North Korea's Nuclear Capabilities: A Fresh Look

David Albright*

Institute for Science and International Security

April 22, 2017

www.isis-online.org

www.isisnucleariran.org

@TheGoodISIS

**Mark Gorwitz contributed importantly to these slides*

Purpose of Talk Today

- What is the size and nature of North Korea's nuclear weapons program? How do they procure abroad for these programs?
- Any quantitative estimates will have significant uncertainty. e.g. estimates of separated plutonium and weapon-grade uranium stocks are not precise.
- Estimates of the number of nuclear weapons are derived from the estimates of plutonium and weapon-grade uranium stocks.
- Sufficient information is known to derive credible median values with uncertainty ranges.

Nuclear Weapons Capabilities

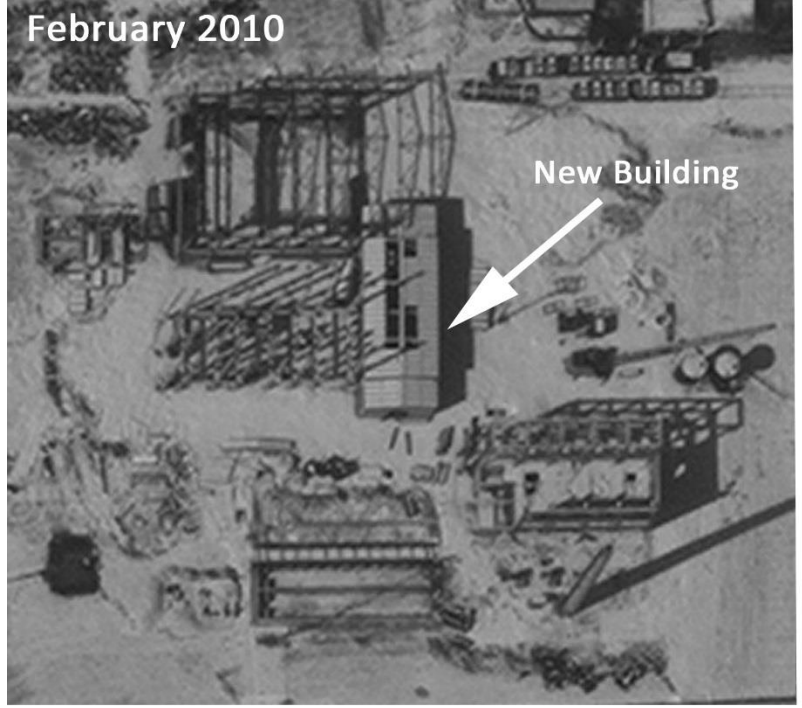
- The bottom line is that North Korea has an improving nuclear weapons arsenal
- North Korea's nuclear weapons capability benefits from
  - Procurements abroad;
  - A functioning industrial complex making plutonium and weapon-grade uranium;
  - An ability at sites unknown to research, develop, and manufacture nuclear weapons;
  - Possible integration facilities that could mate a nuclear warhead to a ballistic missile;
  - Nuclear warhead storage capabilities;
  - Nuclear testing at its Punggye-ri underground test site and associated component testing and cold-testing facilities at unknown locations; and
  - A robust program to develop, manufacture, and test missiles of various ranges.

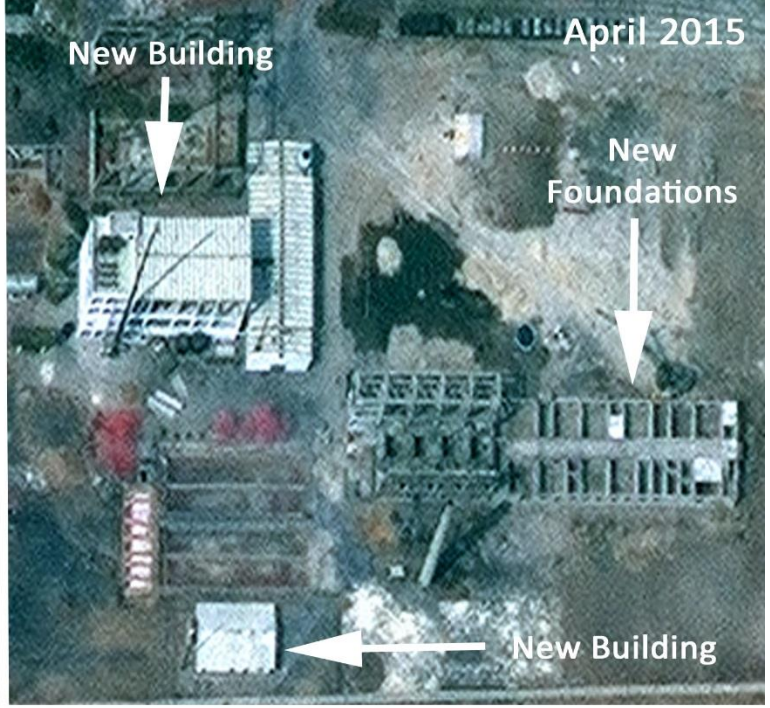
Growth of North Korea's Nuclear Weapons Complex in Recent Years

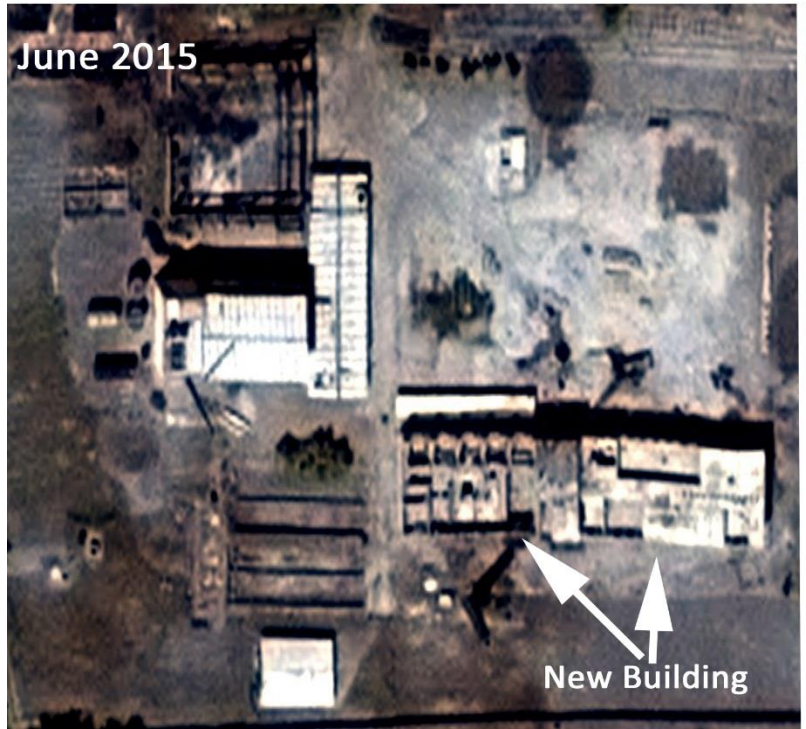
The last several years have witnessed a dramatic and overt build-up in North Korea's nuclear weapons capabilities. The main activities include:

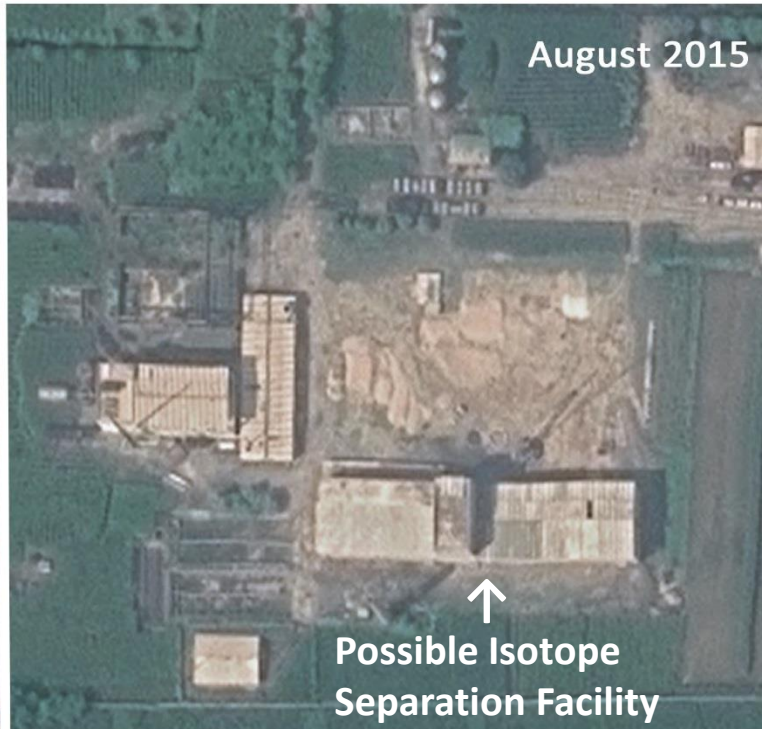
- Five underground nuclear tests in 2006, 2009, 2013, and 2016;
- Restart and refurbishment of the small five megawatt-electric (MWe) reactor at Yongbyon after a several year halt;
- Separation of several kg of plutonium in 2009 and again in 2016 from the 5 Mwe reactor at the Radiochemical Laboratory at Yongbyon;
- On-going construction of an experimental light water reactor (ELWR) at Yongbyon (type of reactor is uncertain);
- Construction by a nuclear organization of a new graphite production facility;
- Revelation of a centrifuge plant at Yongbyon in 2010 and subsequent doubling of its floor size a few years later;
- Construction of facilities to make thermonuclear materials, including a lithium 6 enrichment plant and an Isotope Production Facility able to separate tritium;
- Modernization and construction of many buildings at Yongbyon, including likely one able to manufacture fuel for the ELWR and others to support reactor and centrifuge operations;
- Refurbishing of uranium mines and mills;
- The development and manufacture of nuclear weapons at sites unknown;
- A great deal of work related to the development and manufacture of ballistic missiles;
- These activities have been supported by extensive overseas procurements of equipment, material, and technology.

