Future Directions In The DPRK's Nuclear Weapons Program: Three Scenarios For 2020

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NORTH KOREA'S
NUCLEAR FUTURES SERIES

US-KOREA INSTITUTE AT SAIS

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TABLE OF CONTENTS

Future Directions in the DPRK's Nuclear Weapons Program: Three Scenarios for 2020[1]

Like many secret nuclear weapons programs, the DPRK goes to great lengths to hide its capabilities to produce nuclear explosive materials and nuclear weapons. Despite these actions, a picture can be drawn of North Korea's current and projected plutonium and weapons-grade uranium (WGU) stocks. Knowing these plutonium and WGU stocks can, in turn, allow an estimate of the DPRK's current number of nuclear weapons and a range of projections of the number North Korea could build in the next several years. Although great uncertainty surrounds these projections, as well as the quality of North Korea's nuclear weapons, these projections form a reasonable picture of the DPRK's possible nuclear weapons futures, absent actions to significantly limit its nuclear programs.

After summarizing estimates of stocks of separated plutonium and weapons-grade uranium as of the end of 2014, this report develops three projections of future nuclear arsenals through 2020: low-end, medium, and high-end nuclear futures. In developing these projections, which are intended to bound North Korea's nuclear futures, a number of constraints are considered, including the number and size of nuclear production facilities, future underground testing, the extent and success of nuclear weaponization efforts, costs and access to necessary goods and classified and proprietary technologies abroad.

[1] Paper prepared for the North Korea's Nuclear Futures Project at the US-Korea Institute at the Johns Hopkins School of Advanced International Studies, and originally published at 38North.org. The plutonium and weapons-grade uranium estimates through 2014 are part of a project that estimated plutonium and highly enriched uranium inventories worldwide that was generously supported by the Nuclear Threat Initiative.

Background

The last several years have witnessed a dramatic and overt build-up in North Korea's nuclear weapons capabilities. The main activities include:

- Separation of several kg of plutonium in 2009 after the collapse of the Six Party Talks;
- Conduct of underground nuclear tests in 2009 and 2013;
- Restart of the small 5 megawatt-electric (MWe) reactor at Yongbyon after a several-year halt;
- Construction of an experimental light water reactor (ELWR) at Yongbyon;
- Revelation of a centrifuge plant at Yongbyon and subsequent doubling of its size; and
- Modernization and construction of many buildings at Yongbyon, probably to enable future production of fuel for the 5 MWe reactor and the ELWR and to support the centrifuge plant.

All these activities have increased suspicions that that there may be significant covert nuclear activities, including the operation of a second centrifuge plant and the construction of nuclear weapons.

Current Plutonium and Weaponization Capabilities[2]

Separated Plutonium Stock

As of the end of 2014, the DPRK is estimated to have a stock of 30-34 kg of separated plutonium, or an average of 32 kg.[3] The plutonium was produced in a small nuclear reactor at the Yongbyon Nuclear Scientific Research Center's 5 MWe reactor, which has a total thermal power of about 20 megawatt-thermal (MWth). Although the reactor is aged and started operating in 1986, North Korea has been renovating it in recent years, implying that it may continue operating for many more. In the reactor, plutonium is produced in the uranium fuel along with other radioactive elements. The plutonium slowly builds up in the fuel and the entire core load of fuel is typically discharged every two to four years. Because the discharged fuel is highly radioactive, it is transported in heavily shielded casks by truck to a nearby specialized processing plant, called the Radiochemical Laboratory. This plant chemically separates the plutonium from the uranium and other radioactive materials and converts it into metal form. As metal, the plutonium is the raw material for building nuclear weapons.

Adjacent to the 5 MWe reactor, the DPRK is constructing what is called an experimental light water reactor (ELWR) with a stated power of about 100 MWth and an electrical output of about 30-35 MWe. The ELWR has not yet started operation but could do so in 2015 or 2016.

Whether the ELWR will be strictly for civil purposes is not known. In particular, will North Korea use this reactor to make plutonium for nuclear weapons? Normally, this type of reactor is not used to make weapons-grade plutonium. However, North Korea could deploy known methods to produce weapons-grade plutonium in a practical manner and separate the plutonium in the Radiochemical Laboratory without major modifications.

If the ELWR were limited to strictly civilian use and optimized to make electricity economically, it would produce plutonium that is not ideal for nuclear weapons—called reactor-grade plutonium. Typically, the fuel, in which the plutonium is produced, contains low-enriched uranium (LEU) containing about 3-4 percent uranium-235, and this fuel is typically heavily

[2] This section draws from Albright, "North Korean Plutonium and Weapon-Grade Inventories, End 2014," January 15, 2015 (to be published). There is additional plutonium in the fuel in the core of the 5 MWe reactor and perhaps some in discharged irradiated fuel, but none of this plutonium is separated and thus unavailable for weapons as of the end of 2014. However, this plutonium is added to the nuclear explosive material stocks in the three post-2014 projections discussed below. This paper is part of a project that estimated inventories of plutonium and highly enriched uranium worldwide that was generously supported by the Nuclear Threat Initiative.
[3] Ibid.

irradiated in this type of reactor, creating the reactor-grade plutonium rather than the more desirable weapons-grade plutonium sought by nuclear weapons programs. Moreover, North Korea's Radiochemical Laboratory is not designed to separate the plutonium from the ELWR fuel, and would require significant modifications to do so.

If North Korea wanted to use this reactor to produce weapons-grade plutonium, it could do so using a more practical method developed in the 1980s by the US Department of Energy when it was considering alternative methods of making weapons-grade plutonium and tritium for US nuclear weapons. In this case, a light water reactor uses enriched uranium driver fuel (10-20 percent enriched in the isotope uranium-235) and natural or depleted uranium targets, where the weapons-grade plutonium is produced in the targets. Reactor-grade plutonium would be produced in the driver fuel. The weapons-grade plutonium in the targets would be recovered, and targets can be designed to make them relatively straightforward to process in the Radiochemical Laboratory, requiring manageable changes to this plant. An advantage of this method is that there would be no need to process the ELWR driver fuel; it can be stored indefinitely. The processing of this driver fuel would require major modifications to the Radiochemical Laboratory that would be hard to achieve in practice. However, with a driver/target system, the DPRK could efficiently and on a sustained basis make weapons-grade plutonium. Depending on design, it could produce up to 20 kg of weapons-grade plutonium per year.

