sophisticated, give higher yields for the same amount of fissile material and would be better primary drivers for thermonuclear weapons, it is possible that all DPRK fission weapons are unboosted. They would not depend upon a reliable supply of decaying tritium.

Unboosted fission bombs are "good enough" and much simpler, more dependable and reliable. DPRK claims of accomplishing fusion in past nuclear tests need not be excluded. They represent physics experiments that would be highly attractive to aspiring weapons physicists and they would still provide useful test data.

One intelligence indicator of tritium production would be serious efforts to separate lithium isotopes. Tritium is efficiently produced in a nuclear reactor by irradiating ^{6}Li which is only about 7.7% concentration in natural lithium. Enrichment is preferable for reactor tritium production. Enrichment to a high concentration of ^{6}Li is necessary to produce thermonuclear weapons such as the one suspected in Kim-6. Some effort in lithium chemistry has been observed in DPRK scientific literature but it is not a strong indicator especially in the absence of any other intelligence information.[25]

Do not be misled by open-source descriptions of thermonuclear warheads

At the time of the fifth DPRK test, Kim-5, there were misleading articles in the press saying that the device could not be thermonuclear *because the yield was too small*. It is true that the yield was 25kt or less and that would be a very small thermonuclear device. But the same articles went on to say that *a thermonuclear device* ***must*** *have a yield of hundreds of kilotons.* **This is false!** Explosive devices can be made very small as we have seen with the 40kt W-68 device. 40 kt was the minimum yield acceptable for this SLBM mission limited in size and weight by the submarine missile. The only way to achieve it was with a very small thermonuclear weapon. A special case of miniaturization.

Thermonuclear weapons with a yield of much less than 100 kt have been built and fielded in large numbers. Media claims that thermonuclear weapons *must be very large* are media hype and indicate a serious lack of experience on the part of the media.

DPRK has published photographs of the alleged Kim-6 device. Kim Jong Un is seen examining the device and it is clear that it has a diameter much reduced from the early US

---

[25] North Korea's Lithium Research Networks and its Quest for a Hydrogen Bomb
Justin V. Hastings, Hangeul Lee, and Robert Kelley, *The Korean Journal of Defense Analysis*
Vol. 30, No. 3, September 2018, 337—352

and Soviet nuclear bombs. More importantly the DPRK published a movie of technicians assembling the alleged Kim-6 test device and the details are convincingly accurate for what one would expect from such a device.[26]

Increasing the yield is very expensive and makes a small difference

The destructive force of a bomb increases as the 1/3 power of the increased yield so even doubling the yield gives you very little military effect. A city and its population can be destroyed or neutralized with one 20 kt bomb dropped near the center making it unlivable even if not everyone is killed. Doubling the yield of a weapon only slightly increases physical damage to the target and might double the cost and weight. It is only large increases in yield, factors of ten for example, that justify the extra cost of increasing warhead yield. Particularly on a civil or soft target, the political and social impact will be the same for any nuclear explosion, no matter the size, in a city center.

The difference between '*strategic*' and '*tactical*' nuclear weapons

Nuclear weapons are frequently labelled as either "strategic" or "tactical." These distinctions are not always useful. Some tend to ascribe the size of the weapon's yield as the distinction. Large weapons are usually classed as strategic because they would be aimed at infrastructure of an enemy country – civil populations, large military forces and hardened ballistic missile silos. This may require yields of hundreds of kilotons. That is strategic. This tendency got out of hand in the arms race of the 1950s and 1960s where there was a race to build bigger and bigger bombs. Note that the yield of the largest weapons in P-5 designated NPT Weapons States stockpiles having been getting smaller and smaller in the 1970s and beyond. Accuracy of delivery systems and logical engineering forced this change.

Tactical weapons, on the other hand, would be used on a battlefield to address an imbalance of forces where one side needs to stop an enemy advance, or in specific encounters like sinking an enemy ship. These weapons require much lower yields to address a battlefield encounter, often less than one kiloton up to a few tens of kilotons.

These definitions have evolved for years in the classical European nuclear battlefield. The battlefield of the Korean peninsula may be different. If all DPRK nuclear weapons have a yield of about 15 kt they are equally adapted to any mission from sinking a capital ship to destroying the heart of a city. This logic might even be extended to threats the DPRK poses to Japan.

It is useful to consider a very recent event, the explosion of a huge fertilizer warehouse in the city of Beirut, Lebanon in 2020.[27, 28] This chemical explosion had an estimate blast of about 0.2 to 2.7 kt of TNT, similar to a small unboosted single-stage bomb. It occurred in the port area adjacent to high rise office and apartment towers. There was significant damage

---

[26] New methodology offers estimates for North Korean thermonuclear stockpile, 30-Jul-2020, Vitaly Fedchenko Robert E. Kelley, Jane's Intelligence Review, https://www.janes.com/new-methodology-offers-estimates-for-north-korean-thermonuclear-stockpile

[27] https://www.reuters.com/graphics/LEBANON-SECURITY/BLAST/yzdpxnmqbpx/

[28] https://www.llnl.gov/news/just-how-big-was-2020-beirut-explosion

to the tower buildings but none collapsed. There was not a significant fire in the business district, only at the explosion site in warehouses at the port. More than 200 people died, several thousand were injured and several hundred thousand displaced. This was, of course, only blast damage and there was no radiation. Nevertheless, it is a modern example of the amount of damage from a blast in or near a city. The Reuters reference 26 gives several examples of damage from conventional and nuclear blasts.