Gas Centrifuge Plant and Possible Tritium Separation at Yongbyon for Thermonuclear Devices


February 2010
New Building


April 2015
New Building
New Foundations
New Building


June 2015
New Building


August 2015
Possible Isotope Separation Facility

Plutonium, Weapon-Grade Uranium (WGU), and Nuclear Weapons Estimates

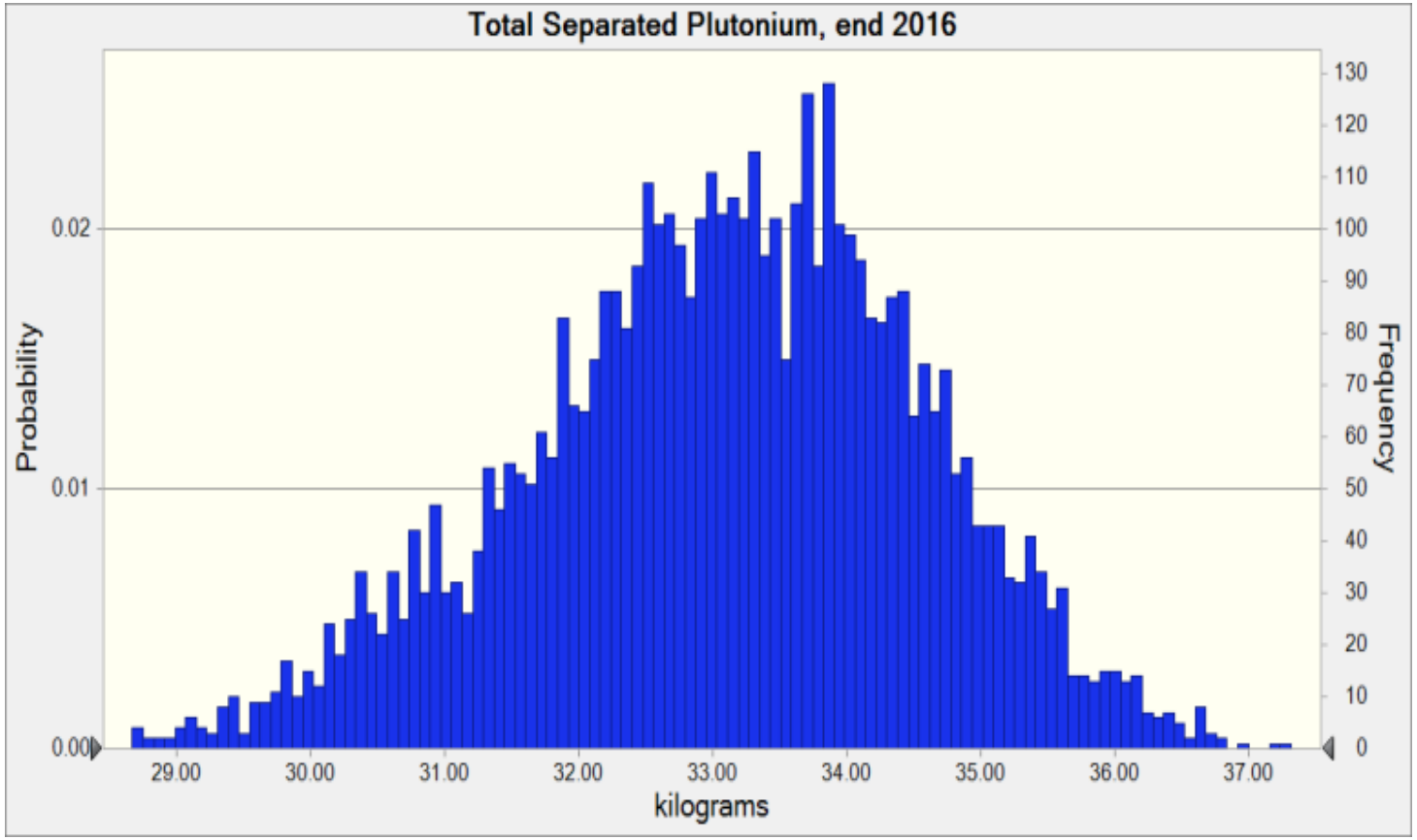
5 MWe Reactor Remains the Only Source of Plutonium

- It restarted in early 2016 after fuel unloading during late 2015, according to International Atomic Energy Agency (IAEA) reporting and assessments of commercial satellite imagery
- During the last year, it does not appear to have operated at full power.
- Periodically, water is seen exiting or splashing from the secondary discharge pipe near the river. In the winter, snow or ice melt indicates the discharge of hot water from the pipe.
- Our assessment is that reactor power has been intermittent for a while

Plutonium Estimate Through 2016

- The baseline of this estimate relies on North Korea's plutonium declarations during the Six Party Talks and a subsequent Institute study of North Korea's plutonium and weapon-grade uranium stocks as of the end of 2014.
- The estimate uses the software called CrystalBall to calculate a distribution of results which propagate uncertainties in input variables.
- Several adjustments to that 2014 estimate are applied in this study, namely:
  - Reduction due to two nuclear tests in 2016 (a range of values, to be discussed later) (median is about 7 kg, where tests are assumed to use plutonium)
  - Addition of about 5.5-8 kg from a plutonium separation campaign in 2016
  - Addition of up to 4 kg from possible undeclared separation in early 1990s (not in the 2014 study)

Distribution of Plutonium values, end 2016



Median: 33.1 kg; standard deviation: 1.56 kg; full range: 23.2 to 37.3 kg

North Korea Appears Capable of Making Weapon-Grade Uranium

- North Korea has a complex of facilities to enrich uranium.
- A declared one is at the Yongbyon nuclear complex, which started operation in 2010.
- According to a defector who worked on centrifuge assembly at Yongbyon, the Yongbyon facility has only a small centrifuge assembly hall, operated under clean room conditions, where pre-assembled parts are delivered and assembled into final components. He stated that he was involved in the initial centrifuge assembly of the Yongbyon plant and had no prior experience assembling centrifuges.
- North Korea has a centrifuge manufacturing complex making many of the parts and facilities to make uranium hexafluoride.
- Evidence supports that North Korea operated a pilot centrifuge plant in the late 1990s and early 2000s, which is now shutdown
- North Korea may have an undeclared centrifuge plant that started prior to 2010.

Is there another, earlier centrifuge plant?

- The evidence for this plant is substantial but controversial.
- I will outline two sets of information supporting the existence of this plant.
- I should first mention that North Korea's military first doctrine would tend to support that the Yongbyon centrifuge plant is not the first one. This argument essentially recognizes the Yongbyon plant as one dedicated initially to making low enriched uranium for the experimental light water reactor.
- However, the uncertainty in this view remains substantial and we do not conclude the existence of this other plant is established beyond doubt.

Chronology of Procurements Related to Centrifuge Plant

- Procurements are extensive and follow the types of procurements done by A. Q. Khan for Pakistan's centrifuge program
- 2002/2003 procurements sufficient for about 8,000-10,000 P2-type centrifuges (e.g. Optronix case and 8000 aluminum casings from Russian company Norilsk Nickel)
- Between 2003 and 2008, many procurements
- 2008 procurements sufficient for 2000 centrifuges
- End 2010, procurements for extension of the Yongbyon centrifuge plant. Procurements sufficient for 500-1000 centrifuges
- Early 2016, procurements sufficient for one low enriched uranium (LEU) cascade

Secret Centrifuge Plant?

- Would North Korea procure so much in the early 2000s and not build a centrifuge plant? Why would it wait until the late 2000s to build one at Yongbyon, ostensibly related at the time of its revelation in 2010 only to the production of low enriched uranium (LEU)?
- North Korea's procurement history suggests the existence of a secret or undeclared, production-scale centrifuge plant that was built in the mid-to-late 2000s.
- Assuming that North Korea was following the Khan plan, then the plant could have several thousand P2 centrifuges.

WGU detected in North Korea

- Weapon grade uranium was found on materials the United States brought out of North Korea in 2006 and 2007 as part of the Six Party Talks.
- U.S. intelligence agencies assessed that this weapon-grade uranium was made in North Korea at a production-scale plant.
- This assessment was not unanimous.
- Accepting this U.S. assessment implies that North Korea was operating a production-scale centrifuge plant by 2007.

Why Not Assume a Second Plant Making Weapon-Grade Uranium?

- On balance, the evidence supports the existence of two production-scale centrifuge plants.
- However, the lack of concrete evidence of the plant raises doubt about its existence. There is also uncertainty about the amount of WGU it could have made, if the plant experienced start-up and operational problems.
- Moreover, there are plausible explanations that the Yongbyon centrifuge plant is North Korea's first production-scale plant.
  - North Korea could have suffered delays caused by the difficulty of building and operating centrifuges.
  - These difficulties would have been compounded by the unexpected busting of the Khan network in 2003 and 2004, a network that North Korea may have needed to provide substantial on-going centrifuge assistance.
- Centrifuge work could have continued well into the 2000s at a pilot centrifuge plant suspected to have existed at the Panghyon Aircraft Plant, near Panghyon Airforce Base.

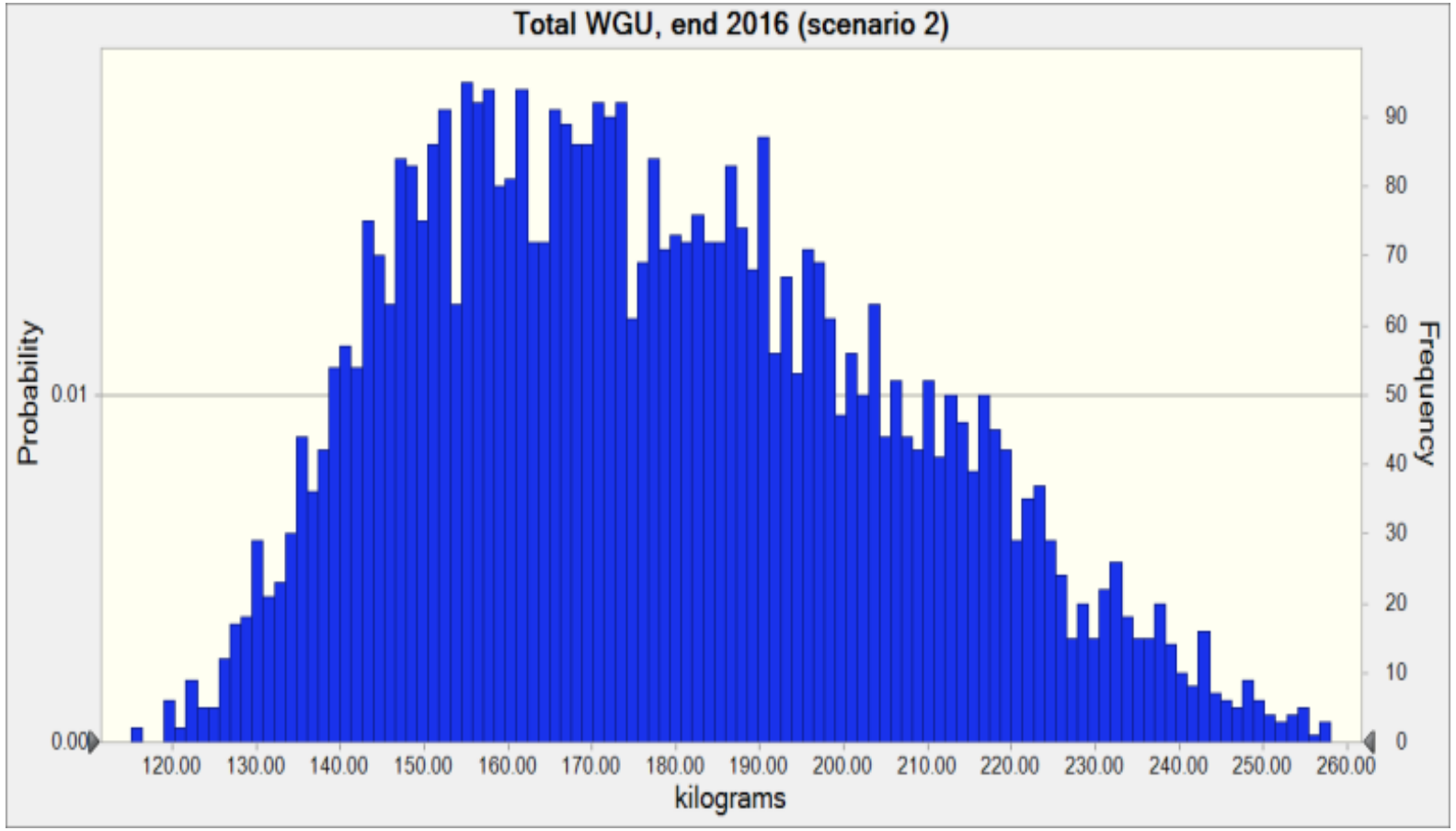
One or Two Centrifuge Plants

- On balance in terms of our estimates, we still consider that the argument has not been made sufficiently to consider only the case of North Korea having two centrifuge plants in operation, each producing significant amounts of weapon-grade uranium.
- As a result, we continue to use a range where one case considers both plants in operation, one of which is at an unknown location and the other is at Yongbyon, and the other case allows only for the operation of the Yongbyon centrifuge plant