Plutonium-Based Weapons

North Korea has stated publicly that is has built nuclear weapons. Most of these weapons are likely based on plutonium. Its effort to develop plutonium-based nuclear weapons goes back to at least the 1980s. This section estimates the number of nuclear weapons North Korea could have built from its separated plutonium stock at the end of 2014.

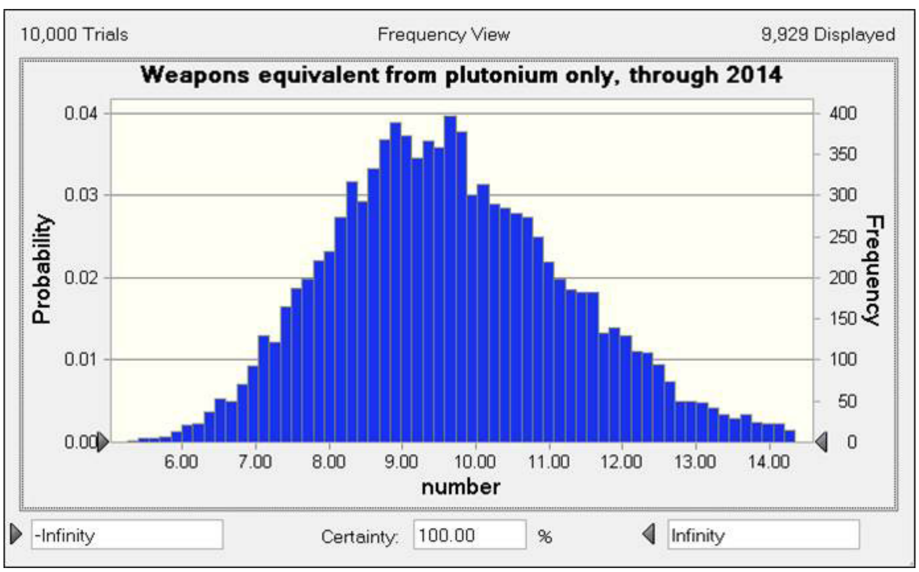
Little is known concretely about North Korea's development or deployment of deliverable nuclear weapons, although it is likely able to build a warhead, perhaps one of limited reliability, which can fit atop a Nodong missile with a range of less than 800 miles.[4] North Korea has worked on nuclear weaponization for over 20 years and may have received nuclear weapons designs from the A.Q. 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 and possibly other missiles. In particular, given the likely dimensions of such a warhead, Pyongyang should also be able to place it on a large Taepodong inter-continental ballistic missile (ICBM), although whether such a weapon would prove operationally effective remains unclear due to probable problems with reliability as well as what appears to be lack of reentry vehicle testing.

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 of the

[4] Albright, "North Korean Miniaturization," *38 North,* 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.

type detonated by the United States during the World War II Manhattan Project. The Trinity explosion contained about 6 kg of plutonium. Over time, North Korea likely reduced the amount of plutonium it needed in each weapon to significantly less than 6 kg. In its Six Party declaration, the North stated that the 2006 nuclear test contained only 2 kg of plutonium. Although there is wide skepticism about this particular declaration, it reinforces the point that North Korea is likely seeking to use less plutonium in each test than the United States used in the Trinity test.

A North Korean nuclear weapon is assumed in this analysis to contain between 2 and 5 kg of plutonium, where values in the middle of the range are weighted more than those at the ends of the range. This weighting reflects a judgment that North Korea is unlikely to use on average as little as 2 kg or as much as 5 kg per weapon. The most likely values are about 3-4 kg. With this range and a separated plutonium inventory of 32-34 kg, Crystal Ball™ software is used to estimate the number of nuclear weapons that can be made. The results are 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, reflecting the weighting of the amount of plutonium per weapon discussed above. 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 distribution is below.



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 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.

Weapons-Grade Uranium and Weaponization Capabilities through 2014[5]

Great uncertainty surrounds the DPRK's production of weapons-grade uranium, the type of enriched uranium typically used in nuclear weapons.[6] 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.

North Korea is believed to have been using a P2-type centrifuge in its uranium enrichment program, which is composed of a single rotor tube with a bellows in the middle of the tube. It received several such centrifuges from Pakistan and a great deal of associated manufacturing and assembly technology. It is also believed to have produced P2-type centrifuges in large quantities.[7]

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.

An estimate of WGU production depends on several factors, including whether there is a secret centrifuge plant in addition to the Yongbyon plant, how many P2-type centrifuges have been deployed successfully, and how well have these centrifuges operated. For example, the centrifuges are assessed as relatively inefficient when operating in production-scale cascades, where a centrifuge in such a cascade achieves an average enrichment output that is only 50-80 percent of the output of a centrifuge operating alone. For more details on inefficiencies and other factors underlying these estimates, the reader is referred to a study by the author.[8]

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[5] This section draws from Albright, "North Korean Plutonium and Weapon-Grade Inventories, End 2014," January 15, 2015 (to be published).

[6] 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.

[7] David Albright and Paul Brannan, *Taking Stock: North Korea's Uranium Enrichment Program*, Institute for Science and International Security, October 8, 2010.

[8] "North Korean Plutonium and Weapon-Grade Inventories, End 2014," op. cit. See also *Taking Stock: North Korea's Uranium Enrichment Program*, op. cit.

To better understand the amount of weapons-grade uranium that North Korea could have produced through 2014, two scenarios are considered based on the available evidence. The first assumes that a second centrifuge plant is operating. The second assumes that the Yongbyon plant is the only one.

