North Korean Plutonium and Weapon-Grade Uranium Inventories[1,2]

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Summary

A difficult challenge is estimating North Korea's stocks of plutonium and highly enriched uranium, and the number of nuclear weapons fashioned from this material. The problem is complicated by the extreme secrecy surrounding North Korea's uranium enrichment and nuclear weaponization programs.

North Korea's secret effort to build nuclear weapons goes back decades. It embarked on a nuclear weapons program in the early 1980s when it started building a small nuclear reactor at the Yongbyon Nuclear Research Center north of Pyongyang. During much of that program, North Korea has concentrated on increasing its stocks of nuclear explosive materials and improving its ability to make nuclear weapons.

Because of the history of negotiations with North Korea aimed at limiting plutonium production, much detail is available on this facet of North Korea's nuclear efforts—its plutonium production at the 5 megawatt-electric (MWe) gas graphite reactor and plutonium separation at the Radiochemical Laboratory at Yongbyon. However, questions about the size of North Korea's plutonium stock persist.

In the early 1990s, the International Atomic Energy Agency (IAEA) challenged the completeness of North Korea's plutonium declaration under its safeguards agreement, assessing

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[1] This report is part of a series on national and global stocks of nuclear explosive materials in both civil and military nuclear programs. This project was generously funded by a grant from the Nuclear Threat Initiative.

[2] Summarized findings of this study appeared earlier in *Future Directions in the DPRK'S Nuclear Weapons Program: Three Scenarios for 2020* by Albright, published as an **ISIS Report**, February 26, 2015. http://www.isis-online.org/uploads/isis-reports/documents/North_Korea_Nuclear_Futures_26Feb2015-Master-ISIS_Final.pdf This same study was simultaneously published by the US-Korea Institute at the School of Advanced International Studies, Johns Hopkins University under its Nuclear Futures Series. http://38north.org/wp-content/uploads/2015/02/NKNF-Future-Directions-2020-Albright-0215.pdf

that North Korea had produced more plutonium than it had declared.[3] That discrepancy remains between the IAEA's investigation and North Korea's official declaration of the amount of plutonium separated at Yongbyon. Despite this difference, and as a result of intense negotiations between North Korea and the United States, North Korea froze its plutonium program at Yongbyon in 1994, leading to far less plutonium production and separation than North Korea planned.

In October 2002, Bush Administration officials in Pyongyang accused North Korea of having a secret, relatively large uranium enrichment program that could make weapon-grade uranium (WGU) for nuclear weapons. However, there was no confidence regarding the size of this enrichment program at the time.[4]

After U.S. charges of a secret uranium enrichment program, tensions escalated on the Korean peninsula, leading North Korea to deny it had any such program and suspend its plutonium freeze at the Yongbyon site in late 2002. It proceeded to restart the 5 MWe reactor, and the plutonium separation plant. It then declared it was making nuclear weapons.

Eventually, after the success of the Six Party Talks in the mid-2000s, North Korea shut down both the small reactor and plutonium separation plant. However, by late 2009, these talks had collapsed. The North proceeded to reopen the separation plant briefly to process a stock of irradiated fuel from the 5 MWe reactor, obtaining a small addition to its total separated plutonium stock. In 2013, it restarted the 5 MWe reactor.

In parallel, during much of this period, North Korea built up its gas centrifuge program. Its interest in gas centrifuges dates to the late 1980s, although progress in this area has been slow and dependent on foreign assistance. Significant progress had to await assistance from the Pakistani A.Q. Khan and his centrifuge colleagues at the Khan Research Laboratories near Islamabad in the 1990s.[5] After two decades of development and many denials, in November 2010, North Korea revealed a production-scale gas centrifuge plant at the Yongbyon site, while denying the existence of any other production-scale plant. Since revealing the Yongbyon centrifuge plant, few doubt that North Korea can produce weapon-grade uranium. Determining how much it may have produced remains controversial. Does North Korea have one or two production-scale centrifuge plants? These estimates consider both cases, where scenario 1 includes two centrifuge plants and scenario 2 includes one such plant. In any case, increasingly, it is accepted that North Korea has made weapon-grade uranium.

North Korea's Military Fissile Material Stocks, end of 2014	
Separated Plutonium	30-34 kg
Irradiated Plutonium	2-4 kg
Weapons Grade Uranium – Scenario 1	240 kg **(median only)**
Weapons Grade Uranium – Scenario 2	100 kg **(median only)**

[3] See Albright and Kevin O'Neill, *Solving the North Korean Nuclear Puzzle* (Washington, D.C.: ISIS Press, 2000).
[4] David Albright and Paul Brannan, *Taking Stock: North Korea's Uranium Enrichment Program*, Institute for Science and International Security, October 8, 2010.
[5] David Albright, *Peddling Peril* (New York: Free Press, 2010).

All the estimates contain uncertainties, which are described or quantified in the report. For example, the standard deviations of scenario 1 and 2 are 73 kilograms and 15 kg of WGU, respectively. In general, there is a need for more precise information about these stocks, in particular about the size of North Korea's centrifuge program.

In the case of WGU, a range of medians of the two scenarios is 100-240 kilograms. This range can serve as a rough estimate of the amount of WGU North Korea possesses.

Nuclear weapons can be made from either plutonium or weapon-grade uranium (WGU) or both combined. To give an indication of the potential number of nuclear weapons equivalent, the number of WGU- and plutonium-based nuclear weapons are added independently. However, the actual number of nuclear weapons would be expected to be fewer in number. It is assumed that only about 70 percent of the total amount of plutonium and WGU is used in nuclear weapons. In terms of nuclear weapons, the results for the two scenarios—one or two centrifuge plants--are summarized in the following table.

Table Estimated Number of Nuclear Weapons, Equivalent and Built through 2014 (medians only)

	Nuclear Weapons Equivalent	Estimated Nuclear Weapons Built
Scenario 1-Two Centrifuge Plants	22	15-16
Scenario 2-One Centrifuge Plant	15	10-11

Combining the estimates, North Korea is estimated to have 10-16 nuclear weapons as of the end of 2014.

North Korean Plutonium Stock

Estimating North Korea's plutonium stock depends on assembling a range of information. A core piece of information is North Korea's official declaration of its separated plutonium holdings and fate through about mid-2007 under the Six Party Talks agreements. Information about this declaration is combined with a variety of other information to derive a plutonium estimate. A qualitative uncertainty assessment is also developed.

In 2008, during the freeze and disablement process established by the Six Party Talks, North Korea declared the amount of plutonium that it had separated up to the recent freeze in its plutonium production and separation facilities. This freeze occurred in mid-2007. None of the parties to the Talks have made this declaration public. However, interviews with members of the Six Party governments and other government experts, who want to remain anonymous, provide a reliable estimate of North Korea's declaration of how much plutonium it states it had separated through this date. The declaration also provides a limited amount of information about its fate.

One Six Party source stated that North Korea possessed about 30 kilograms of separated plutonium in 2007. This value is net and does not include the amount of plutonium consumed by the 2006 underground test and the inevitable loss of some plutonium in the operation of the plutonium separation plant. North Korea, according to this source, declared the latter as two kilograms of plutonium.[6] Surprisingly, this source added (and confirmed by several other knowledgeable officials), North Korea declared that the 2006 underground nuclear test used only two kilograms of plutonium, far less than the standard 4-6 kilograms often believed at the time to be in each North Korean nuclear weapon. Two kilograms of plutonium would imply a sophisticated nuclear weapon design that North Korea was not believed to have mastered. Perhaps, this is why North Korea announced that the expected explosive yields of its 2006 and 2009 tests were significantly lower than expected. In this case, the lower yield of about four kilotons would have resulted from the miniaturization of the devices, where yield had been sacrificed for device size. In addition, the failure of the 2006 test may have resulted from seeking to test an advanced design. Alternatively, this claim of two kilograms of plutonium may be a bluff, part of a North Korean strategy to create ambiguity about its nuclear capabilities and thus increase hesitation on the part of its enemies, particularly the United States. For the purposes of this report, on balance, the estimate of the amount of plutonium used in the 2006 test, and subsequent tests, is a range, where two kilograms is included as a lower bound and four kilograms is the upper bound. Based on these considerations, the amount of separated plutonium declared by North Korea was 34-36 kg, where again about 30 kilograms plutonium remained in separated form usable for making nuclear weapons.