Case 1: Yongbyon Only, Pu and WGU Production, through 2016 (5 MWe reactor, one centrifuge plant, no LWR

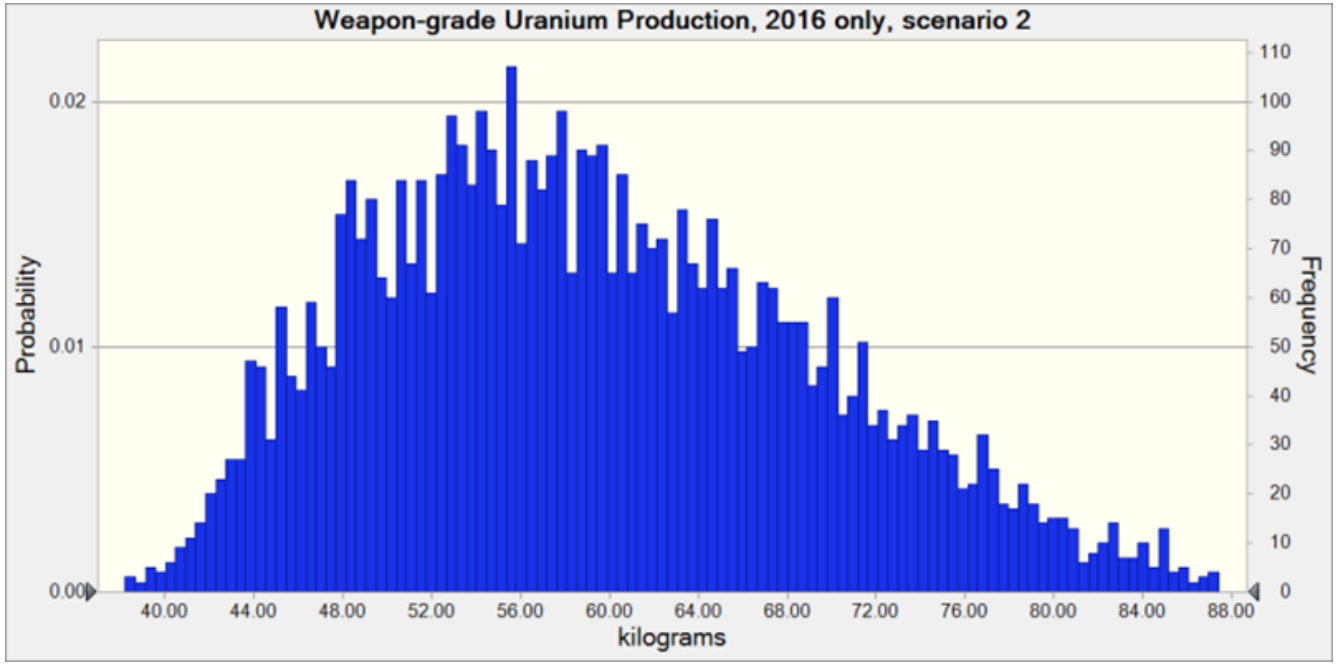
- In case 1, there is plutonium produced in the 5 MWe reactor and weapon-grade uranium produced in the Yongbyon centrifuge plant.
  - This estimate is based on the assessment that the 5 MWe reactor operated intermittently during the last few years and generated about 5.5-8 kg of separated weapon-grade plutonium in 2016, or less than 4 kg per year since it restarted in 2013 (discharge in late 2015).
  - The centrifuge plant is assumed to have operated with fairly high inefficiencies, due to difficulty of operating centrifuges in general and the use of a four-step Khan type arrangement to make weapon-grade uranium. In practice, the median outcome assumes an effective average enrichment output while in cascades for each P2 centrifuge of about 3.25 swu per year, compared to 5 swu/yr for a single centrifuge's operation.
  - The tails assay is assumed as between 0.3 and 0.4 percent.
  - The centrifuge plant is estimated to have spent three years of its early operation ramping up and producing low enriched uranium (LEU) fuel for the ELWR at Yongbyon. It subsequently shifted to weapon-grade uranium production, although the plant is assumed to have produced some more LEU after 2012 for the ELWR and the IRT reactor. The ELWR has not started and appears to have been de-emphasized or encountered difficulties, reducing its need for LEU. If the ELWR would operate, it would require LEU, which would significantly impair the ability of the Yongbyon centrifuge plant to make WGU.
  - The centrifuge plant is assumed to have 2000 centrifuges until the end of 2015 and 3000-4000 afterwards.

Estimate of Weapon-Grade Uranium Stock, Case 1, through 2016



Median: 175 kg; Standard deviation: 28.5 kg; full range: 115 to 276 kg

Annual WGU Production in Yongbyon Plant, in 2016 (3000-4000 P2 centrifuges)



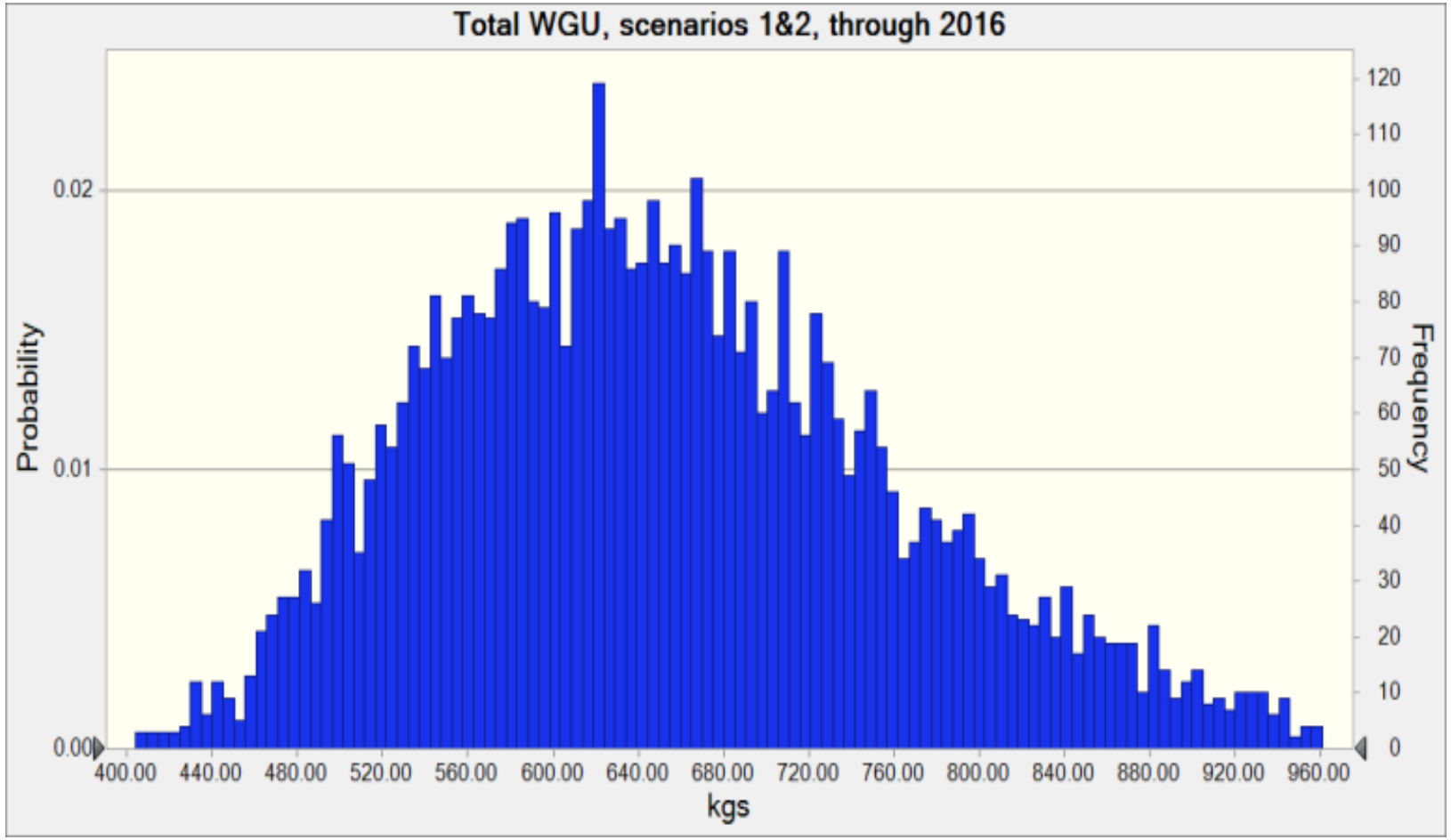
Trials	5,000
Base Case	80.00
Mean	59.38
Median	58.36
Mode	---
Standard Deviation	10.01
Variance	100.19
Skewness	0.4308
Kurtosis	2.66
Coeff. of Variation	0.1686
Minimum	38.20
Maximum	92.55
Range Width	54.35

Median: 58 kg per year; Standard deviation: 10 kg per year; full range: 38- to 93 kg per year

Case 2: Yongbyon and Secret Centrifuge Site, Plutonium and WGU Production, through 2016
(5 MWe, two centrifuge plants, and LWR possible)

- Case 2 is comprised of the same facilities as in Case 1 plus another centrifuge plant that pre-dated the Yongbyon centrifuge plant by 0-5 years, with the same assumptions about efficiency and tails assay.
- The second plant is assumed to have 3000-4000 P2 centrifuges and encountered the same inefficiencies as the Yongbyon centrifuge plant. Its startup is taken as sometime between 2005 and 2010. The main difference in this case is that the secret centrifuge plant is estimated to have produced WGU for several more years than the one at Yongbyon and to have somewhat more centrifuges.
- Under case 2, there is enough enrichment capacity to produce significant amounts of WGU and sufficient LEU for the LWR.