Both scenarios assume that North Korea is making weapons-grade uranium. 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 two scenarios are:

- ***Scenario 1:*** North Korea operates two production-scale centrifuge plants, the first of which started production 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 for reactor fuel only through 2014. It contains at least 2,000 P2-type centrifuges and could produce WGU but does not. One reason may be that North Korea does not want any evidence of WGU production to be detected by international inspectors in case a negotiated freeze at Yongbyon leads to a monitored shutdown of the centrifuge plant.
- ***Scenario 2:*** North Korea has only one production-scale centrifuge plant that started in 2010. During 2010 and 2011, the plant made LEU for the ELWR; 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, for example, as a result of the recent expansion in the size of the Yongbyon centrifuge plant.

It is a matter of speculation how North Korea would use WGU in nuclear weapons. It could use the WGU to fashion fission weapons similar to its plutonium-based fission weapons, albeit necessitating more fissile material and a larger-diameter warhead design. Alternatively, North Korea could use WGU in conjunction with plutonium, or a "composite core," to seek fission weapons with a significantly greater explosive yield. The North could also use the WGU with plutonium in designing one-stage thermonuclear explosive devices. The last option is possible in the future with further nuclear tests but unlikely as of 2014. North Korea is likely able to build composite core designs but no evidence of such work has emerged, and this option is also considered unlikely as of the end of 2014.

If the WGU were used in crude fission weapons without any plutonium, then North Korea would likely need less than a "significant quantity" (SQ) of WGU. The SQ is technically defined by the International Atomic Energy Agency (IAEA) as the "approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded."[9] In the case of WGU, which is 90 percent enriched in the isotope uranium-235, a SQ is 25 kg of

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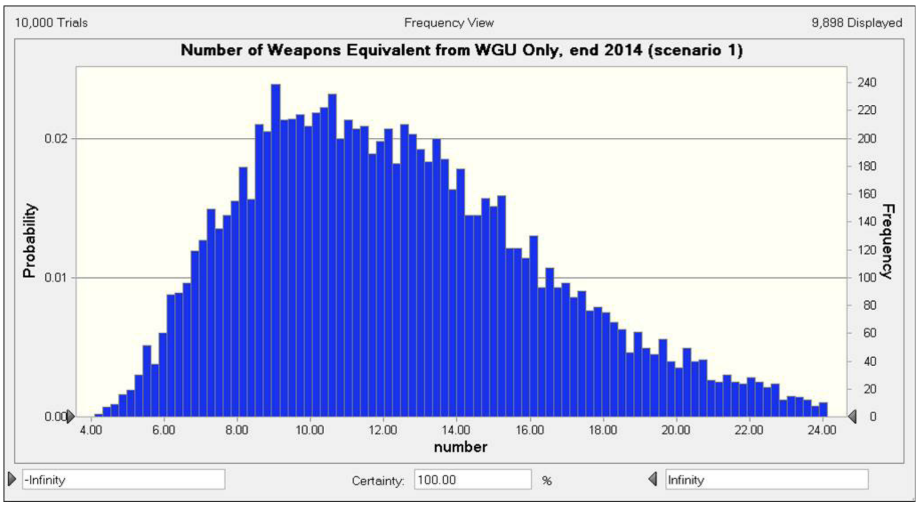
[9] IAEA, "IAEA Safeguards Glossary: 2001 Edition," *International Nuclear Verification Series, 3.* http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf.

uranium 235 in 27.8 kg of WGU.[10] How much less is unclear, but 15-25 kg of WGU per weapon would likely include many possible weapons designs. Over time, the North would likely learn to use less WGU per weapon of a fixed explosive yield, and in later future projections, the lower part of the range will be weighted as more likely.

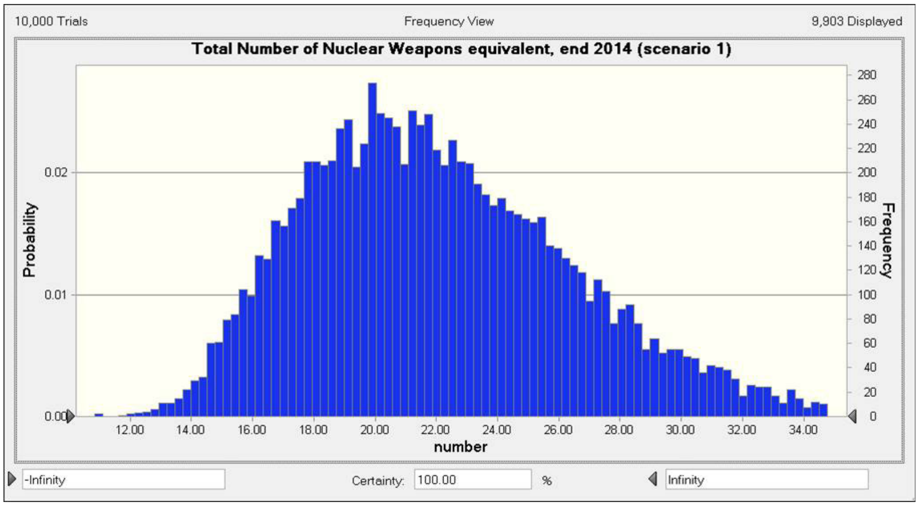
Results of Scenario 1: Two Centrifuge Plants

Using Crystal Ball™ software to perform the calculation, the median estimate of Scenario 1 is about 240 kg of weapons-grade uranium through 2014, with a standard deviation of about 70 kg. With this amount of WGU, the number of nuclear weapons equivalent has a distribution with a median of 12 nuclear weapons equivalents and a standard deviation of about four. The slightly 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 possible, the number of WGU- and plutonium-based nuclear weapons are added independently. The resulting distribution has a median of 22 nuclear weapons equivalent and a standard deviation of 4.5. The distribution is below.

[10] More generally, for highly enriched uranium, which contains 20 percent or more of uranium 235, the SQ is 25 kg of uranium 235. So for 20 percent HEU, the amount of HEU containing one SQ of uranium 235 is 125 kg.