Another knowledgeable source stated that North Korea declared in 2008 that it had separated a total of between 37 and 38 kilograms of plutonium up to the freezing of its facilities in 2007. This estimate is somewhat greater than the above corresponding one, which is 34-36 kg. In this second estimate, as above, about 2 kg would have been lost during processing. However, this source said about 4 kg of separated plutonium were used in the 2006 test, evidently viewing

[6] In a plutonium separation plant like the one at Yongbyon, some plutonium ends up in the nuclear waste or held-up in pipes and equipment. In this case, the plutonium losses comprise roughly five percent of the total plutonium declared as separated. These losses still require independent verification of their size and nature.

North Korea's claim about using two kilograms as unreliable. Reflecting these losses of 6 kg leaves an estimated stock of 31-32 kilograms of separated plutonium at the end of 2006.

If the two estimates are combined, the result is a total range of 30-32 kilograms of usable, separated plutonium as of mid-2007. These values do not include plutonium produced in the 5 MWe reactor by that time but not yet separated. That value will be discussed below. This value also does not account for undeclared plutonium North Korea may have produced.

North Korea's official plutonium declaration falls at the lower end of the range ISIS predicted by estimating the operation of the Yongbyon reactor and subsequent separation of plutonium. For example, ISIS assessed in 2007 that North Korea had between 28 and 50 kilograms of separated plutonium following the 2006 test.[7] As can be seen, the declared plutonium value corresponds closely with the lower bound of this ISIS range. Some of the discrepancy with regards to the upper limit can be attributed to the 5 MWe reactor not working as well as expected in the period 2002-2005, reducing the upper bound by up to 10 kg. This leaves a discrepancy of about 8-10 kg, which is the upper bound estimate of the amount of undeclared plutonium North Korea produced prior to 1992. Thus, this discrepancy hinges mainly on how much undeclared plutonium did North Korea actually produce prior to 1992.

U.S. verification of North Korea's plutonium declaration had just started prior to the end of the Six Party process in 2009 and unfortunately this effort was not completed. There are two periods of time where questions remain about undeclared plutonium. As mentioned above, the IAEA uncovered evidence that in the early 1990s, North Korea did not declare kilogram quantities of separated plutonium. The United States at the time estimated that North Korea could have been hiding up to about 8-10 kilograms of separated plutonium, although this estimate should probably be viewed as a high-side estimate.[8] The IAEA at the time stated only that the amount involved kilograms of plutonium. Another question concerns the amount of plutonium produced by the 5 MWe reactor from 2003 to 2008. In this case, North Korea could have under-declared its plutonium production in the reactor during this period.

To help the United States verify North Korea's declaration during the Six Party process, Pyongyang turned over 15,000 pages of operating records of the Yongbyon reactor. The subsequent analysis of these documents reportedly uncovered no evidence of additional plutonium production. Although the reactor documents were an important first step in terms of verifying North Korea's declaration, these records by themselves did not resolve the discrepancy since they could have been altered. Other measures were also called for by the United States, including access to North Korean facilities, sampling, and interviews with personnel involved in these programs. One key request was to analyze the reactor core, in particular its graphite moderator, to determine total plutonium production. The United States says it acquired North Korea's agreement in October 2008 to sample the graphite in the core of the Yongbyon reactor, a method that can provide a reasonably accurate estimate of total plutonium production in the reactor over its lifetime. However, North Korea later claimed it never agreed to any sampling of the reactor core, although this was disputed by other parties to the Six Party Talks. Any future

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[7] Albright and Brannan, *The North Korean Plutonium Stock*, ISIS, February 20, 2007.
[8] *The North Korean Plutonium Stock*, op. cit. and *Solving the North Korean Nuclear Puzzle*, op. cit.

verification arrangement will need to include sampling, and other measures, in order to effectively verify North Korea's plutonium declarations.

Thus, North Korea could have up to an additional 8-10 kg of separated plutonium that it never declared. However, the actual value could be significantly lower than these values as well, say only a few kilograms. Absent more information, in this report, we are not including this possible undeclared inventory of separated plutonium. However, a reasonable qualitative uncertainty is that the North Korean stock of separated plutonium could be 10-30 percent greater.

It should be noted that not all of North Korea's plutonium is weapon-grade.[9] In the early periods, the reactor also produced fuel-grade plutonium, which contains more plutonium 240 than typically desired for use in nuclear weapons. It is unknown how North Korea treats fuel-grade plutonium. Does North Korea not use it to make nuclear weapons out of concern that the extra plutonium 240 would reduce the weapon's reliability? North Korea could design a weapon to use it but the design would likely need more fuel-grade plutonium per weapon to achieve a particular explosive yield than if weapon-grade plutonium were used instead. Alternatively, if the amount of plutonium per weapon were to remain fixed, then the yield would be less if fuel-grade instead of weapon-grade plutonium were used.

Since the reactor was restarted in the early 2000s, North Korea is assessed to have run the reactor so as to produce weapon-grade plutonium. One question is whether it also produced very high quality weapon-grade plutonium, called super-grade, in order to create a stock to blend up fuel-grade to weapon-grade plutonium.

Separation of Plutonium after Collapse of the Six Party Talks in 2008

At the time of its 2008 declaration, North Korea also had a core load of plutonium that had not yet been separated when it stopped the reactor under the Six Party Talks. After the talks collapsed, North Korea separated this plutonium in the Radiochemical Laboratory. Based on information about North Korea's declaration and the operation of the reactor, the irradiated fuel reportedly contained about eight kilograms of plutonium.

This additional separation brings North Korea's total to about 38-40 kilograms of separated plutonium.

Plutonium Losses in Additional Nuclear Tests

Of these 38-40 kilograms, North Korea used some plutonium in the 2009 test and likely in the 2013 nuclear test. Although the 2013 test could have used weapon-grade uranium instead, no evidence of such use has emerged, and this analysis assumes that the 2013 test depended on plutonium. This remains another uncertainty in the analysis.

These tests worked better than the 2006 test, but there is little information about the amount of fissile material in each test. Here, we assume that a plutonium test contained about 3-4 kilograms of weapon-grade plutonium (see also discussion below). As discussed above, we

[9] *North Korean Nuclear Puzzle*, op cit.

assume that both the 2009 and 2013 tests used plutonium, meaning that these two tests used a total of about 6-8 kilograms of plutonium. Subtracting these values, North Korea is estimated to have a stock of 30-34 kilograms of separated plutonium for nuclear weapons.

Restart of 5 MWe Reactor

In mid-2013, evidence emerged that North Korea had restarted the 5 (MWe reactor at Yongbyon. The reactor stopped operation in 2007, and its cooling tower was later demolished. However, North Korea restarted the reactor without rebuilding the cooling tower, discharging heated water directly into the river.[10]

The operational status of the reactor was difficult to discern in 2013 and 2014. The reactor appears to have been shut down by late summer 2014 for maintenance or fuel removal.[11] Based on past operations, the reactor has not operated long enough to have produced sufficient plutonium in the core to warrant discharging the irradiated fuel and chemically processing it to separate out plutonium. In the past, North Korea irradiated the fuel for at least 2-3 years before discharging the core. The reactor is small and tends to produce plutonium relatively slowly, requiring a few to several years of operation to build up enough plutonium to warrant economically replacing the fuel. Then the plutonium can be separated from the irradiated fuel in another six or twelve months.

Although it appears too early for a total core refueling, it is possible that North Korea has carried out a partial refueling. As happened in the late 1980s or early 1990s, North Korea could have replaced hundreds of defective fuel rods with fresh ones.[12] Fuel rods could also have been shuffled within the core with some being removed and new fuel rods inserted.