Estimate of Weapon-Grade Uranium Stock, Case 2, through 2016



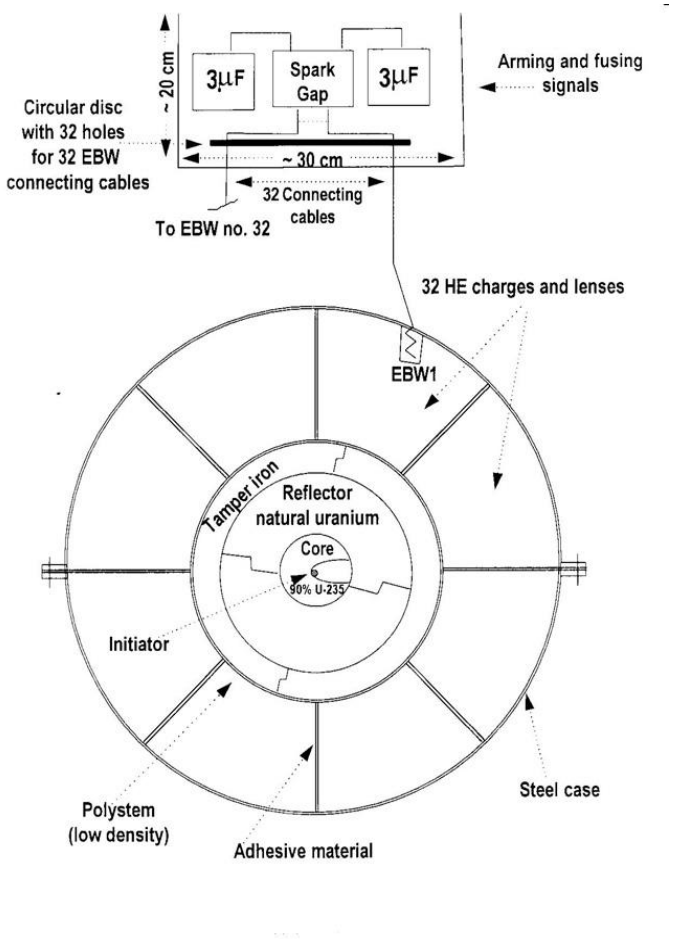
Median: 644 kg; standard deviation: 110 kg; full range: 404 to 1071 kg

Assumptions about Material in Nuclear Weapons

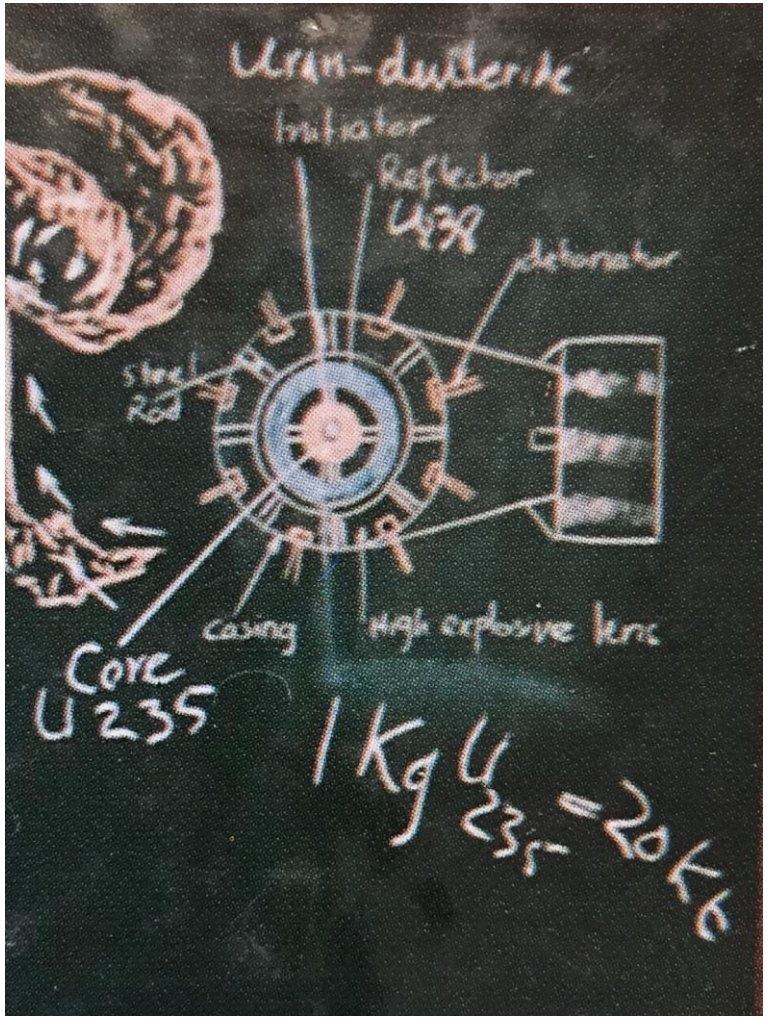
- The basic estimate of the number of nuclear weapons equivalent is calculated by assuming each weapon contains either plutonium or weapon-grade uranium. Ranges of possible values of plutonium or weapon-grade uranium are then used to estimate a number of weapons-equivalent.
- An assumption is made that only 70 percent of the plutonium or weapon-grade uranium ends up in nuclear weapons.
- For plutonium, the assumed range is lognormal with a minimum of 2 kg, a median of 3.5 kg, and a standard deviation of 0.6 kg, which means that 68 percent of all values are between 2.9 and 4.1 kg. Most estimates put the value at 4 kg, but lower values are selected here.
- For weapon-grade uranium, the range is assumed to be 15-25 kilograms, uniformly distributed (see next slide). In this case, the larger values assume that miniaturization is achieved by increasing the mass of weapon-grade uranium, as was done by the Chinese in the design given to Pakistan in the early 1980s. The lower value is from a declared Iraqi design from about 1990.