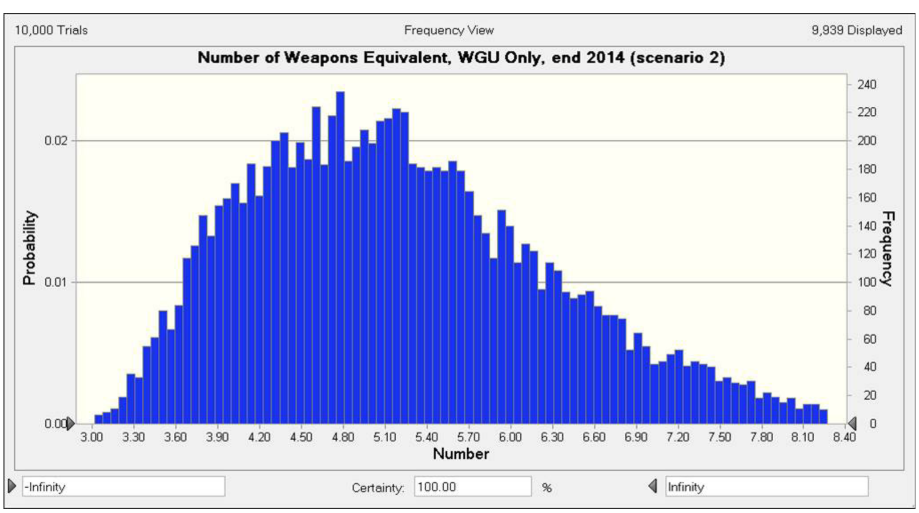


As discussed above, the actual number of nuclear weapons would be expected to be fewer in number, because plutonium and WGU would be held up in the manufacturing processes, lost during processing, or maintained in a reserve. Again, it is assumed that only about 70 percent of the total amount of plutonium 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.

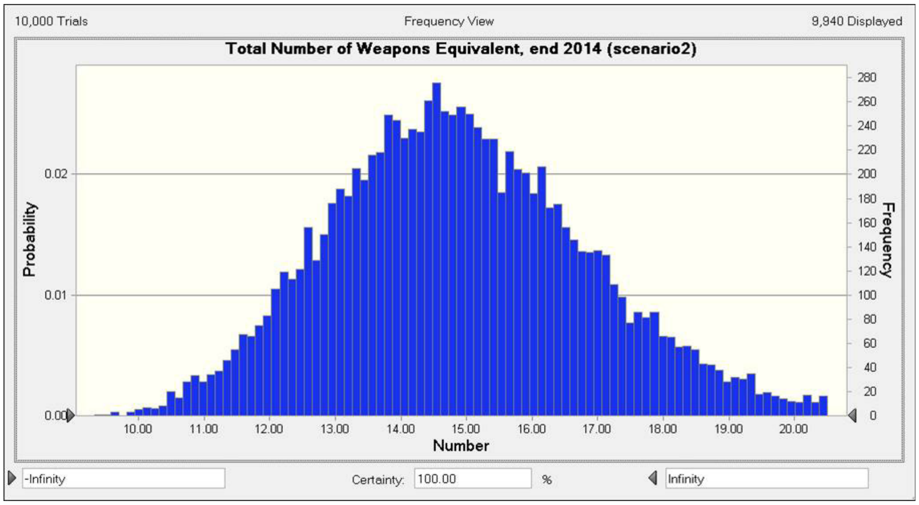
Results of Scenario 2: One Centrifuge Plant

Once again, using Crystal Ball™ software to perform the calculation, the median estimate of Scenario 2 is about 100 kg of weapons-grade uranium through 2014, with a standard deviation of 15 kg.

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 skewed distribution is below.



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 possible, 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 distribution is below.



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.

The results of 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

Projections through 2020

Over the next several years, North Korea could pursue quantitative and qualitative improvements in its nuclear weapons stockpile. This section lays out a set of projections through 2020 that capture the boundaries of North Korea's possible nuclear arsenal futures.

Regardless of the specific projections, North Korea is expected to continue developing its nuclear weapons capabilities. At the March 31, 2013 plenary meeting of the Workers' Party of Korea, Kim Jong Un said that North Korea "should increase the production of precision and miniaturized nuclear weapons and the means of their delivery and ceaselessly develop nuclear weapons technology to actively develop more powerful and advanced nuclear weapons."[11] He implied in this speech that North Korea would seek more precise nuclear-tipped ballistic missiles able to reach the United States.

In this context, North Korea's nuclear program may focus on:

- Increasing production of fissile material and the size of its overall stockpile;
- Conducting more nuclear tests;
- Increasing the explosive yield of its nuclear weapons, including more advanced designs using composite cores or thermonuclear materials to achieve higher yields;
- Achieving additional miniaturization of warheads without sacrificing yield;
- Reducing the amount of plutonium or WGU needed in a nuclear weapon;
- Increasing the safety, security, and reliability of its nuclear weapons although it is highly unlikely to achieve the levels, for example, in the US arsenal;
- Continuing to seek a range of goods abroad for its nuclear programs, including classified and proprietary information; and
- Increasing its level of self-sufficiency in order to avoid restrictions imposed by sanctions and export controls.

Key factors that will affect their ability to make these improvements are:

- Level of political and economic commitment;
- Overcoming technical barriers; and
- Level of foreign assistance.

[11] See http://www.ncnk.org/resources/news-items/kim-jong-uns-speeches-and-public-statements-1/KJU_CentralCommittee_KWP.pdf.