It is less likely, although not impossible, that the entire core was removed in late 2014. For example, after a year's operation, (assuming a shutdown in August 2014), the current core of fuel could contain up to 3-4 kilograms of weapon-grade plutonium. If the core were not replaced until after two to three years of operation, the fuel in the core would be expected to contain up to double to triple these amounts of plutonium; the exact amount would depend on the actual operation of the reactor. Discharging a core containing this amount of plutonium, namely 9-12 kilograms, would be more consistent with past practices.

Nonetheless, some activities have been detected in commercial satellite imagery of the Yongbyon site that support the view that fuel has been removed for chemical processing. A relatively large truck, possibly a spent fuel truck, was located close to the spent fuel receiving building at the reprocessing site in late 2014.[13] These trucks are used to move irradiated fuel

[10] David Albright and Robert Avagyan, "Steam Venting from Building Adjacent to 5MWe Reactor: Likely Related to Reactor Restart," ISIS Report, September 11, 2013.
[11] David Albright and Serena Kelleher-Vergantini, "Yongbyon: Centrifuge Enrichment Plant Expands while 5 MWe Reactor is Possibly Shut Down," ISIS Report. October 3, 2014. http://isis-online.org/uploads/isis-reports/documents/Yongbyon_October_3_2014.pdf
[12] *Solving the North Korean Nuclear Puzzle*, op. cit.
[13] David Albright and Serena Kelleher-Vergantini, "Yongbyon: Monitoring Activities during Shutdown of 5 MW Reactor," ISIS Report, December 5, 2014. http://isis-online.org/uploads/isis-reports/documents/Yongbyon_December5_2014_Final.pdf

from the 5 MWe reactor to the Radiochemical Plant across the river. In addition, steam was seen exiting from a cooling tower or venting system at the Radiochemical Laboratory, possibly implying that this facility was again operating.

Although reprocessing of the whole core is viewed as a less likely possibility, North Korea may have nonetheless decided to harvest the plutonium early and be willing to use more fuel than normal in order to gain quicker access to some plutonium for nuclear weapons. It may view the production of nuclear weapons as a high priority, justifying this action. If it were pursuing this option, any significant separation of plutonium would be expected to occur in 2015.

In sum, the plutonium produced in the 5 MWe reactor since it restarted in 2013 is unlikely to have been separated by the end of 2014. This plutonium is estimated to total roughly 3-4 kilograms.

Separated Plutonium Inventory, end 2014

Since no plutonium is assumed to have been separated in the last few years, North Korea is estimated to have a stock of 30-34 kilograms of separated plutonium for nuclear weapons at the end of 2014.

Plutonium-Based Nuclear Weapons

How many nuclear weapons could North Korea build from a stock of 30-34 kilograms of separated plutonium? Little is known concretely about North Korea's development or deployment of deliverable nuclear weapons, although it is likely able to build a warhead, perhaps one of mixed reliability, which can fit atop a Nodong missile with a range of less than 800 miles.[14] North Korea has worked on nuclear weaponization for over 20 years and may have received nuclear weapons designs from the Khan network in the 1990s or earlier from China, as Pakistan did in the early 1980s. These developments support assessments that North Korea can build a miniaturized warhead for a Nodong missile and other missiles. A Nodong warhead with a triconic nose cone would be expected to have a diameter of slightly less than 0.6 meters.

Any nuclear weapons program is likely to pursue successive designs that use smaller quantities of plutonium in each weapon. In the case of North Korea, faced with a limited stock of plutonium, one would expect that the nuclear weaponization program focused early on developing designs requiring less plutonium than that of first generation fission weapons such as the Trinity explosion in August 1945, which had about six kilograms of plutonium. Over time, North Korea has likely reduced the amount of plutonium it needed in each weapon.

The average plutonium content of North Korean nuclear weapons is assumed in this analysis to contain between two and five kilograms of plutonium. Unlike above, five kilograms is used instead of four kilograms as the upper bound because a weapon could use more plutonium than a

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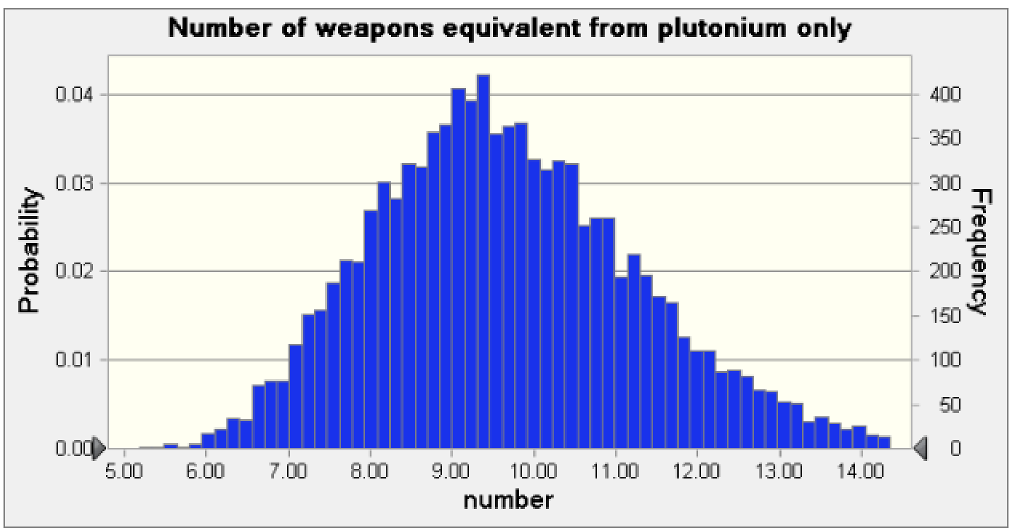
[14] Albright, "North Korean Miniaturization," *38North*, February 13, 2013. http://38north.org/201/02/albright021313/ and National Air and Space Intelligence Center, *Ballistic and Cruise Missile Threat*, Wright-Patterson Air Force Base, NASIC-1031-0985-09, April 2009.

test device in order to increase its explosive yield. We lower the bound to two kilograms to account for possible advancements in North Korea's weapon design.

However, in this analysis, not all values in this range are viewed as equally likely. Values in the middle of the range are weighted more than those at the ends of the range and the lower half of the range is weighted slightly more than the upper half. This weighting reflects a judgment that North Korea is unlikely to use on average as little as 2 kilograms or as much as five kilograms per weapon but is seeking to minimize its amount of plutonium in a nuclear weapon. The more likely values are in the range of 3 to 4 kilograms.

In the case of estimating the number of nuclear weapons that can be made from a stock of plutonium, a more sophisticated method is used to generate a range of possible values, namely frequency distributions using Crystal Ball™ software. The result is a slightly skewed distribution with a median of 9.6 nuclear weapons, which would imply 9-10 nuclear weapons. The distribution's standard deviation is 1.7. The standard deviation measures how many results are within almost 70 percent of the median. It can be used to produce a range of values that likely capture the true value. In this case, this range would be about 8-11 nuclear weapons.

The full distribution follows:



Its full range is from 5-18 nuclear weapons, mainly reflecting the wide range of 2-5 kilograms of plutonium per weapon. However, the values at the limits of the distribution are viewed as less likely than the ones nearer the median. This report presents both the full range and the range generated from the standard deviation.

This calculation does not factor in the uncertainty in the plutonium inventory, as discussed above. Instead, this estimate focuses on the uncertainty in the number of nuclear weapons resulting from uncertainties in the amount of plutonium used per weapon.

It should be noted that this assumes all the available plutonium is used in nuclear weapons. Thus, these values provide the nuclear weapons equivalent of a given amount of plutonium. The actual number of nuclear weapons would be expected to be fewer in number.

A fraction of this stock of plutonium would be tied up in the manufacturing complex that makes plutonium components of nuclear weapons or lost during such processing. Some separated plutonium may be held in a reserve for underground nuclear testing or for new types of weapons. In this estimate, it is assumed that only about 70 percent of the total amount of plutonium is used in nuclear weapons. Applying this assumption, North Korea would have approximately 6-8 nuclear weapons made out of plutonium as of the end of 2014.