Examples of Implosion FissionDesigns

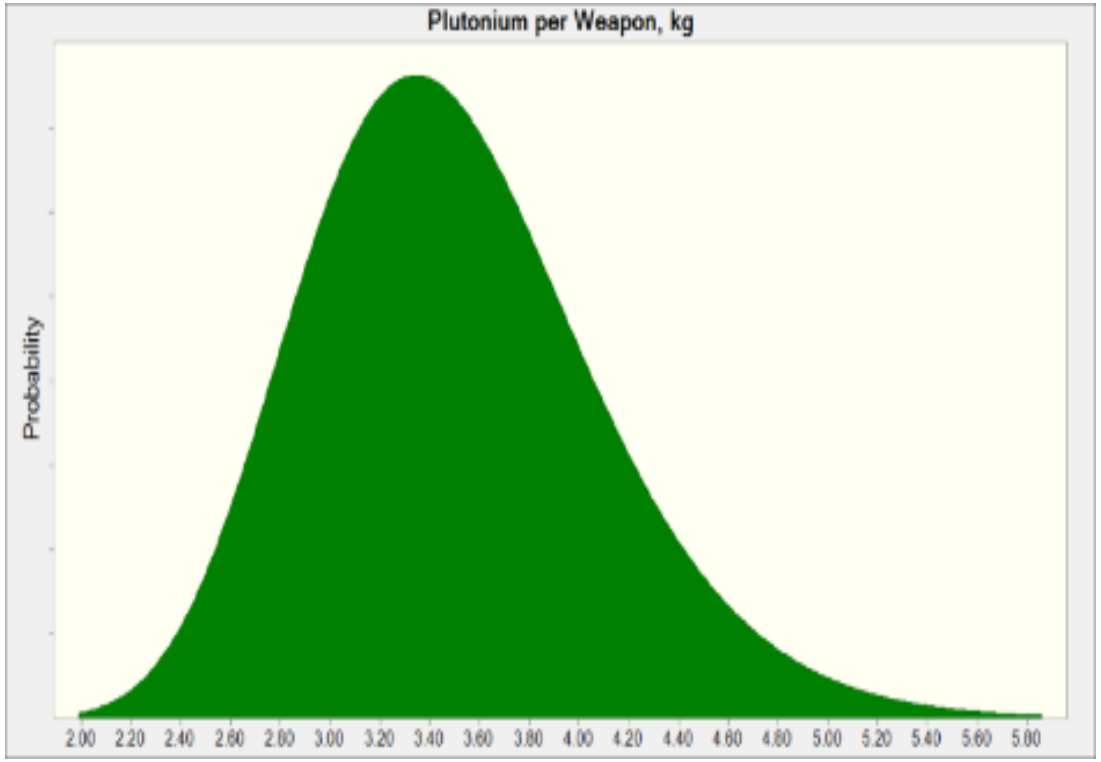
Iraqi

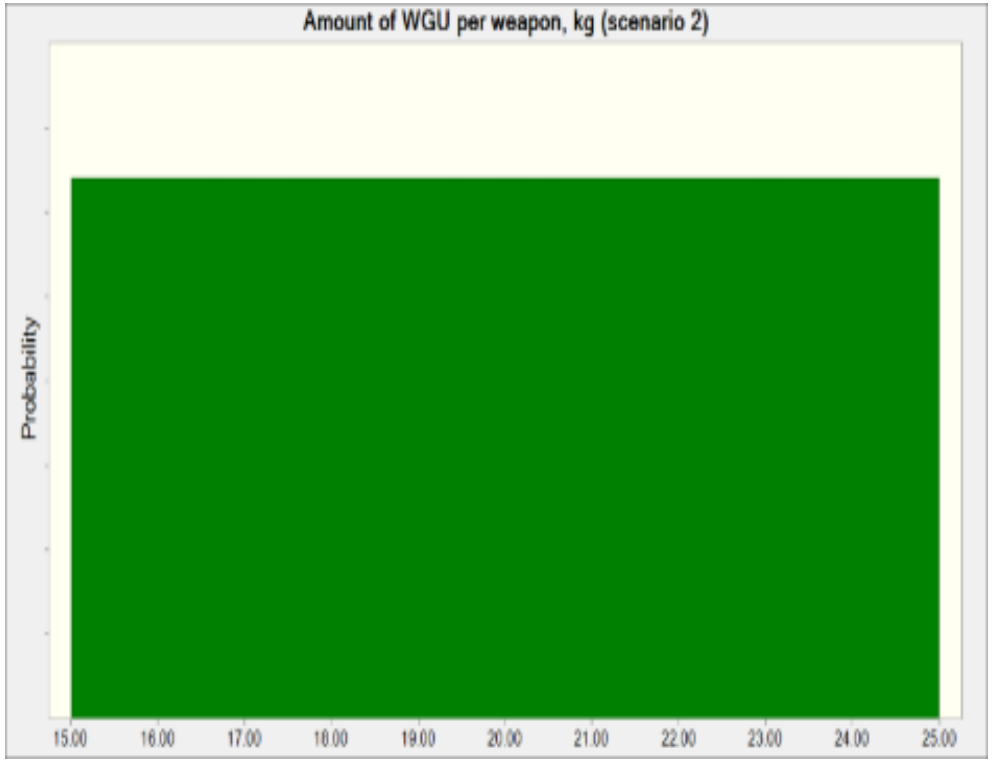


Pakistani

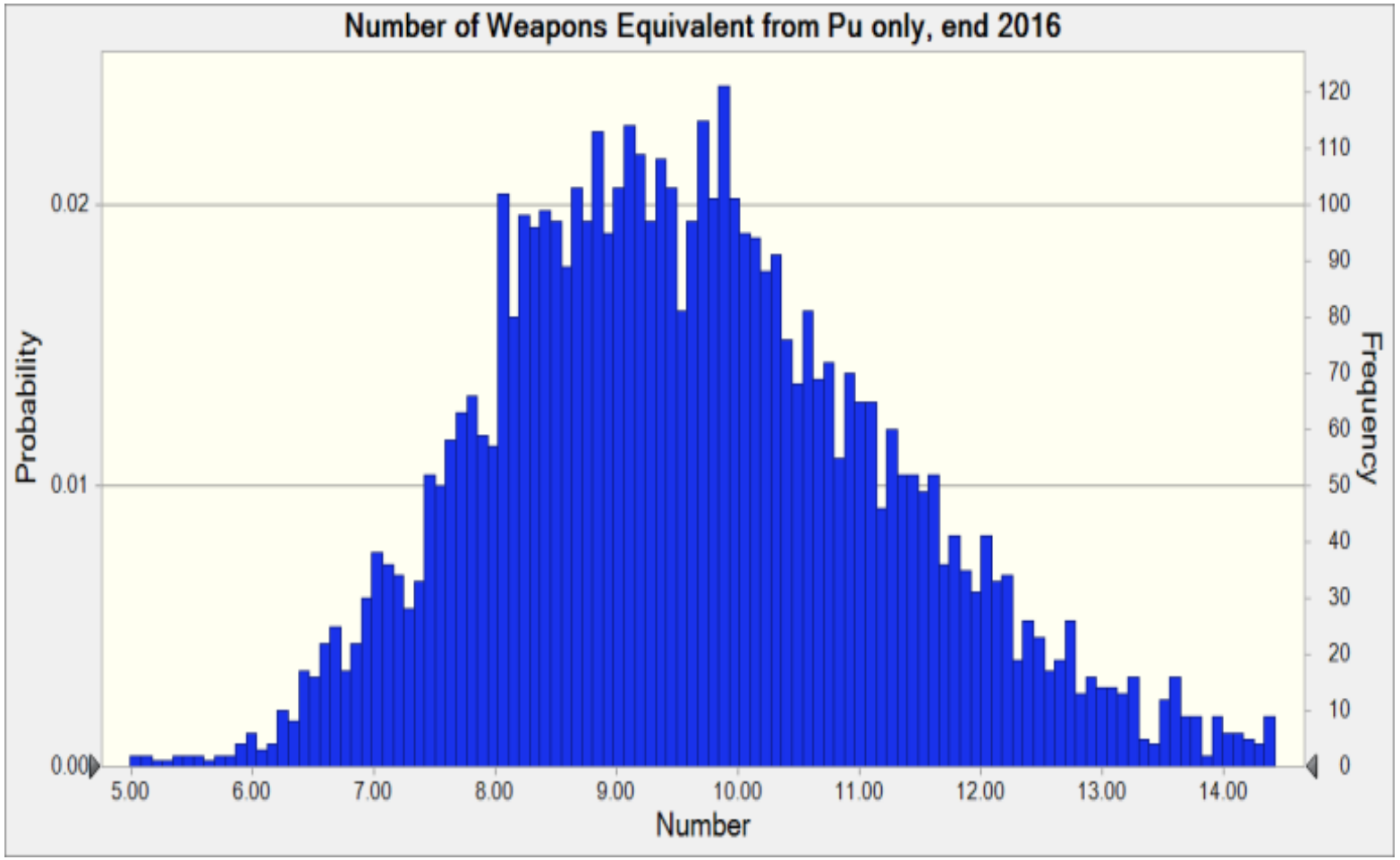


Assumed Distributions of Plutonium and WGU per weapon



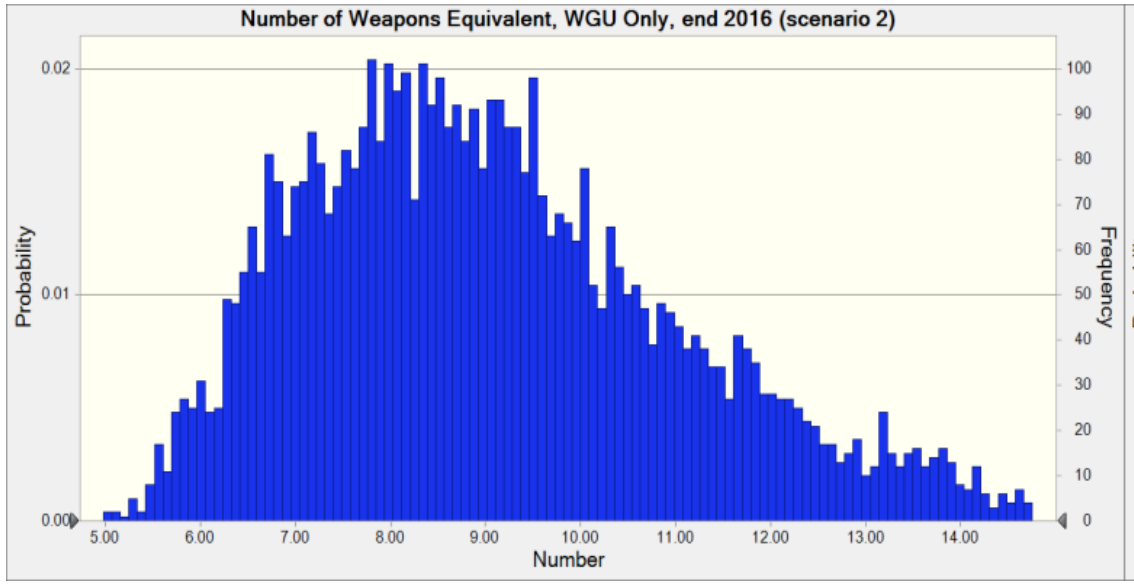


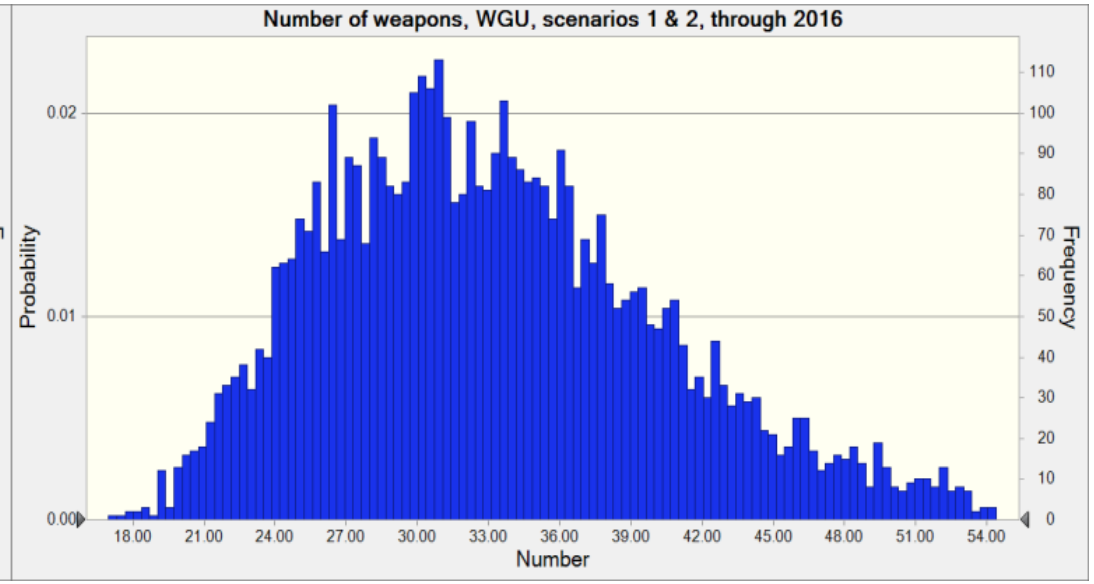
Results: Number of Weapons Equivalent from Plutonium, end 2016



Median: 9.5 weapons eq.; standard deviation: 1.7; full range: 5 to 17

Results: Number of Weapons Equivalent from WGU, Case 1 and Case 2, end 2016

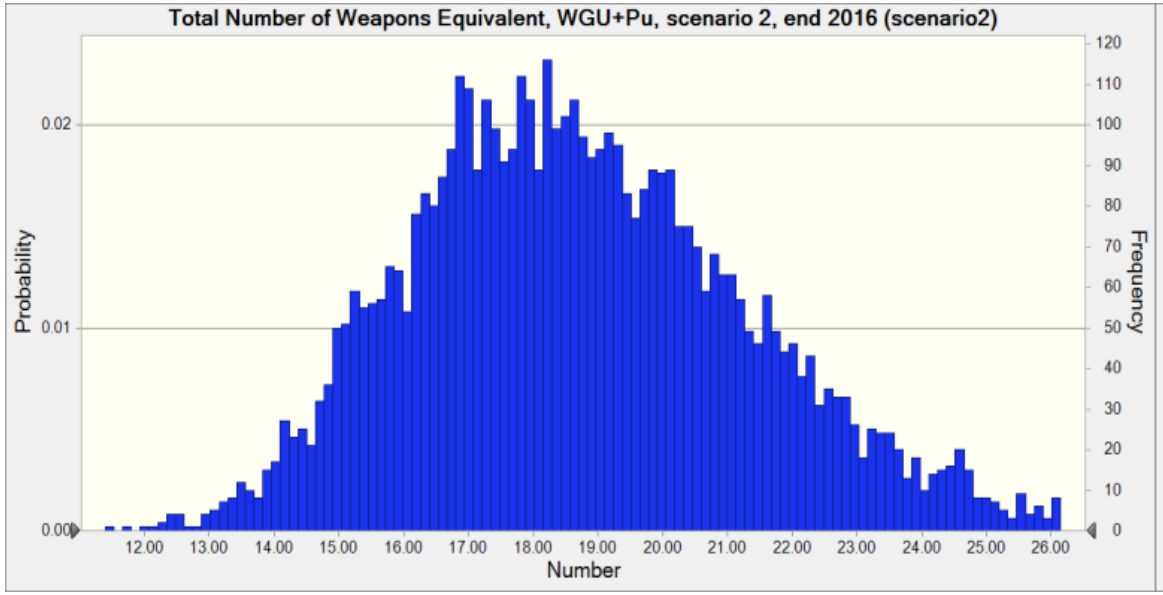


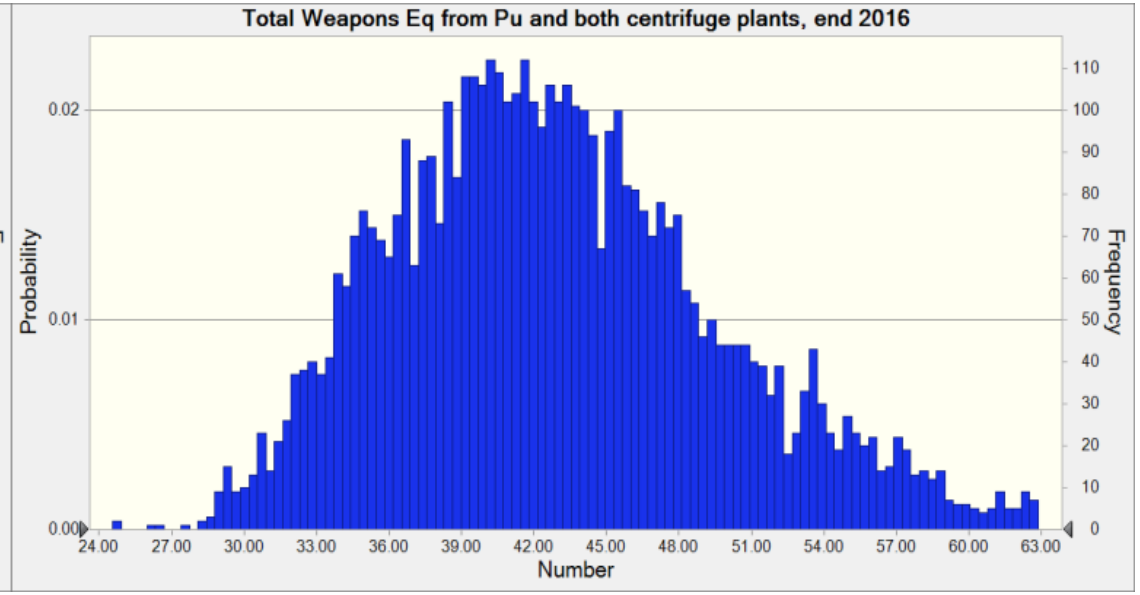


Case 1
Median: 8.83 weapons eq.; standard deviation: 2.0
Full range: 5 to 17 weapons equivalent