Three projections through 2020 are developed in this section:

- ***Low-end Projection through 2020:*** Progress is slow as economic and technical constraints are numerous (including no further nuclear tests); difficulties are encountered in advancing current nuclear efforts and the North's political commitment wanes.
- ***Medium Projection through 2020:*** This projection assumes moderate growth based on a continuation of its current nuclear trajectory and development practices as well as political and economic commitment. The program is a mixture of successes and failures. Efforts to acquire technology/assistance from abroad make slow progress as does Pyongyang's effort to achieve self-sufficiency.
- ***High-end Projection through 2020:*** The general assumption underlying this projection is that nuclear weapons progress is steady and successful. North Korea steps up its commitment to build a nuclear arsenal, vigorously pursues technology development through, in part, increasing the number of nuclear tests and faces few economic constraints. Pyongyang also achieves a high level of success in acquiring technology/assistance from abroad as well as in achieving self-sufficiency.

Low-end Projection through 2020

North Korea's production of fissile material is limited to the 5 MWe reactor and centrifuge plant at Yongbyon. It either does not or cannot militarize the ELWR to make weapons-grade plutonium. The centrifuge plant is limited to 3,000-4,000 P2-type centrifuges, and North Korea does not deploy any more advanced than the P2-type. Moreover, the North will need to produce LEU for the ELWR. The centrifuges operate with poor efficiency, as they have done up through 2014.[12] The 5 MWe reactor will experience outages and poor operational efficiencies, limiting production to an average of 2-3 kg per year of weapons-grade plutonium.

In this scenario, Pyongyang does not conduct any further nuclear tests. Nonetheless, it would make limited advances in its nuclear weapons skills and designs, such as achieving some additional miniaturization of warheads without sacrificing the explosive yield. However, the North would not be able to reduce the amount of plutonium or WGU needed in a nuclear weapon. Marginal improvements would be made in the safety, security and reliability of its nuclear weapons. Finally, without testing there would be limits to developing more advanced weapons. The North would be limited to using shells of fissile material or other shapes for the core that would permit significant additional miniaturization. It would be unable to develop boosted or thermonuclear weapons as well as a reliable source of tritium for thermonuclear devices.

North Korea's arsenal would be limited to fission-only weapons made from either plutonium or WGU. The explosive yields would not be high, likely on order of 10 kilotons. Its arsenal would involve a small number of weapon designs, or physics packages, and they would be adapted to various delivery systems, such as the Nodong and possibly longer-range missiles.

[12] The centrifuge efficiency is taken as 50-80 percent.

While Pyongyang will require foreign goods for its various nuclear programs, such as vacuum equipment, pumps, instrumentation, sophisticated computer numerical controlled (CNC) machine tools and specialized chemicals and metals, it will experience difficulty procuring them. These procurement challenges will reduce the efficiency of its centrifuges and 5 MWe reactor. Moreover, the North will not succeed in procuring nuclear weapons data or designs overseas that would help further modernize its stockpile. Any nuclear cooperation with other countries—such as Iran—would be minimal and achieve few results.

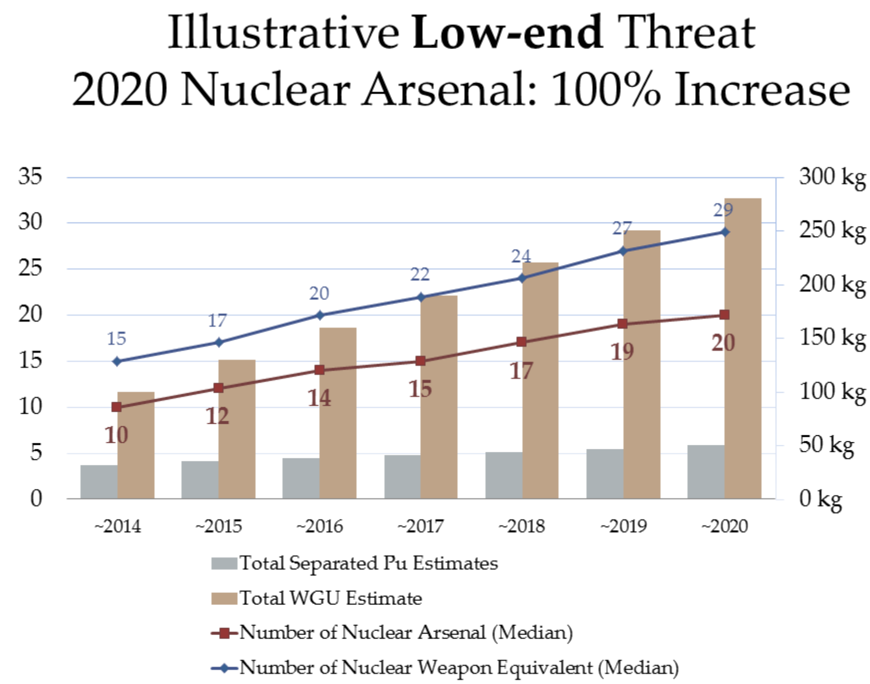
Low-end Nuclear Arsenal. By 2020, North Korea would modestly increase the size of its nuclear arsenal, which would be comprised of fission weapons with explosive yields of about 10 kilotons. Miniaturization would allow the North to mount nuclear weapons on ballistic missiles but limited to existing types like the Nodong and a Taepodong deployed as an ICBM. Each weapon would be made from either separated plutonium or weapons-grade uranium. The stockpile would not include any composite cores or thermonuclear nuclear weapons.

To derive the total amounts of plutonium and weapons-grade uranium through 2020, the amounts of plutonium and weapons-grade uranium produced through 2014 under Scenario 2 (one centrifuge plant) are added to the values from the period 2015-2020, where the assumptions above are used to derive inventories in the latter period with the Crystal Ball™ software.

The median of the total plutonium estimates through 2020 is 50 kg with a standard deviation of 2 kg. The median of the WGU estimate through 2020 is 280 kg with a standard deviation of 60 kg. Assuming that each weapon contains either plutonium or WGU, the median of the number of nuclear weapon equivalents is 29 with a standard deviation of 5.[13] About half of these weapons contain plutonium and half contain WGU. From 2014 through 2020, the number of weapon equivalents grows at an average rate of about 2.3 weapons equivalent per year.