Light Water Reactor

North Korea is building next to the 5 MWe reactor what it calls an experimental light water reactor (LWR). It stated the reactor would produce 100 megawatts-thermal (MWth), or an estimated 30 megawatts of electricity (MWe).[15] Although North Korea first announced that the reactor would be finished in 2012, it was still not operational as of the summer of 2015. In late 2011, a senior North Korean nuclear official acknowledged to one of the authors of this report that finishing the reactor would be difficult. Some foreign procurements have continued after 2011 for this reactor. It remains unclear whether North Korea has experienced difficulties finishing the plant or is less committed to its completion.

According to Siegfried S. Hecker, former Director of Los Alamos National Laboratory, during his visit to Yongbyon in 2010, the North Koreans said that the reactor will use uranium dioxide fuel enriched to 3.5 percent, and a full core will contain four tonnes of uranium. In late 2011, based on discussions with senior Yongbyon officials by the author of this report, North Korea was in the process of working on making the fuel.

In addition to electricity, this reactor will produce plutonium as a byproduct of its operation. In normal operation, this reactor will produce reactor-grade plutonium, which, while not ideal, could be used directly in nuclear weapons. The use of reactor-grade plutonium in nuclear weapons would result in a lower explosive yield if it were substituted for weapon-grade plutonium in an existing warhead design. Over an extended period of storage, the warhead could also suffer from the extra heat generated by reactor grade plutonium relative to weapon-grade plutonium. However, separating the plutonium from the irradiated fuel would require major modifications of the Radiochemical Laboratory, which was designed to process a different type of fuel namely fuel from gas-graphite reactors. Moreover, LWR irradiated fuel is in general much harder to process than gas-graphite spent fuel, adding to the risk of proceeding this way.

However, by using a different type of core, any modifications to the Radiochemical Laboratory can be kept to a minimum while also using the LWR to produce weapon-grade plutonium, the more desirable form for weapons. In this case, the core would be comprised of “driver” fuel and

[15] Siegfried S. Hecker, *A Return Trip to North Korea’s Yongbyon Nuclear Complex*, Center for International Security and Cooperation, Stanford University, November 20, 2010. http://iis-db.stanford.edu/pubs/23035/HeckerYongbyon.pdf

“target” elements. The driver fuel contains low-enriched uranium that produce neutrons and targets made from depleted or natural uranium targets that absorb the neutrons and produce weapon-grade plutonium. The driver fuel would need to be enriched higher than typical for LWRs, to 10-20 percent in the isotope uranium 235. The targets would be replaced in the core when they contained an optimal amount of weapon-grade plutonium and can be designed to ease their chemical processing to separate plutonium. The driver fuel would remain in the reactor until fully irradiated and replaced far less frequently than the targets. The U.S. Energy Department evaluated the use of a commercial LWR reactor to make weapon-grade plutonium and tritium in a similar core in the late 1980s and early 1990s. The DOE considered the use a commercial light water reactor that would have driver fuel enriched to 10 percent and two basic types of targets that would produce either weapon-grade plutonium or tritium.[16]

The driver fuel and targets should be within North Korea’s ability to design and make. The driver fuel would be similar to fuel containing 3.5 percent LEU, or the type of fuel North Korea is already required to produce. Typically, the driver fuel would be expected to experience significantly higher irradiation levels than 3.5 percent enriched fuel, possibly posing a technical challenge and leading to greater requirements for enriched uranium if the driver fuel is discharged prior to reaching full design irradiation.

The existing plutonium separation plant at Yongbyon would likely need modification to extract the plutonium from the targets. But the targets should be far easier to chemically process than LEU fuel. Any irradiated LEU fuel could be stored long-term in water.

If North Korea decided to use the LWR as a source of weapon-grade plutonium for weapons, it could grow its nuclear weapons arsenal significantly by using a driver fuel/target system. Slated to be 100 MWth, or four to five times larger than the existing Yongbyon reactor, the LWR could produce roughly 20 kilograms of weapon-grade plutonium per year.[17] At 3-4 kilograms of plutonium per weapon, twenty kilograms is enough for 5-6 nuclear weapons per year. The actual annual amount of weapon-grade plutonium could vary significantly, depending on the reactor’s actual performance.

Based on existing evidence of the construction progress of this reactor, plutonium production in the LWR would not be expected in 2015.

Uranium Enrichment Program

[16] Due to a lack of need for weapons plutonium, these plans were never implemented. The United States produces tritium in a commercial light water reactor but the core uses standard LEU.

[17] ISIS did not perform detailed calculations but a rough estimate was conducted with the support of a reactor expert who was familiar with the use of driver fuel/target systems in reactors. The estimate assumes a 70-80 percent capacity factor, a conversion of 0.85 grams of weapon-grade plutonium per megawatt-thermal-days, and an estimated 10 percent reduction in plutonium output to account for the plutonium produced in the driver fuel, which is not usable. The resulting estimate is 19.5-22.3 kg weapon-grade plutonium per year. To assess enrichment requirements, the nuclear reactor expert said that a rule of thumb is that a core composed of 10-20 percent LEU driver fuel would have the same amount of uranium 235 as a core of 3.5 percent LEU fuel.

Great uncertainty surrounds the DPRK's production of weapon-grade uranium, the type of enriched uranium typically used in nuclear weapons.[18] WGU is enriched uranium that contains 90 percent or more of the key nuclear explosive isotope uranium-235. This section focuses on estimating weapons-grade uranium production through 2014. It remains uncertain how many centrifuge plants North Korea has built. In addition to the production-scale plant at Yongbyon, US intelligence officials have long asserted that the North has another, hidden, production-scale centrifuge plant.

Major gaps exist in knowledge about the status of North Korea's uranium enrichment program. It is known that North Korea acquired up to two dozen centrifuges and a significant amount of technology, materials, and equipment from the Pakistani A.Q. Khan and his colleagues at Khan Research Laboratories.[19] After years of denial about the existence of such a program, on June 13, 2009, North Korea announced it would commence uranium enrichment, stating, "Enough success has been made in developing uranium enrichment technology to provide nuclear fuel to allow the experimental procedure."[20] Looking back, this announcement appears to represent North Korea's public declaration of its decision to build the Yongbyon enrichment plant, which it revealed in November 2010 to a group of visiting Americans. However, key parts of the history and status of North Korea's enrichment activities remain unknown. In particular, how many centrifuge plants does North Korea operate, how much enriched uranium has Pyongyang produced, and how much of it is weapon-grade uranium?

North Korea is not self-sufficient in the wherewithal to produce gas centrifuges. As a result, it has acquired a wide variety of goods overseas to both develop and build centrifuges.[21] These procurements have shed additional light on North Korea's gas centrifuge program.

According to government sources with deep knowledge about North Korean nuclear procurements, starting in the early 2000s, North Korea sought to procure enough goods to be able to build 10,000 centrifuges. This process appears to have been largely finished although additional procurements for the centrifuge program continue. For many years, these procurements are mainly happening in China which is North Korea's main smuggling platform for its nuclear programs. North Korea has had an easier time than Iran acquiring needed goods in the last ten years for its centrifuge program. Like Iran, North Korea has successfully developed an illicit purchasing network in China. However, North Koreans are more entrenched in the Chinese economy, share a border with China, and must overcome weaker national and international sanctions on proliferation-sensitive goods than Iran. As a result, it has more

[18] In practice, nuclear weapons can be made from highly enriched uranium (HEU), which is any enriched uranium which contains 20 percent or more of the key isotope uranium-235. In contrast, WGU is a form of HEU containing 90 percent or more of the isotope uranium-235. Weapons programs seek WGU because a nuclear weapon made from HEU containing 20 percent uranium-235 would require far more HEU than one made from WGU and be substantially larger and heavier, characteristics that make deployment on missiles for example far more difficult, if not impossible. Sometimes, such as when they were unable to reach weapon-grade a weapons program used HEU enriched to 80-85 percent enriched as a substitute for WGU in a design, accepting that a significantly lower explosive yield would result.

[19] *Taking Stock: North Korea's Uranium Enrichment Program,* op. cit. and *Peddling Peril,* op. cit.

[20] "DPRK Foreign Ministry Declares Strong Counter-Measures against UNSC Resolution," KCNA, June 13, 2009.