Case 2
Median: 32.5 weapons eq.; standard deviation: 7.5
Full range 17 to 65

Results: Number of Weapons Equivalent from Pu and WGU, Case 1 and Case 2, end 2016





Case 1
Median: 18.5 weapons eq.; standard deviation: 2.6
Full range: 11 to 30 weapons eq.

Case 2
Median: 42.33 weapons eq.; standard deviation: 7.1
Full range: 25 to 75 weapons eq.

Nuclear Weapons vs. Nuclear Weapons Equivalent

- The actual number of nuclear weapons would be expected to be fewer in number than given by the above nuclear weapons equivalent values;
- A fraction of the plutonium or WGU would be tied up in the manufacturing complex that makes nuclear weapons components or would be lost during such processing;
- Some of this material would be expected to be held in a reserve for underground nuclear testing or new types of weapons;
- In these estimates, it is assumed that **only 70 percent** of the total amount of plutonium or WGU is used in nuclear weapons.

Plutonium, Weapon-Grade Uranium (WGU), and Nuclear Weapons Stocks, through 2016, medians only(a)

Case	Mass(kgs)		# Weapons-Equivalent			Weapons (70% FM)		
	Pu	WGU	Pu	WGU	Total(b)	Pu	WGU	Total
5 MWe reactor and One centrifuge plant (scenario 2)	33	175	9.5	8.8	18	6.7	6.2	13
5 MWe reactor and Two centrifuge Plants (scenarios 1 & 2)	33	645	9.5	32.5	42	6.7	22.8	30
Composite cores (2 kg plutonium per core; rest WGU):					16.6			11.6

Comments

(a) Each nuclear weapon is assumed to contain either plutonium or weapon-grade uranium
(b) Values do not add due to nature of statistical analysis and rounding

Estimate through 2016

- A straightforward interpretation of the calculations is to use the median values of the estimates through 2016
  - 33 kg Plutonium
  - 175-645 kg Weapon-Grade Uranium
  - 13 to 30 nuclear weapons
  - Alternatively, up to 12 nuclear weapons using a composite core of plutonium and weapon-grade uranium (see below).
  - Thirty percent of the plutonium and weapon-grade uranium is in production pipelines, lost during processing, or in a reserve.

Projections through 2020

- The same basic approach is used to project the estimates through 2020.
- The number of centrifuges in each plant stays the same, as does their relative inefficiency. A rationale for not adding centrifuges or increasing efficiencies is to account for the greater sanctions that are expected to limit North Korea's imports of critical equipment and materials, including spare parts.
- Plutonium production in the 5MWe reactor is assumed to remain the same, at about 2-4 kg per year.
- In a new worst case estimate, leading to three estimates, it is assumed that the ELWR starts operating 2018, producing weapon-grade plutonium.

Projected Plutonium, Weapon-Grade Uranium (WGU), and Nuclear Weapons Production, through 2020, medians only(a)

Case	Mass		Weapons-Equivalent			Weapons (70% FM)		
	Pu	**WGU**	**Pu**	**WGU**	**Total(b)**	**Pu**	**WGU**	**Total**
5 MWe reactor, one Centrifuge plant (scenario 2)	48	409	13.8	20.8	35	9.7	14.5	**24**
5 MWe reactor two Centrifuge plants (scenarios 1 & 2)	48	1120	13.8	56.4	70	9.7	39.5	**49**
5 Mwe reactor, two Centrifuge plants, and LWR (scenarios 1 & 2)	91.8	1120	26.5	56.4	83	18.5	39.5	**58**
Composite cores (2 kg plutonium per core; rest WGU)								
No LWR					24.			17
LWR					46			32

Comments

(a) For ease of projections, no further nuclear tests are assumed. If there are further tests, these numbers will need to be reduced.

(b) Values do not add precisely because of nature of statistical calculation and rounding

What do these nuclear weapon estimates mean?

- They are certainly rough in nature.
- The range of the medians at end of 2016 is 13-30 nuclear weapons, with a growth of about 2.8-4.75 weapons per year.
- This range in the medians can be interpreted as approximating the actual number of nuclear weapons that could be built by North Korea or will be built in the near term.
- I resist using only case 2 and the upper bound, i.e. concluding that there are two centrifuge plants, preferring the range as a more reasonable estimate of the total number of weapons.
- Through 2020, North Korea is assessed as having enough plutonium and weapon-grade uranium for about 25-50 (rounded) nuclear weapons. A worst case, involving the operation of the Experimental Light Water Reactor, is that it would have enough plutonium and weapon-grade uranium for up to 60 nuclear weapons by the end of 2020.
- I would like to discuss another estimate of the number of weapons, before turning to a discussion of thermonuclear weapons and other advanced nuclear weapons.

Composite Cores of Plutonium and Weapon-Grade Uranium

- A more advanced use of plutonium and weapon-grade uranium in nuclear weapons may involve combining them into what are often called composite cores, where for example the plutonium is at the center and the weapon-grade uranium in a shell around the plutonium.
- North Korea appears to face a plutonium shortage, potentially motivating composite cores.
- Composite cores would allow for greater explosive yields and allow for the development of thermonuclear weapons.
- Its September 2016 test suggests that it was seeking to learn to use either plutonium or weapon grade uranium or both in nuclear weapons (see next slide).

North Korean Declaration After September 2016 Nuclear Test

The standardization of the nuclear warhead will enable the D.P.R.K. to produce at will and as many as it wants a **variety of smaller, lighter and diversified nuclear warheads of higher strike power** with a firm hold on the technology for producing and **using various fissile materials**. This has definitely put on a higher level the D.P.R.K.'s technology of mounting nuclear warheads on ballistic rockets.

-- "DPRK Succeeds in Nuclear Warhead Explosion Test," KCNA, September 9, 2016.

Unclassified Data on Composite Cores

- In general, such information is classified but there have been some relevant declassifications of composite fission weapons from the 1950s, albeit fairly sophisticated designs.
- Russian data from a 1953 fission test are available
  - RDS-4 device, 28 kt, 5th test **4.2 kg Pu** **6.8 kg WGU (90%)**
- British data are available for a small, tactical weapon and a boosted fission primary of the 1950s:
  - Wee Gwen,* <1 kt, unboosted **1.6 kg Pu** **2.42 kg uranium 235 in WGU**
  - Tony, 2-10 kt, primary, boosted **2.25 kg Pu** **1.4 kg uranium 235 in WGU**
  - It should be noted that the British obtained the original designs of these systems from the United States.

*Wee Gwen was a small, lightweight, low yield unboosted composite core fission warhead intended for a British Army version of the US Davy Crockett close support infantry weapon.

Wee Gwen and its Variations

(From http://www.nuclear-weapons.info/vw.htm#W-54)

Davy Crockett vehicle-mounted weapon with the W-54 warhead, identical to Wee Gwen. Photo: NAM, Alburquerque, NM.

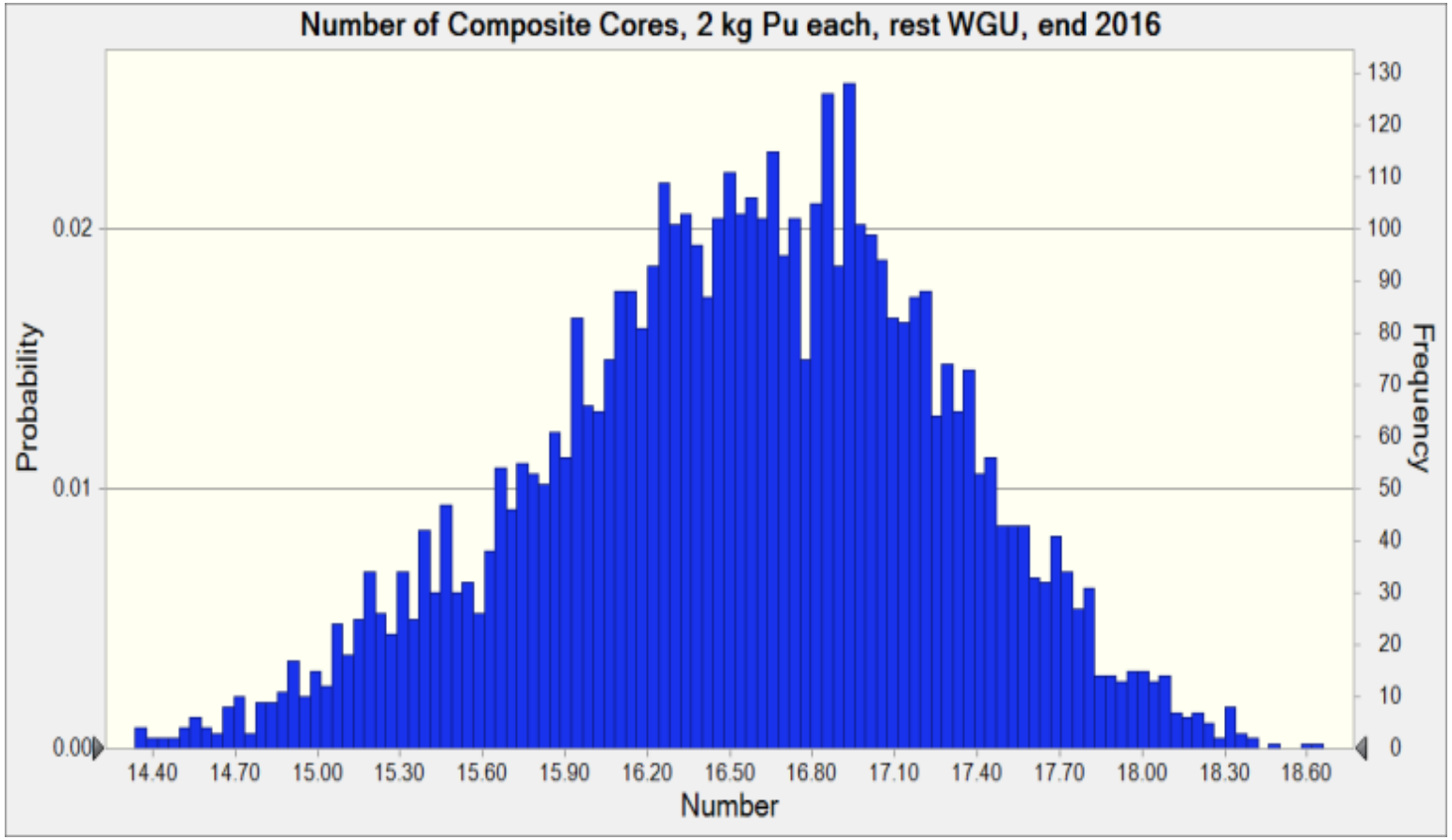
Little Feller nuclear test of a W-54 warhead identical to Wee Gwen. Photo: NAM, Alburquerque, NM.