Only a percentage of plutonium and WGU is used in the actual weapons—some will be tied up in the manufacturing process, lost to waste, or held in a reserve. In the low-end projection, with about 70 percent of the plutonium and WGU used in the weapons, the DPRK's total arsenal will consist of approximately 20 fission nuclear weapons at the end of 2020.

[13] A plutonium-based weapon is assumed to contain 2-5 kg of weapons-grade plutonium, with the values between about 3-4 weighted, and a WGU-based weapon contains 15-25 kg of weapons-grade uranium, with each value in this range equally likely.



Medium Projection through 2020

North Korea operates the 5 MWe reactor reasonably well, producing an average of about 3-4 kg of weapons-grade plutonium per year. The ELWR is partially militarized and makes a moderate amount of weapons-grade plutonium—5 to 10 kg—each year. The plutonium from the ELWR will become available starting in 2018.

North Korea operates two centrifuge plants limited to a total of 6,000-7,000 P2-type centrifuges throughout this period. Moreover, the Yongbyon plant will need to produce LEU for the ELWR. The centrifuges will continue to work with relatively poor efficiency, but better than in the low-end projection.[14] North Korea will conduct development work on a centrifuge similar to the Pakistani P3-type centrifuge, which has four maraging steel segments and three bellows, giving an output double the P2-type centrifuge. Nonetheless, during this period the North does not deploy any advanced centrifuges.

In this scenario, North Korea conducts nuclear tests at its current rate of about one every 3-4 years. Advances are made in nuclear weapons development skills and designs, such as achieving additional miniaturization of warheads without sacrificing explosive yield. The North makes progress in using shells of fissile material instead of solid core designs and developing non-spherical shapes of the plutonium or WGU core, allowing further miniaturization. However, it does not reduce the amount of plutonium or WGU needed in a weapon. Improvements are also achieved in the safety, security and reliability of the North's stockpile.

[14] Here the centrifuge efficiency is 60-80 percent.

The North develops and deploys an additional weapon design that contains plutonium and weapons-grade uranium in the same core, allowing a significant increase in the weapon's explosive yield up to 50 kilotons. Fission weapons with either plutonium or weapons-grade uranium will remain the majority of its stockpile. However, their yields are larger on average, in the range of 10-20 kilotons, another benefit of continued nuclear testing and advances in design skills.

By the end of 2020, advances in miniaturization will result in a stockpile of warheads that can be deployed on missiles of various ranges beyond those in the low-end projection, including shorter-range ballistic missiles for battlefield use or more modern intermediate-range ballistic missiles (IRBMs) and ICBMs such as the Musudan and KN-08 road-mobile missiles.

In addition, Pyongyang will develop a more advanced nuclear weapon design although it will not be fully tested or deployed by 2020. It will develop a reliable but small source of tritium and deuterium. Both could be used to boost the explosive yield of a fission weapon and to achieve a one-stage thermonuclear weapon, which uses tritium, deuterium and lithium within a composite core of plutonium and weapons-grade uranium. The North will be able to test these designs, likely with a reduced yield because of test site limitations.

North Korea will continue to require foreign goods for its various nuclear programs but will experience only mixed success in procuring them. Progress will be made in producing some key materials and equipment domestically. Nonetheless, overseas procurement failures will reduce the efficiency of its centrifuges, reactors, and nuclear weapons program, but not as severely as in the low-end projection. While the North will not succeed in procuring nuclear weapons data or designs overseas, it will benefit from limited nuclear cooperation with Iran, which will aid Pyongyang's centrifuge program and procurement efforts.

Medium Nuclear Arsenal. By 2020, North Korea would increase the size of its nuclear arsenal several fold. The arsenal would consist of mostly fission weapons with explosive yields of about 10-20 kilotons. Several will have composite cores. These weapons could be mounted on a wide range of delivery systems.

The total amounts of plutonium and weapons-grade uranium is based on the amount of plutonium and weapons-grade uranium produced through 2014 under Scenario 1 (two centrifuge plants) added to the values from the period 2015-2020, where the assumptions above are used to derive inventories in the latter period with Crystal Ball™ software. The median of the total plutonium estimates through 2020 is 80 kg with a standard deviation of 5 kg. The median of the WGU estimate through 2020 is 790 kg with a standard deviation of 105 kg. Assuming that each weapon contains either plutonium or WGU, the median of the number of nuclear weapon equivalents is 69 with a standard deviation of 8.[15] About one-third of these weapons contain plutonium and two-thirds contain WGU. From 2014 through 2020, the number of weapon equivalents grows at an average rate of almost eight weapons equivalent per year.

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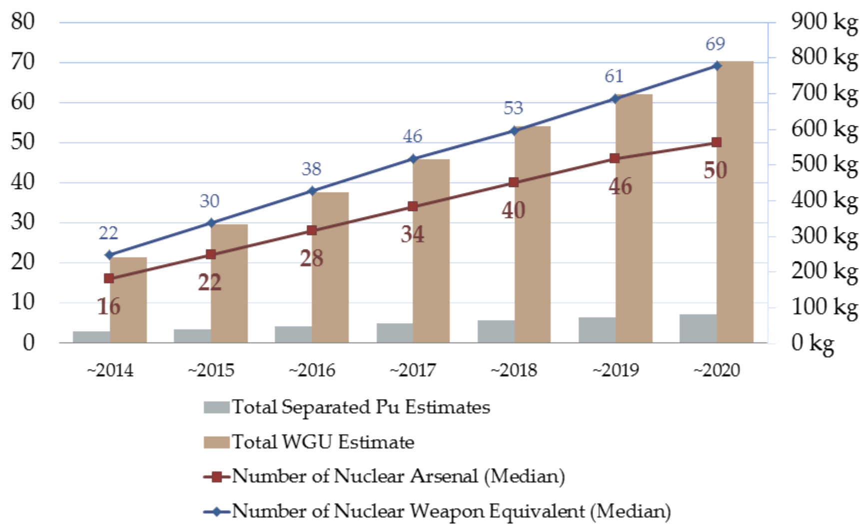
[15] A plutonium-based weapon is assumed to contain 2-5 kg of weapons-grade plutonium, with the values from about 3-4 weighted, and a WGU-based weapon contains 15-25 kg of weapons-grade uranium, with each value in this range equally likely.