[21] Taking Stock: North Korea's Uranium Enrichment Program, op. cit.

successfully exploited China's weak implementation of export controls and U.N. Security Council sanctions to acquire a wide range of dual-use goods for its centrifuge program.

Based on assessments of individual North Korean procurements, North Korea, like Iran, hires private Chinese companies to acquire a range of high-tech, dual-use goods and raw materials, including from European, Japanese, and possibly U.S. companies. The quality of indigenously produced Chinese high-tech goods has been relatively poor, and centrifuge programs usually need reliable, high quality goods. Thus, these private Chinese companies working for North Korea approached foreign suppliers in China for these high-tech goods. These private Chinese companies often violate Chinese export controls or Security Council sanctions either inadvertently or deliberately by then supplying the goods to North Korea. In doing so, these companies may provide false end-user statements to the supplier, typically listing China as the final destination or a company in a nearby country that is viewed as a legitimate end-user. Foreign companies located in China have great difficulty spotting these smuggling efforts, and the Chinese government does a poor job of exposing these transactions or helping companies to avoid them. Unless China does a better job of enforcing its export controls, North Korea will face few constraints in getting the goods it needs for its nuclear programs, including its centrifuge program.

Yongbyon Centrifuge Facility. On November 12, 2010, North Korea revealed to Stanford University Professor Hecker and his colleagues a 2,000-centrifuge uranium enrichment plant at the Yongbyon nuclear site.[22] The building is located on the site of the fuel fabrication complex at Yongbyon. According to North Korea, it had just started producing low enriched uranium. However, Hecker obtained no evidence that the centrifuges were operational or had enriched uranium.[23]

Since that time, North Korea is believed to have produced enriched uranium at the plant, despite start-up problems. A North Korean nuclear official stated in late 2011 in Pyongyang that this is the first time North Korea had operated such a plant, and this facility was constructed quickly, resulting in problems.

North Korea appears to have had more success than Iran in developing more capable centrifuges. Based on a dimensional analysis of Hecker's estimates, the centrifuges appear to be a version of the P2 centrifuge, which is more advanced than the P1 machine that Iran copied and installed in large numbers at the Natanz Fuel Enrichment Plant.[24]

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[22] Hecker, A Return Trip to North Korea's Yongbyon Nuclear Complex, op. cit.

[23] For example, he did not report hearing the frequency hum of the drive converters. However, he reported that the tops of the centrifuges were in place and the piping attached, which implies that the centrifuges could be operating.

[24] To evaluate Hecker's dimensional estimates, ISIS contacted a centrifuge expert familiar with the P1 and P2 centrifuges. This expert replied, "Hecker's estimate of diameter and length refers to the outside dimensions of the vacuum housing and not to the actual centrifuge rotor. The outside diameter of the P1 and P2 housings differs by only about 15 mm (both being slightly more than 200 mm) and so I doubt whether he could see that difference by eye. The length of the P2 rotor between end caps was 1,050 mm. To this, one has to add the dimensions of the top and bottom bearings, the axial drive motor thickness and the thicknesses of the top and bottom housing flanges. From memory, this amounts to another 400 or 500 mm. The 1,800 mm thus sounds a little long. However, if the vacuum housing is mounted on a pedestal (as seen on some designs and certainly as used in Iran) the overall height from the floor level to the top of the vacuum housing could well be 1,800 mm."

The centrifuge building is approximately 120 meters long and has a blue roof. When U.S. experts left Yongbyon in April 2009, the building was not involved in centrifuge operations.

North Korea has stated that the plant's total enrichment capacity is 8,000 separative work units (swu) per year. With 2,000 P2-type centrifuges, the average would be four swu per year per centrifuge. This average value for the North Korean centrifuge is credible, despite being somewhat lower than the expected output of the original G2 centrifuge in cascade. The G2 is the German design stolen by A.Q. Khan in the Netherlands in the 1970s and renamed the P2 (Pakistan-2) centrifuge. (North Korean engineers focused on this machine while present at A.Q. Khan Laboratories in the 1990s.)[25] Each G-2 centrifuge had a capacity of about five swu per year per centrifuge when operated by URENCO in the 1970s. However, documentation from A.Q. Khan passed to Libya specifically mentions that the P2 machine output, when in a cascade, would more likely achieve four swu per year per machine. Actual values could be lower (see below).

Khan's rationale for this statement is not known. This average of four swu per year may reflect a lower enrichment output for each centrifuge than the ones operated at URENCO, or additional inefficiencies when centrifuges are connected into cascades. In the former case, the lower enrichment output could result from the centrifuge rotor spinning more slowly than originally designed, perhaps due to inferior substitute materials in the centrifuge's construction. However, the North Koreans have not provided their centrifuge's operational speed. Alternatively, assessing the average enrichment output of the North Korean centrifuges across a cascade can incorporate several inefficiencies that reduce total separative output. This loss in efficiency could also be caused by poorly assembled machines that failed to start-up, survive uranium hexafluoride commissioning, reach operational speed, or failed earlier in their operation than expected. An advanced industrial state operating the G2 machine could expect these losses to amount to no more than a few percent. Losses in cascade output of North Korean centrifuges, however, may be 20 percent or higher. In this report, the average value of four swu per year per centrifuge when in cascade is taken as the maximum value for the P2 centrifuge model.

Hecker also reported that there were six cascades for an average of 333 centrifuges per cascade, assuming 2,000 centrifuges. This number is almost exactly double the number of P2 centrifuges in the cascades producing LEU in a Pakistani design provided to Libya and Iran by the A.Q. Khan network. However, Pakistan also appears to have had a centrifuge cascade design dedicated to making LEU that had more centrifuges than the cascade design of 164 centrifuges used by Libya and Iran. ISIS has learned of official documentation destined for Libya and found in January 2005 that Pakistan arranged the G2 machine in cascades of 344 centrifuges.[26] According to Khan's 2004 statement to the Pakistani government about his proliferation activities, North Korea received centrifuge cascade designs from Khan Research Laboratories in the 1990s dedicated to making LEU,[27] which may be the one employed at the Yongbyon plant.

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[25] *Taking Stock: North Korea's Uranium Enrichment Program,* op. cit.
[26] The information was in a letter from A.Q. Khan that was found by authorities at the South African firm Tradefin Engineering.
[27] *Taking Stock: North Korea's Uranium Enrichment Program*, op. cit. See also Albright, *Peddling Peril*, op. cit.

Subsequently, the author confirmed in Pyongyang in late 2011 that that each cascade held 344 centrifuges, for a total of 2,064 centrifuges in the Yongbyon plant.

There is little information about the operation of this plant since the fall of 2010. North Korea reported in late 2011 that the plant had start-up problems, citing defects in the facility and North Korea's inexperience in operating a centrifuge program. But North Korea did not provide details about how the plant is experiencing problems. These problems affect, possibly significantly, estimates and projections of enriched uranium production.

While North Korea has said that the plant is for producing LEU for use as fuel in the LWR program, the enrichment plant could be used to make weapon-grade uranium (WGU, 90 percent uranium 235) for nuclear weapons. In fact, the method to produce WGU using designs developed by Khan Research Laboratories involves step-wise production of WGU, where the step devoted to the production of LEU requires about 70 percent of the total number of centrifuges to make weapon-grade uranium. As is the case with Iran's Natanz Fuel Enrichment Plant, the 3-4 percent LEU that North Korea may be producing at the Yongbyon plant is nearly 70 percent of the enrichment effort towards making weapon-grade uranium for nuclear weapons. North Korea can further enrich its stock of LEU to weapon-grade relatively quickly either at the Yongbyon facility or at a centrifuge plant located elsewhere.