A W-54 Wee Gnat warhead identical to the British Wee Gwen warhead packaged in its carry-bag. Photo: US Army.

Composite Cores of Plutonium and Weapon-Grade Uranium

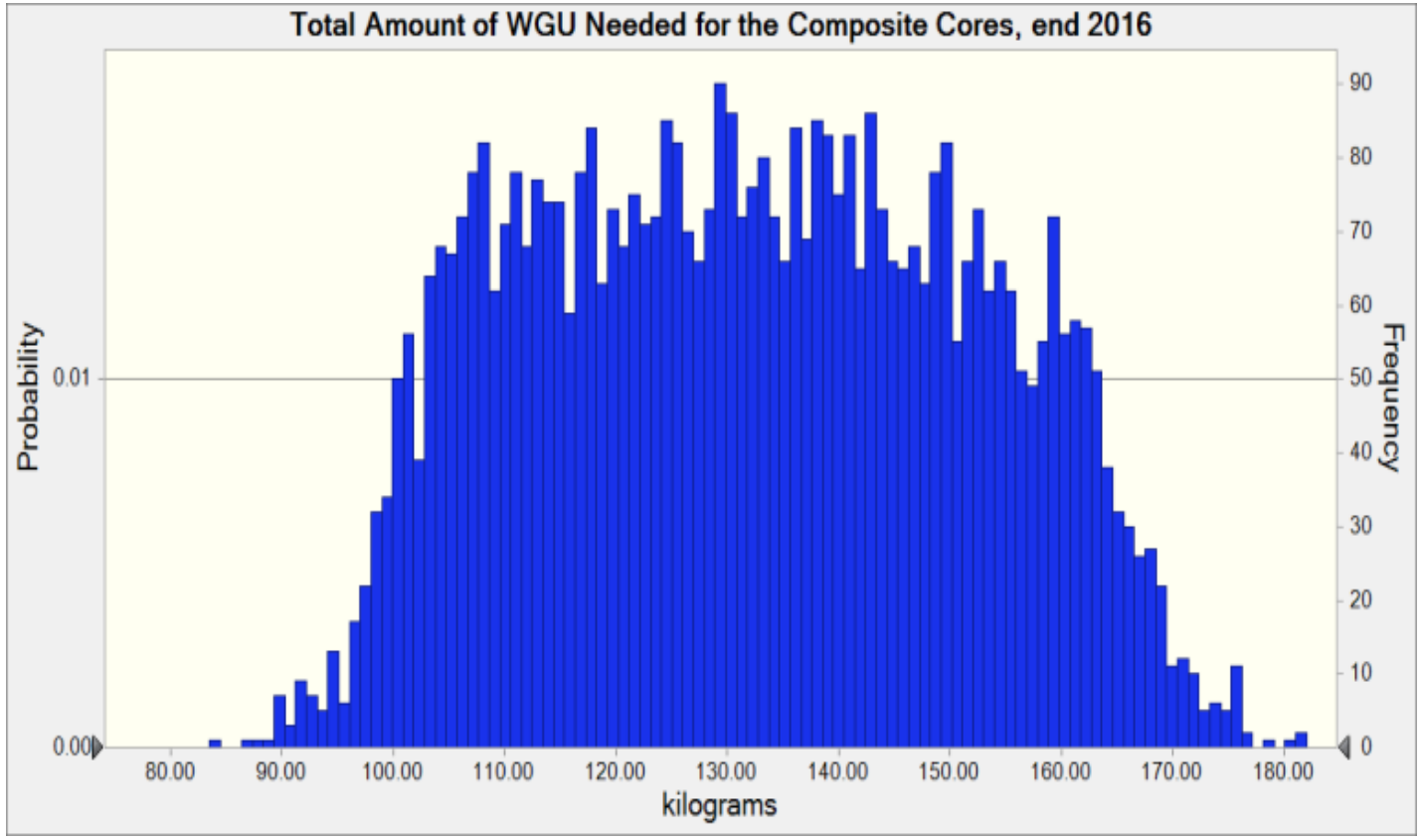
- One simple model of a composite core in the case of North Korea would be to assume that each weapon contains 2 kg of weapon-grade plutonium. Here is the emphasis would be on a greater yield.
- It is unknown how much WGU would be needed to ensure that the device would work and achieve a yield of about 10 kt, but we assume a high-sided value of 6-10 kg of WGU per device would be sufficient.
- A composite design thus contains 2 kg of plutonium and 6-10 kg of WGU
- This design should be easier to miniaturize and still achieve yields in range of at least 10 kilotons.

Number of Composite Cores, Pu=2kg, Weapon-Equivalent



Median: 16.6; standard deviation: 0.8; full range: 11.6 to 18.7

Composite Cores: Weapon-Grade Uranium Requirements (6-10 kg per weapon)



	Forecast values
Trials	5,000
Base Case	173.75
Mean	131.98
Median	131.71
Mode	---
Standard Deviation	19.72
Variance	388.89
Skewness	0.0593
Kurtosis	2.04
Coeff. of Variation	0.1494
Minimum	73.14
Maximum	181.97

Median: 132 kg; standard deviation: 20 kg; full range: 73 to 182

Number of Composite Cores

- If the 70 percent assumption is applied, then the median number becomes 11.6 nuclear weapons, vs. a median of 6.7 plutonium-based weapons in the previous estimate.
- To this estimate of 11.6 weapons, one would need to add any fission weapons built with only WGU.
- In the lower bound, i.e. one centrifuge plant, there may not be enough WGU for all of the composite core devices, let alone additional devices made from weapon-grade uranium only.
- As of the end of 2020, it could have enough nuclear explosive material for up to 17-32 nuclear weapons using a composite core of plutonium and weapon-grade uranium.

Findings: Plutonium and WGU Stocks Provide Flexibility to North Korea's Weapons Options

- North Korea's numbers of weapons, based on fissile material estimates, are relatively large and growing.
- North Korea keeps secret the number of nuclear weapons that it has built, and there is little, if any, reliable public information about this value. The range of 13-30 nuclear weapons as of the end of 2016, based on the estimates of North Korea's production and use of plutonium and WGU, is an assessment.
- North Korea is assessed as having enough plutonium and weapon-grade uranium for many crude fission weapons and several composite cores weapons.
- Continued testing would provide opportunities to improve its weapons in terms of less fissile material (plutonium) per weapon, increased miniaturization, and greater explosive yields.
- Developing thermonuclear weapons, which can achieve all three above goals, is a declared priority. It appears capable of doing so, as will be discussed later.

Making Militarily Useful Nuclear Weapons

- Miniaturization is assessed as being done for the Nodong missile for a plutonium-only weapon. It makes sense to give North Korea credit for being able to miniaturize other warheads but it may experience problems as it seeks to use composite cores or thermonuclear materials. As a result, nuclear warhead miniaturization efforts likely continue.
- Other weaponization issues probably continue to be under development, i.e. reliability, safety, and security of nuclear weapons.
- These issues are affected by the types of delivery; longer range missiles need nuclear warheads that are more robust.

Fitting Warheads to Nuclear Weapons Delivery Systems

- **Aircraft dropped bombs**: unknown if exist but likely able to design
- **Nodong missile**: miniaturized, plutonium-based likely; unknown if could build miniaturized fission only composite core design but possible
- **Medium range missile**, land-based, warhead unknown
- **Intermediate range missile**, land-based, warhead unknown
- **ICBM**, land based, warhead unknown
- **Sea-launched missile**, medium range, warhead unknown
- **Tactical nuclear weapons**, such as backpack bombs and land mines; speculative if exist or planned

These delivery systems would likely entail different nuclear weapons designs and combinations of plutonium and weapon-grade uranium. A thermonuclear warhead is probably being developed for some of these systems.

Improving its Core Compression Capabilities: Another Way of Minimizing Plutonium Use

- North Korea has an incentive to minimize the amount of plutonium it needs per warhead.
- The discussion on composite cores suggests one way to do that, e.g. substitute WGU.
- Another way to reduce the amount in a weapon is to improve the compression of the core or include thermonuclear materials to increase the efficiency of the fissioning of the plutonium.
- North Korea stated its 2006 test used 2 kg of plutonium; a statement met with great skepticism. However, can North Korea successfully field a device with 2 kg of plutonium and no weapon-grade uranium?
- Others have early in their program
  - In 1953 (sixth test?), Russia exploded a RDS-5 device with 2 kg of plutonium, achieving a yield of about 5.8 kt. It is unknown if this was a pure fission device.
  - In 1953, Russia exploded another RDS-5 device with 0.8 kg of plutonium, achieving a yield of about 1.6 kt. It is unknown if this was a pure fission device.
- Russia was undoubtedly far better at achieving high compressions than North Korea.
- But on-going testing would allow North Korea to improve in its ability to compress a core of fissile material.
- A side benefit of seeking less plutonium per weapon could also be learning to use less high explosives per weapon.

Thermonuclear Weapons

North Korea's January 2016 Thermonuclear Bomb Declaration

- North Korea called it a thermonuclear test
- What should one make of the January 6, 2016 test?
- Seismic data did not reveal a large explosion, e.g. estimates of roughly 15 kilotons.
- However, the test was detonated at about double the depth of the 2013 test:
  - Roughly 700-800 meters below a mountain peak in 2016 vs. about 350 meters in 2013.
  - This would imply that North Korea expected a larger yield.
- Would it bluff, e.g. just dig a longer, deeper tunnel? Maybe. Or North Korea may have been using the available space in the mountain.
- So far, I know of no data from radioactive releases that could shed light on the nature of test.
- Nonetheless, it is reasonable to conclude that North Korea detonated some type of thermonuclear device. But not successfully.