In this scenario, less fissile material is assumed to be tied up in-process or lost in waste than in the low-end estimate. In addition, some of the plutonium and WGU will be in nuclear weapons composite cores (say <5 weapons), reducing the total number of weapons as derived above, where each weapon is assumed to contain only plutonium or WGU. On balance, in the medium projection, the number of nuclear weapons is assumed to be about 75 percent of the nuclear weapons equivalent, giving an arsenal of about 50 nuclear weapons.

Illustrative **Medium** Threat
2020 Nuclear Arsenal: 212.5% Increase



High-end Projection through 2020

In this projection, North Korea operates the 5 MWe reactor efficiently, making use of overseas procurements that allow an increase in reactor power to 25 MWth and effective maintenance. The result is an average production of about 5-6 kg of weapons-grade plutonium per year. Pyongyang militarizes the ELWR, enabling it to produce more weapons-grade plutonium than in the previous scenario, 15-20 kg each year. Also, the plutonium would become available two years earlier, starting in early 2016.

North Korea will operate two centrifuge plants with a combined 8,000-9,000 P2-type centrifuges. One will be the Yongbyon centrifuge plant with a capacity of 4,000 P2-type centrifuges starting at the beginning of 2015. The other will be an upgraded centrifuge plant at another location containing 4,000-5,000 P2-type centrifuges operating at this level in early 2015. As before, the Yongbyon centrifuge plant will need to produce LEU for the ELWR. The reactor will achieve higher capacity factors than in the medium scenario. The centrifuges will work with better efficiency than in the previous projections.[16] Moreover, the North will complete development work on a new centrifuge similar to the Pakistani P3-type, with an output that is double that of

[16] The centrifuge efficiency is 70-80 percent.

the P2-type centrifuge. The first 2,000 P3-type centrifuges will become operational at the start of 2019. These centrifuges will be in addition to 8,000-9,000 P2-type centrifuges already in operation.

Under this scenario, nuclear weapons tests are increased to a rate of one per year enabling the North to make significant advances in its nuclear weapons skills and designs. It develops smaller diameter, lighter-weight nuclear weapons able to fit an increasing variety of shorter range missiles for battlefield use. Pyongyang is able to make further reductions in the amount of plutonium and WGU used in a nuclear weapon.[17] It makes significant improvements in the safety, security and reliability of its nuclear weapons, allowing nuclear weapons to be deployed more easily.

As in the medium scenario, additional designs that contain plutonium and weapons-grade uranium in the same core are developed and deployed, allowing a significant increase in explosive yield up to 50 kilotons. The North also continues to field weapons with either plutonium or weapons-grade uranium, as in the two other projections. But in the high-end scenario, it increases the average yield of its fission weapons to 20 or more kilotons.

While developing a reliable source of tritium and deuterium for nuclear weapons development, the North makes significant progress in using both to boost the explosive yield of a fission weapon. A new boosted yield design is tested and incorporated into a significant number of composite core weapons although the bulk of the stockpile remains centered on weapons using either plutonium or uranium.

Pyongyang also develops a one-stage thermonuclear weapon, which uses tritium, deuterium and lithium within a composite core of plutonium and large quantities of weapons-grade uranium. One such device is tested by 2020, with a yield of about 100 kilotons. However, this one-stage weapon is too large for missile delivery, but North Korea is aiming to make it deployable as soon as possible. Work is done on designing and developing a two-stage thermonuclear weapon but not tested by 2020.

North Korea will be very successful in procuring foreign goods for its various nuclear programs and will achieve greater self-sufficiency in making key materials and equipment domestically. Procurements, whether domestic or abroad, will be adequate and not interfere with the programs' progress. Moreover, Pyongyang will succeed in procuring nuclear weapons data and an advanced weapon design overseas, making an important contribution to speeding up the North's nuclear weapons developments. It cooperates actively with Iran on all nuclear areas, reducing inefficiencies in facilities and bottlenecks in procurements.

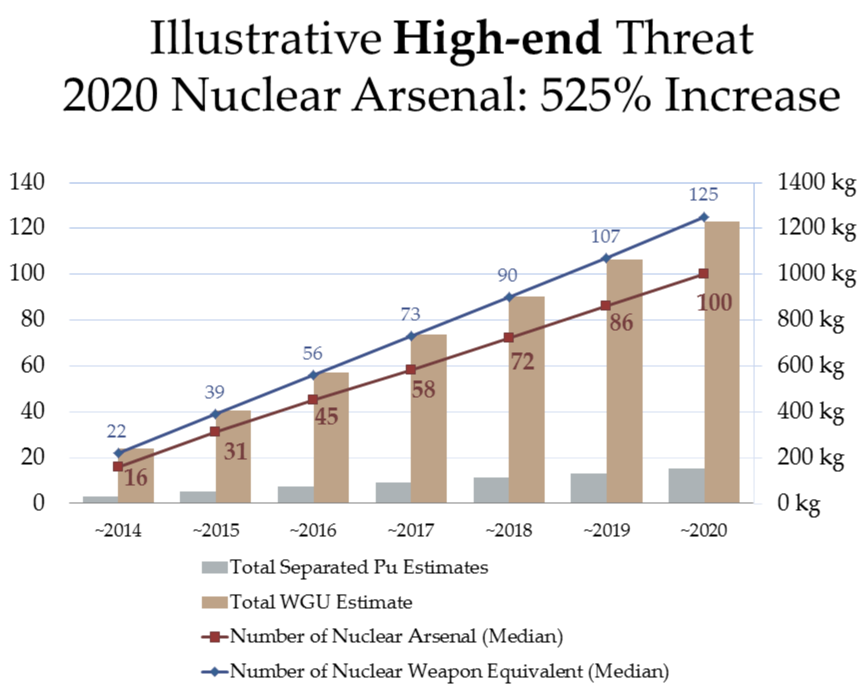
High-end Nuclear Arsenal. By 2020, North Korea would increase the size of its nuclear arsenal many fold. The arsenal would still consist of mostly fission weapons but the explosive yields would average 20 kilotons or more, which is greater than in the medium estimate. Several will have composite cores and North Korea will be working to deploy one-stage thermonuclear

[17] For plutonium, the range is 2-4 kg, where mid-values are weighted and for WGU the range is 15-20 kg, where each value is equally probable.

weapons with yields of about 100 kilotons. With the exception of thermonuclear weapons, the North's arsenal could be mounted on a wide range of delivery systems from short-range ballistic missiles (SRBMs) to the newer road-mobile Musudan IRBM to the KN-08 ICBM.