This scenario can be better understood by considering an example of Khan Research Laboratories' step-wise design. The WGU-production cascade design that Khan sold to Libya comprised 5,832 P2 centrifuges divided into four steps. It was designed to produce optimally about 100 kg of WGU per year.[28] The first step enriches natural uranium up to 3.5 percent; the second step enriches from 3.5 percent to 20 percent; the third takes the material from 20 percent to 60 percent; and the final step enriches the 60 percent material to 90 percent, or weapon-grade. The first step consists of almost 4,000 centrifuges, or nearly 70 percent of the total number of centrifuges used.[29]

By scaling this stepwise design, North Korea could use the 2,000 P2 centrifuges at the Yongbyon plant as part of a 3,000-centrifuge system to make WGU. To do so, it would need an offsite plant with about 1,000 P2 centrifuges to enrich the 3.5 percent material produced at Yongbyon up to WGU. In this system, as mentioned above, the bulk of the enrichment effort would occur at the 2,000-centrifuge Yongbyon plant.

North Korea could also use the Yongbyon plant to make weapon-grade uranium from LEU. It could convert some of the cascades to higher enrichment production after producing the LEU. This method would only be somewhat slower than a four-step process.

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[28] See *Peddling Peril*, op. cit.

[29] The first step contained a total of 3,936 centrifuges enriching natural uranium to 3.5 percent enriched uranium. The second step, composed of 1,312 centrifuges, enriched the 3.5 percent uranium to 20 percent. The third step with a total of 546 centrifuges enriched from 20 percent to 60 percent material. The fourth step, containing only 128 centrifuges, enriched the 60 percent material to 90 percent, or weapon-grade.

In practice, achieving nominal production values of WGU can be difficult. Inefficiencies and other problems in operating centrifuge cascades inevitably lower annual WGU production from nominal values.

Expansion of Centrifuge Plant

In 2013, commercial satellite imagery showed that North Korea was doubling the size of the centrifuge building at the Yongbyon nuclear complex.[30] Construction apparently started sometime in March 2013, preceding shortly the announcement by the North Korean government that it planned on "readjusting and restarting all the nuclear facilities in Yongbyon including uranium enrichment plant and 5MW graphite moderated reactor."[31] This announcement may have been partially intended as an oblique effort to reveal this new construction, and one missed publicly at the time.

The new addition to the centrifuge plant matches the overall length and width of approximately 120 x 15 square meters of the original building, effectively doubling its size. Commercial satellite imagery reveals the internal floor plan of the new addition which is divided into three sections with two smaller rooms and a larger hall of $93x15m^2$.[32] The larger hall appears to be a cascade hall, where the centrifuges would be located.

A doubling of available floor space at this building could allow a doubling of the number of centrifuges installed there. Thus, North Korea could in theory install 2,000 more centrifuges for a total of 4,000 centrifuges with a total declared capacity of 16,000 swu per year in this expanded building. The plant could have become operational by the end of 2014, if construction and installation proceeded as quickly as the installation of the first 2,000 centrifuges.

Other Centrifuge Plants

Few believe North Korea's statement that the Yongbyon centrifuge facility is the country's first or only plant because of how quickly North Korea outfitted this building with a full centrifuge plant. The plant did not exist in this building at Yongbyon as of April 2009, when the Six Party Talks' disablement process ended. It is likely that North Korea built another plant previously and either transferred the capability to Yongbyon or simply built the Yongbyon facility based on its experience of bringing an original, perhaps smaller, plant into operation. For years, U.S. intelligence agencies have posited that North Korea had another centrifuge plant. Some even assert that this plant had produced WGU as early as the mid-2000s.[33]

The Yongbyon centrifuge plant is likely part of a larger gas centrifuge complex with other facilities at Yongbyon, elsewhere in the vicinity of Yongbyon, or in other parts of the country.

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[30] David Albright and Robert Avagyan, "Recent Doubling of Floor Space at North Korean Gas Centrifuge Plant," ISIS Report, August 7, 2013. http://isis-online.org/uploads/isis-reports/documents/Yongbyon_fuel_facility_7Aug2013.pdf
[31] "DPRK to Adjust Uses of Existing Nuclear Facilities," KCNA, April 2, 2013. http://www.kcna.co.jp/item/2013/201304/news02/20130402-36ee.html
[32] "Recent Doubling of Floor Space at North Korean Gas Centrifuge Plant," op. cit.
[33] *Taking Stock: North Korea's Uranium Enrichment Program*, op. cit.

ISIS discussed the full range of possibilities regarding facilities in an earlier report.[34] In any case, the size of other sites housing centrifuges remains at issue. Did North Korea have only a pilot plant, or did it have another production-scale plant?

Few doubt the need for a pilot plant and most would expect that one existed. The evidence and arguments for another centrifuge plant are more debatable but nonetheless credible. The large procurements in the 2000s suggest a much larger centrifuge program than represented at Yongbyon. Libya ordered 10,000 P2 centrifuges from the Khan network with the intention to build a 6,000-centrifuge plant. Given that North Korea is believed to have sought enough components for 10,000 centrifuges, it could have planned on operating 6,000 P2 centrifuges in production-scale plants. In addition, North Korea has a military-first policy, and North Korean missile experts were the first ones to acquire the centrifuge technology from Khan Research Laboratories while working there starting in the 1993-1995 period. The North Koreans taught the Pakistanis about building missile components in the Khan Laboratories centrifuge workshop, where the North Koreans also learned about making P2 centrifuges, according to Khan's 2003 statement to his government.[35] These factors would support that the first centrifuge plant was military in nature and remains secret.

However, there are plausible explanations that the Yongbyon plant is North Korea's first production-scale plant. One explanation is that prior to 2009, North Korea produced only centrifuge components and sub-assemblies for one or two production-scale plants, a major feat in any case. It then shipped components to the Yongbyon site with final centrifuge assembly in a nearby facility close to the current enrichment facility. The period of one and a half years would then be sufficient for refurbishing the building, installing the cascade pipe work and the feed and withdrawal equipment, and assembling and installing the centrifuges. This explanation is credible, particularly given the well-known types of delays that can happen in centrifuge programs in developing countries, where the centrifuges have proven harder to build than commonly expected and shortages in goods can create bottlenecks in centrifuge plant deployments. North Korea, like many countries, has depended extensively on overseas assistance to obtain centrifuge technology and the necessary goods. Moreover, North Korea may have planned on a steady stream of technical assistance from the Khan network and was set back by the unexpected busting of the Khan network in 2003.

Enrichment Scenarios

On balance, the evidence supports that there are two production-scale centrifuge plants in North Korea. However, the lack of concrete evidence of the second plant, e.g. its location or confirmation of its existence, necessitates the consideration of two basic scenarios. The first assumes that a second centrifuge plant exists. The second scenario considers that the Yongbyon plant is the only one.

The selected two scenarios are conservative in the sense that weapon-grade uranium production is not maximized in either one. On the other hand, both assume that North Korea is making weapon-grade uranium.

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[34] *Taking Stock: North Korea's Uranium Enrichment Program*, op. cit.
[35] *Peddling Peril,* op. cit.

Other scenarios are possible, resulting in more or less WGU, but these two are judged as realistic possibilities that do not dramatically over or underestimate the actual WGU stock.

The main characteristics of the scenarios are:

Scenario 1. North Korea operates two production-scale centrifuge plants, the first of which started sometime between the end of 2005 and 2010. The first plant is assumed to have produced WGU and contain 2,000-3,000 P2-type centrifuges. The second one is the Yongbyon centrifuge plant, which is assumed to have made LEU only through 2014. It contains at least 2,000 P2-type centrifuges. Here, the Yongbyon plant could produce WGU but it does not through 2014. A rationale is that North Korea did not want any evidence of WGU production to be detected by international inspectors in case a negotiated freeze at Yongbyon led to a monitored shutdown of the centrifuge plant.

Scenario 2. North Korea has only one production-scale centrifuge plant that it started in 2010. During 2010 and 2011, the plant made LEU for the LWR; afterwards, for three years, it produced WGU. This scenario is close to North Korea's public statements about its centrifuge program. The plant is assumed to have 2,000 P2-type centrifuges; additional centrifuges are assumed not to have become operational as of the end of 2014, such as a result of the recent expansion in the size of the Yongbyon centrifuge plant.