The one major exception to this discussion is the clear strategic purpose of the 250 kt device tested in the 2017 Kim-6 nuclear test. If that warhead can be delivered to an intercontinental target, obviously the United States, it would be considered strategic. It is hard to envision that the Hwasongpho-18 or the 250 kt warhead, for example, would be targeted against any targets on the Korean Peninsula. On the other hand, if a Hwasan-31 15 kt warhead were successfully delivered to Los Angeles, the United States would not argue over whether it was strategic or tactical.

There are no "single stage thermonuclear weapons" in the DPRK stockpile

The term "single-stage thermonuclear weapon" is foolish nonsense. There is no such thing in any practical sense. A 1940s **concept** that a nuclear device could compress a fusion device in the center of a single sphere was shown to be incredibly inefficient and very large. The amount of explosive required for such a device is enormous, back to the size of the first US implosion device or even much larger. The foolish idea of a "single-stage thermonuclear device" was discarded in the 1950s. It was the opposite of miniaturization and was only good for making devices huge if they could be made at all. This is why the development of two-stage devices in the early 1950s, that let radiation flow to a second device, was such an enormous intellectual leap. That combined with the use of solid, dry lithium deuteride fuel instead of gaseous or liquid tritium made devices practical and deadly.[29]

Conclusions

DPRK has announced the standardization of nuclear explosives in its short-range weapons. This is a completely logical and practical step.

A dependable standard weapon has probably been certified in more than one nuclear test. Examination of the nuclear test data shows a cluster of three tests around 15 kt in yield, two in the same year. This is a likely estimate for the intended device yield.

Leader Kim Jong Un has exhorted colleagues to increase the production of nuclear material for national defense. From a practical point of view DPRK *cannot build more plutonium production reactors quickly or clandestinely*. But harder-to-detect uranium enrichment plants could be built clandestinely and in modular increments, probably within a few years.

---

[29] North Korea's Lithium Research Networks and its Quest for a Hydrogen Bomb
Justin V. Hastings, Haneol Lee, and Robert Kelley, *The Korean Journal of Defense Analysis*
Vol. 30, No. 3, September 2018, 337—352

Review of the timeline of contributions of Pakistani centrifuge technology shows a likely relationship between nuclear tests and the availability of VHEU. This suggests a heavy dependence on VHEU in future DPRK threats. There is also a high probability that DPRK gas centrifuge technology is much more advanced than estimates made based upon the 2010 visit of American scientists to the first known DPRK centrifuge plant.

DPRK has succeeded in miniaturizing its weapons stockpile and is moving to a logical and practical ongoing weapons program. It will be important to try to control this program through measures like export control. It would also appear that DPRK is simply going to have a large excess capacity for producing nuclear weapons. There needs to be strong continuous monitoring to ensure that DPRK does not become the supplier to future nuclear weapons proliferation in the way Pakistan did in the late 20th century.

Annex

Pakistani Professor Shaiq A. Haq detailed his centrifuge activities in a resume that is no longer accessible on the web. It can be accessed on the Wayback Machine

Deputy Chief Engineer (Grade 20 post)
Joined KRL in 1979 as an Assistant Engineer (grade 17) and reached the post of Deputy Chief Engineer (grade-20) in 1999. Last assignment conducted in KRL was as the head of Design Section. During 20 years service in KRL, the nature of work varied a lot from time to time, spanning from administrative positions to hands-on jobs
In 1984, after doing MS from USA, responsibilities included engineering software applications development and hardware maintenance of IBM PC computers and VAX mainframe. Developed a computer code in Fortran using NAG library routines on VAX for designing high speed flexible rotors. This code predicts the stability of centrifuge rotors by calculating the modes of vibration using discrete component analysis. In 1986, I started PC based data acquisition projects and developed a vertical rotor balancing machine using IBM PC. In 1987, started research in composite materials to manufacture gas centrifuge rotors and missile launch tubes. In 1988, started a training program for young scientists and engineers to train them on computer software development and IT related disciplines. In 1989, computerized the database of all the engineers in Pakistan using Clipper database management system. This software is still in operation in Pakistan Engineering Council, Islamabad. In 1990 went to UK for doing PhD in computer controlled machines. Gained experience in designing of CNC machines, developing electronic hardware for interfacing machines to IBM PC/AT type computers and writing software in Assembly and C language. This experience was useful in computerizing any machine or process using IBM PCs. In 1994, established a Composites Processing Section in KRL. This section was created as a result of my feasibility study reports. I managed the entire project including building construction, hiring manpower and doing product R&D work. In 1998, this section was involved in the manufacturing of launch tubes for surface to air missiles, anti tank missiles, and gas centrifuge rotors. This section was also involved in the development of hardware and software for CNC filament winding and CNC Laser cutting machines in KRL.
In 1999, as the incharge of Design Section, worked on the computerized control system for Ghauri missile warhead and on the data acquisition system for nuclear cold test sites.