To derive the total amounts of plutonium and weapons-grade uranium through 2020, plutonium and weapons-grade uranium produced through 2014 under Scenario 1 (two centrifuge plants) are added to the values from the period 2015-2020, where the above assumptions are used to calculate inventories in the latter period. The median of the total plutonium estimates through 2020 is 154 kg with a standard deviation of 8 kg. The median of the WGU estimate through 2020 is 1,230 kg with a standard deviation of about 110 kg. Assuming that each weapon contains either plutonium or WGU, the median of the number of nuclear weapon equivalents is about 125 with a standard deviation of 13. About 40 percent of these weapons contain plutonium and 60 percent contain WGU. From 2014 through 2020, the number of weapon equivalents grows at an average rate of about 17 per year.

In this projection, much less fissile material is assumed to be tied up in-process, lost to waste, or held in reserve than in the medium scenario. However, a couple factors reduce the number of weapons made from plutonium and WGU. An increased number of composite cores, namely 5-10, will contain plutonium and WGU, and one test of a single-stage thermonuclear device will have used several tens of kg of WGU. On balance, the number of nuclear weapons is taken as 80 percent of the nuclear weapons equivalent. The end result is an arsenal of about 100 nuclear weapons.



A Final Word

The three scenarios are by no means all the possible paths of development for North Korea's nuclear weapons program. There are, of course, a number of unpredictable different ways that its program might develop over the next 5-10 years. Rather, by laying out what may be the worst and best case analysis, these scenarios capture a band that has a greater chance of predicting the future than focusing on any one probable outcome.

In this context, it is worth noting one additional scenario, namely that North Korea ends nuclear testing but continues and perhaps accelerates its production of fissile material. Under this scenario, Pyongyang's nuclear weapons stockpile could continue to grow to as much as the 50-100 weapons outlined in the medium and high-end scenarios above with very limited qualitative improvements in that stockpile. Moreover, despite its technological limits, given the assessment of Pyongyang's current level of miniaturization, such a stockpile would be able to arm a large number of selected delivery systems in the North's inventory, particularly the Nodong medium-range ballistic missile (MRBM) able to reach South Korea and Japan.

2020 through 2025

After 2020, North Korea could further increase its numbers of nuclear weapons beyond those in the three scenarios and improve their destructive qualities, including further developing thermonuclear weapons. Even in the low-end scenario, North Korea may simply build more fission weapons with plutonium and WGU, slowly growing its arsenal of deployed nuclear weapons at the same rate as in 2015-2020.

In the medium and high-end scenarios, Pyongyang's arsenal would be expected to grow at a faster rate, mainly due to production of more WGU. The increase would result from the deployment of more centrifuges, including more advanced ones. After 2020, even in the medium scenario, North Korea is likely to deploy more advanced centrifuges. With greater numbers of centrifuges, including a growing fraction of more powerful ones, North Korea's rate of WGU production would grow.

North Korea's nuclear weapons would likely become more sophisticated across the board in both the medium and high-end scenarios, as underground tests continue and the North's nuclear weapons experience matures and grows. Particularly, in the high-end scenario, Pyongyang would be expected to deploy an increasing number of more accurate long-range missiles and a growing variety of shorter range battlefield weapons. It would also likely be able to finish developing and then deploying a one-stage thermonuclear weapon with a yield of about 100 kilotons. Also, it may make significant progress in developing two-stage thermonuclear weapons.

Table: Nuclear Futures, through 2020.
Characteristics and Projection Estimates

Characteristics and Estimates	Low-End	Medium	High-End
5 MWe Reactor (kg Pu/yr)	2-3 kg/yr	3-4 kg/yr	5-6 kg/yr
ELWR (kg)			
Year When Militarized	not applicable (n/a)	2018	2016
How Much Pu/yr	n/a	5-10 kg/yr	15-20 kg/yr
Centrifuge Plants			
Number	1	2	2
# P2 Centrifuges	3,000-4,000	6,000-7,000	8,000-9,000
Efficiency of P2s	0.5-0.8	0.6-0.8	0.7-0.8
Advanced Centrifuges	n/a	n/a	2,000 P3
Year Deployed	n/a	n/a	Start 2019
End 2014 Stock (kg)			
Plutonium	30-34 kg	30-34 kg	30-34 kg
WGU	85-115 kg	170-310 kg	170-310 kg
End 2020 Stock (kg)			
Plutonium	48-52 kg	75-85 kg	146-162 kg
WGU	220-340 kg	685-895 kg	1,120-1,340kg
Nuclear Testing	none	1 every 3-4 years	annually
Amount in Each Weapon			
Plutonium	2-5 kg	2-5 kg	2-4 kg
WGU	15-25 kg	15-25 kg	15-20 kg
Weapon Equivalents (median only)			
End 2014	15 weapons eq.	22 weapons eq.	22 weapon eq.
End 2020	29 weapons eq.	69 weapons eq.	125 weapons eq.
Arsenal Size, end 2020	20 weapons	50 weapons	100 weapons
Yield of Pu or WGU			
Fission Weapon	10 kilotons	10-20 kilotons	20+ kilotons
Composite Core Weapons	n/a	<5	5-10
Thermonuclear Weapons	n/a	n/a	0 deployed

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