In both scenarios, a number of assessments are applied to the predicted operation of the centrifuges, namely:

- The separative power of each centrifuge is taken as between 4.8 and 5.2 swu per year, consistent with the output of a P2-type centrifuge operating alone in a test stand;
- To first order, the amount of separative work to produce one kilogram of weapon-grade uranium is derived from an ideal cascade calculator, where the tails assay is assumed to be about 0.3-0.4 percent, and;
- North Korea's centrifuge cascades are assessed as inefficient compared to an ideal cascade, meaning that the average individual centrifuge separative power is less when in cascade than when running individually. In cascade, the average centrifuge separative power is estimated to be 50-80 percent of its value when operating individually. For example, at 80 percent, the average output would be about four swu per year, which is consistent with North Korean officials' statements. At 50 percent, the average centrifuge value in cascade would be about 2.5 swu per year. The calculation assumes that any value in the range of 50-80 percent is equally probable, implying again that the cascades are relatively inefficient.

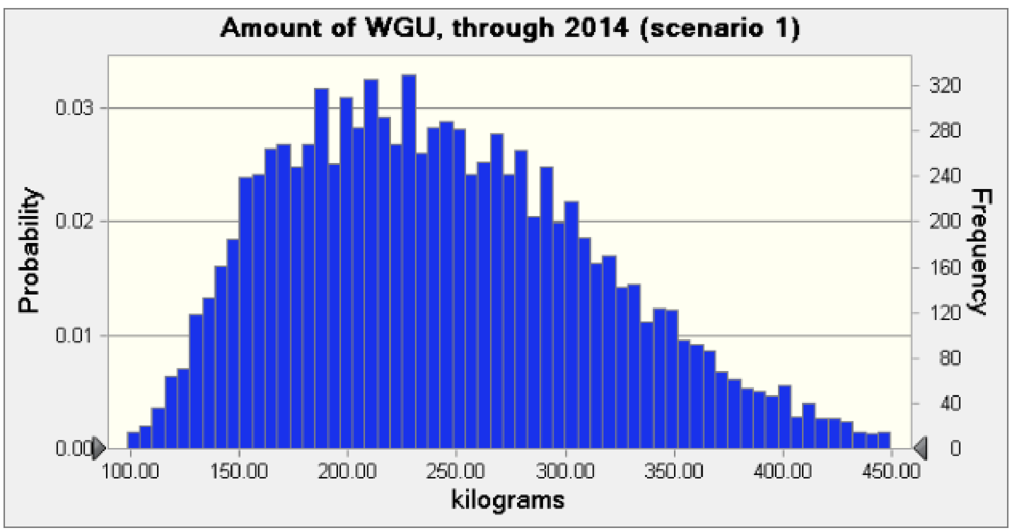
It is a matter of speculation about how North Korea would use WGU in nuclear weapons. It could use the WGU to fashion fission weapons similar, albeit necessitating more fissile material and a larger-diameter warhead design, to its plutonium-based fission weapons. North Korea could use WGU in conjunction with plutonium, or a "composite core," to seek fission weapons with a significantly greater explosive yield. It could also use the WGU with plutonium in designing one-stage thermonuclear explosive devices, which combine thermonuclear material with plutonium and weapon-grade uranium in a core.

If the WGU were used in fission weapons without any plutonium, then North Korea would likely need less than a significant quantity of WGU, which is defined as 25 kilograms of uranium 235 in weapon-grade uranium, or about 27.5 kg of weapon-grade uranium. How much less is unclear, but 15-25 kilograms of WGU per weapon would likely include many possible weapons designs. Over time, North Korea would likely learn to use less WGU per weapon of a fixed explosive yield.

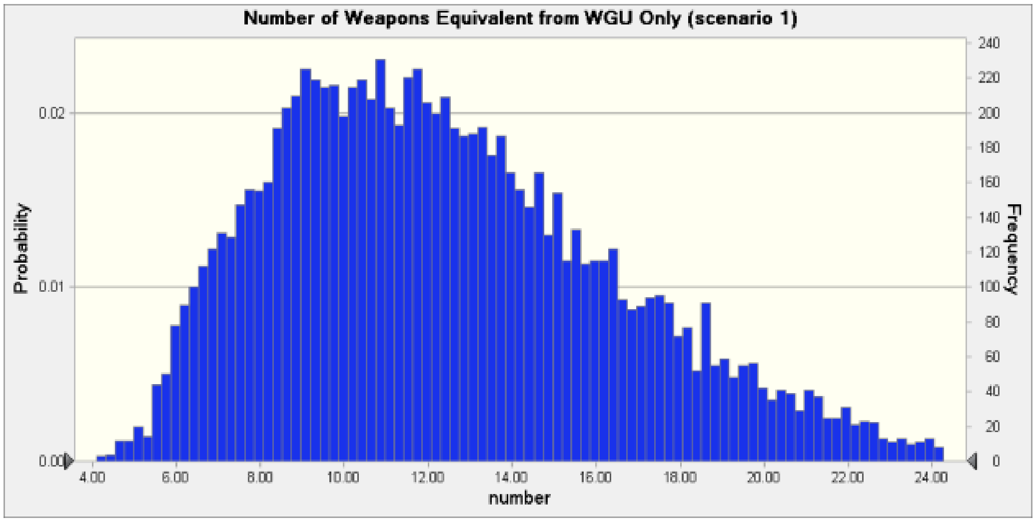
Results for Scenario 1: Two Centrifuge Plants

The calculations involve several variables, each with a range of values. In this case, the estimate of the size of the WGU stock and the number of weapons is calculated with Crystal Ball™ software.

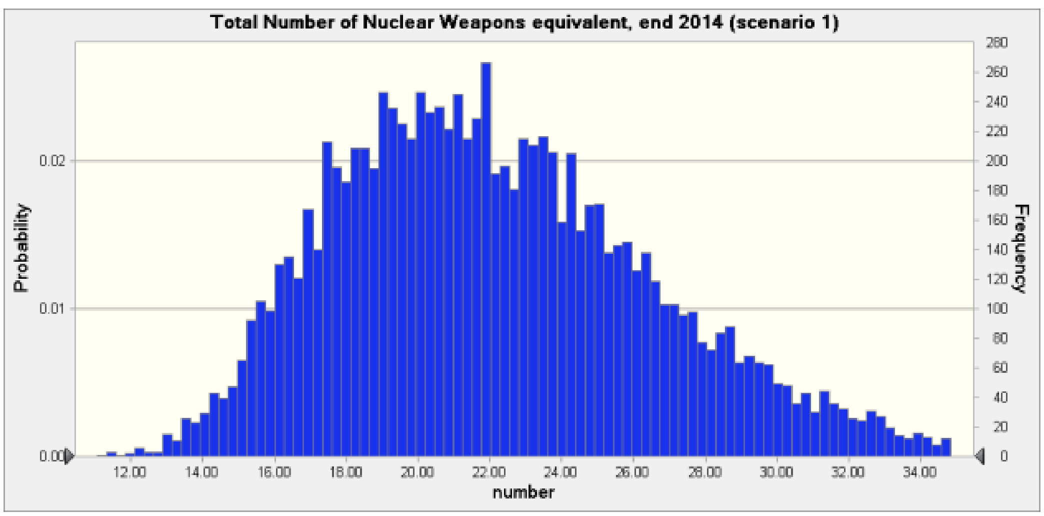
Through 2014, the median estimate of scenario 1 is about 240 kilograms of weapon-grade uranium with a standard deviation of 73 kilograms. The full range is about 100-520 kilograms of weapon-grade uranium. The skewed distribution of results follows:



With this amount of WGU, the number of nuclear weapons' equivalent has a distribution with a median of 12 nuclear weapons and a standard deviation of about four. The full range is 4-32 nuclear weapons. The skewed distribution is:



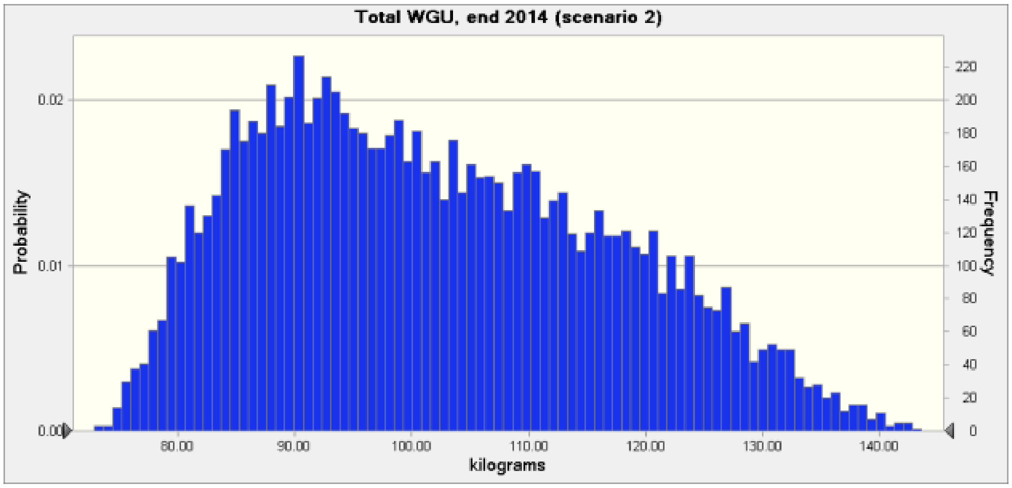
Nuclear weapons can be made from either plutonium or WGU or both combined. To give an indication of the potential number of nuclear weapons equivalent, the number of WGU- and plutonium-based nuclear weapons are added independently. The resulting distribution has a median of 22 nuclear weapons and a standard deviation of 4.5. The full range is 11-43 weapons. The distribution follows:



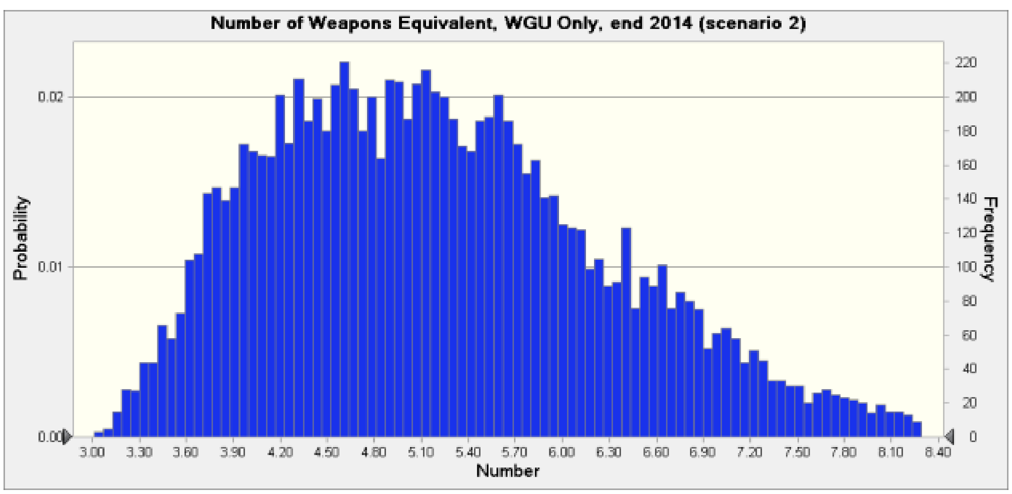
As discussed above, the actual number of nuclear weapons would be expected to be fewer in number, because plutonium and WGU would be held up in the manufacturing processes, lost during processing, or maintained in a reserve. Again, it is assumed that only about 70 percent of the total amount of plutonium and WGU is used in nuclear weapons. Applying this assumption, North Korea would have approximately 15 nuclear weapons with a standard deviation of 3 weapons as of the end of 2014. The number of weapons made from plutonium is estimated at approximately 7 and the number made from WGU is about 8.4, where the latter value is represented as 8-9 weapons.

Results of Scenario 2: One Centrifuge Plant

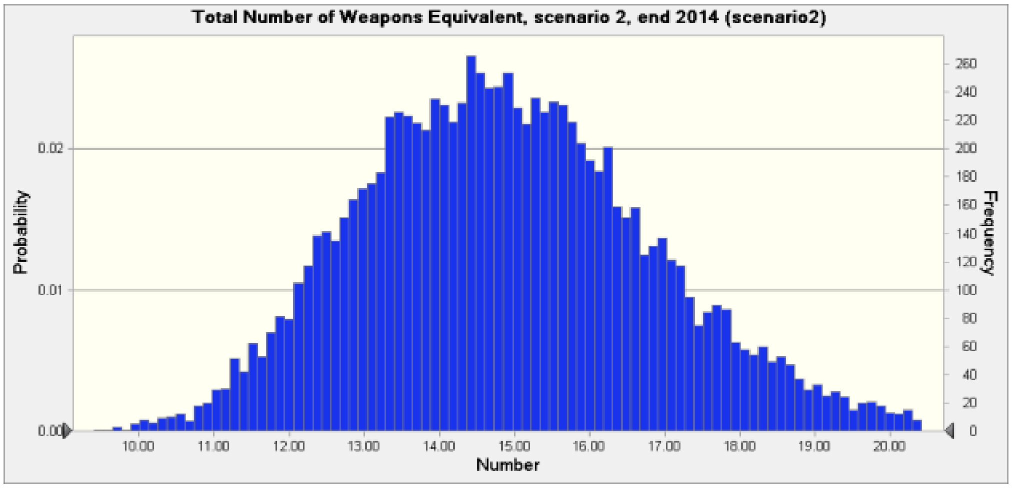
Like before, this estimate uses Crystal Ball™ software to perform the calculation. Through 2014, the median estimate of scenario 2 is about 100 kilograms of weapon-grade uranium with a standard deviation of 15 kilograms. The full range is about 73-145 kilograms of weapon-grade uranium. The skewed distribution of results follows:



With this amount of WGU, the number of nuclear weapons equivalent has a distribution with a median of 5 nuclear weapons and a standard deviation of about one. The full range is 3-9 nuclear weapons. The skewed distribution is:



As discussed above, nuclear weapons can be made from either plutonium or WGU or both combined. To give an indication of the potential number of nuclear weapons equivalent, the number of WGU- and plutonium-based nuclear weapons are added independently. The resulting distribution has a median of 15 nuclear weapons and a standard deviation of 2. The full range is 9-24 weapons. The distribution follows:



As previously noted, the actual number of nuclear weapons would be expected to be fewer in number. Again, it is assumed that only about 70 percent of the total amount of plutonium and WGU is used in nuclear weapons. Applying this assumption to the Scenario 2 distribution, North Korea would have approximately 10-11 nuclear weapons with a standard deviation of about 1.4 weapons as of the end of 2014. The number of weapons made from plutonium is estimated at approximately 7 and the number made from WGU is about 3.5. In the latter case of 3.5 weapons, partial nuclear weapons are of course not possible, and the result is represented as 3-4 weapons.

Conclusion

The separated plutonium estimate at the end of 2014 is 30-34 kilograms of plutonium held by North Korea. Another few to several kilograms of plutonium (about 2-4 kilograms) were produced by the 5 MWe reactor by the end of 2014 but remained in the reactor's core or in discharged irradiated fuel.

The two different scenarios for WGU production result in significantly different results. The median WGU stock of scenario 1 (two centrifuge plants) is about 240 kilograms, and the median WGU stock of scenario 2 (one centrifuge plant) is about 100 kilograms of WGU. A simple method to combine scenarios 1 and 2 is to consider the range of their medians as the estimated amount of WGU produced by North Korea through 2014, or 100-240 kilograms of WGU. Although this range can be justified and allows a comparison to other countries' stocks of highly enriched uranium, it is important to consider each scenario as equally plausible and seek information that can better resolve whether one or two centrifuge plants are operating.

In terms of nuclear weapons, the results for the two scenarios are summarized in the following table.

Table Estimated Number of Nuclear Weapons, Equivalent and Built through 2014 (medians only)		
	Nuclear Weapons Equivalent	Estimated Nuclear Weapons Built
Scenario 1	22	15-16
Scenario 2	15	10-11

Combining the medians results in an estimate that North Korea has 10-16 nuclear weapons as of the end of 2014.