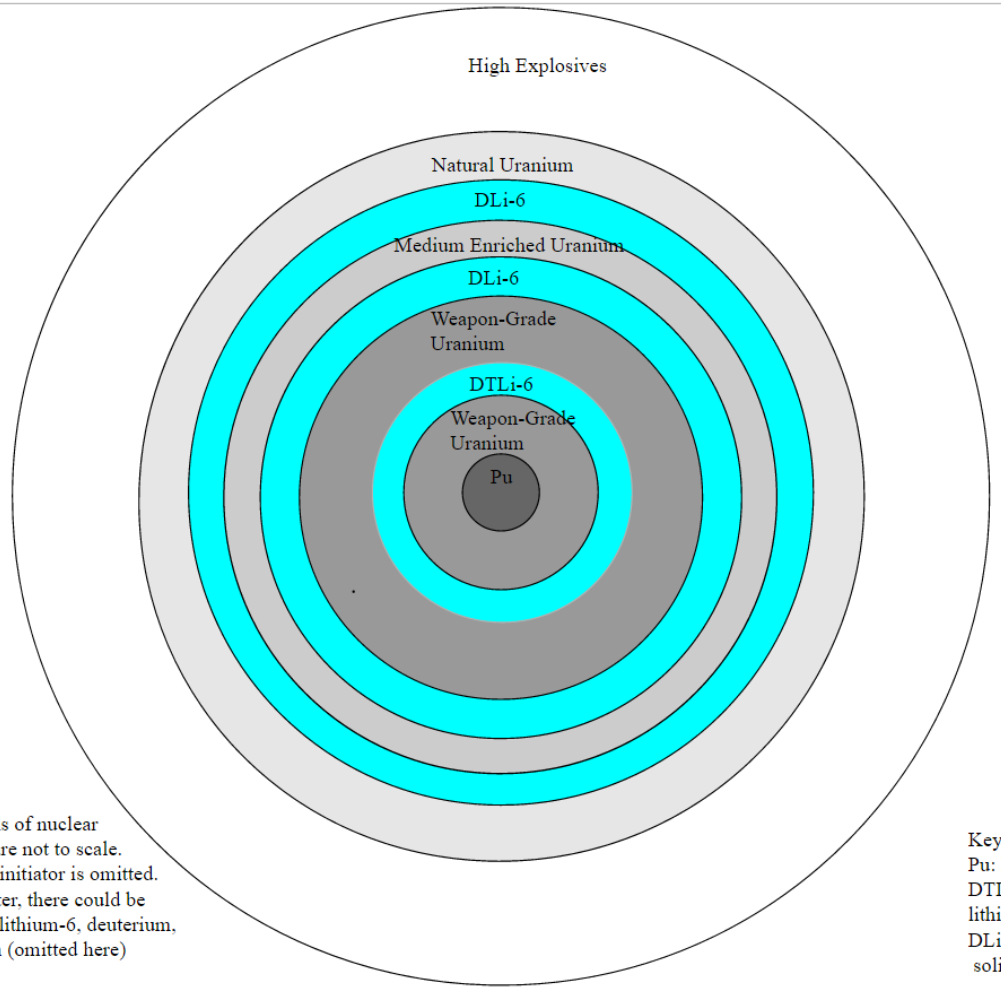
Thermonuclear Materials

- For several years, evidence has accumulated that North Korea was producing or procuring materials needed to make thermonuclear weapons.
- It is assessed as having established a domestic capability to make lithium 6.
- Expressed interest in deuterium.
- Constructed a new Isotope Separation plant at Yongbyon that could separate tritium produced in 5 MWe reactor or in the IRT.
  - 5 grams per year of tritium production in 5 MWe would displace roughly 360 grams of weapon-grade plutonium and need about 5 kg of lithium 6 in about 40 percent enriched lithium aluminum targets.

What Type of Thermonuclear Device? Consider Unclassified Examples

- An H bomb, which is generally considered to be a two-stage fission-fusion (plus fission) device, is highly sophisticated and capable of achieving 1000s of kilotons.
- U.S. type of boosted fission device with tritium/deuterium gas injected into the center of the device. Fusion induced by fission creates neutrons which fission much more of the fissile material, boosting the total yield significantly.
- South Africa worked on a boosted-type device with a lithium-deuterium-tritium tablet at the center of an fission device with a goal to achieve a device with 60-100 kilotons.
- One-stage thermonuclear warhead, sometimes called a layer cake, alarm clock, or onion design. One model is a plutonium core and weapon-grade uranium shells interspersed with lithium 6-deuteride (-tritium) shells.
  - A British one-stage thermonuclear device tested in mid-1950s with a plutonium core had 100 kg of weapon-grade uranium in shells and achieved several hundred kilotons.
  - Russia's 4th test on August 12, 1953 was of the RDS-6s, which was a one-stage thermonuclear device that achieved a yield of 400 kt. It subsequently was weaponized (see image below).

Illustrative Concept of a One-Stage Thermonuclear Weapon



Note: shells of nuclear materials are not to scale.
A neutron initiator is omitted.
At the center, there could be a tablet of lithium-6, deuterium, and tritium (omitted here)

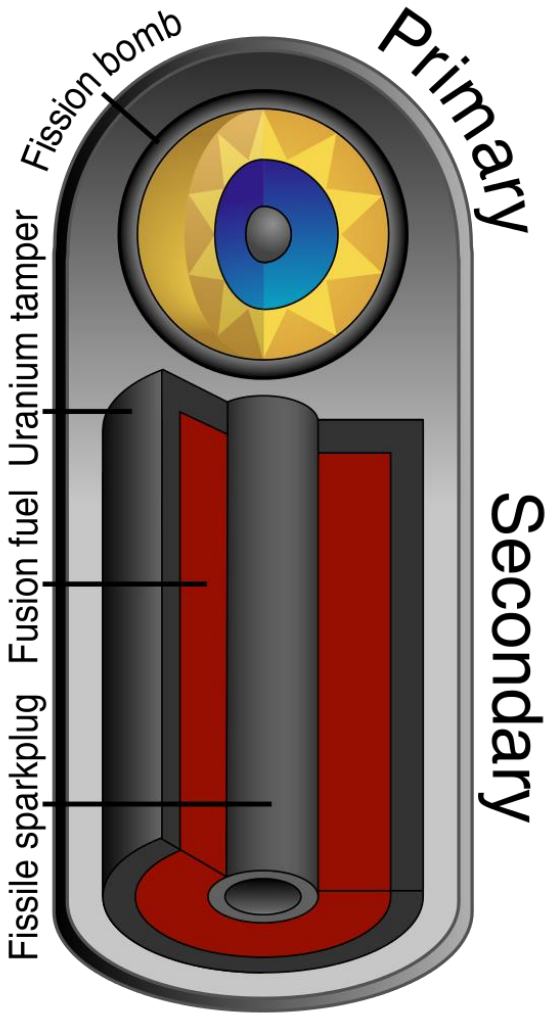
Key:
Pu: Plutonium
DTLi-6: deuterium, tritium, lithium-6 solid
DLi-6: deuterium, lithium-6 solid (lithium deuteride)

The Sloika, or “layer cake:” Soviet Union’s first thermonuclear air-dropped weapon, similar in size to U.S. Fat Man but with yield of 400 kilotons. (Courtesy of the Russian Federal Nuclear Center, VNIIEF; From *Physics Today*.)

Two Stage Thermonuclear Weapon Schematic,

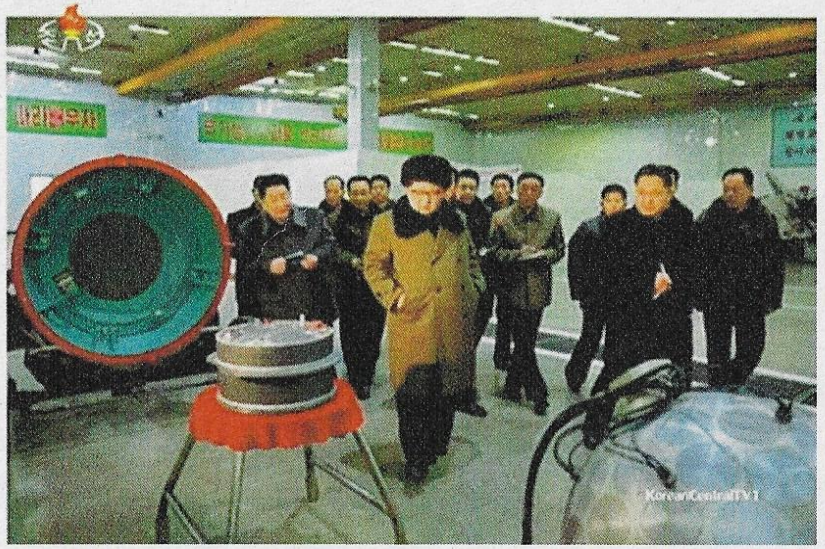
showing primary fission weapon, secondary, which in this case includes a uranium final stage

(Source: Public Domain, https://commons.wikimedia.org/w/index.php?curid=487863)



Assessment

- We tend to discount the first two types, namely two-stage thermonuclear and U.S.-style boosted weapon, as beyond North Korea's capabilities for some time.
- The third type, or one-stage designs, involves many subtypes of varying difficulty, although all are complex to achieve. They allow less plutonium or weapon-grade uranium per weapon or increase the yield of a nominal fission device.
- Several types of one-stage designs are judged as within North Korea's capability.



Nuclear Warhead Image, With Kim Jong Un

- Stated in photo caption to be a thermonuclear weapon.
- Estimated diameter is 60-70 cm, so it would not fit on the Nodong missile, the current version of which has a nose cone requiring a warhead diameter of about 55 centimeters.
- The purpose of the hole with a flange is subject to a great deal of speculation-a hoisting flange? An entrance for an external neutron initiator to initiate the chain reaction? For injecting tritium-deuterium gas for boosting. Based on the bottom left photo, the flange may be to attach the warhead to the reentry vehicle.
- Car battery nearby, which should remind us that this object may not represent an actual nuclear warhead.

Summary of Findings on Fissile Material and Nuclear Weapons

- See handout, *North Korea's Nuclear Capabilities, A Fresh Look"*

Outfitting its Nuclear Efforts from Abroad

DPRK Continues Seeking Goods Abroad for its Nuclear Programs

- The North Korean government directs highly organized and centralized illicit trade efforts to outfit its nuclear programs;
  - The government also uses North Korean government officials stationed at embassies to conduct illicit procurement related business and it recruits private companies to obtain goods.
- North Korea has established entities abroad under its control that seek goods. It also uses North Korean expatriates who own private companies abroad;
- In the past, North Korean government entities have cooperated closely with other governments, such as Pakistan, that have been willing to provide training or needed goods and sensitive technologies;
- It is active in China and Hong Kong seeking goods for its nuclear programs;
  - North Korean entities contract with private Chinese and Hong Kong trading companies and sometimes manufacturing companies to acquire these goods, either from Chinese suppliers or subsidiaries of Western or Japanese suppliers in China.

On-Going Procurements for North Korea's Centrifuge Program

- The operation and expansion of North Korea's gas centrifuge program has depended on importing sensitive goods and technologies from abroad.
- Evidence supports that North Korea is still importing sensitive goods and technologies for its gas centrifuge program, while benefiting from earlier procurements obtained abroad.
- North Korea is **not able** to make all the key materials and equipment needed to make gas centrifuges and build and operate a gas centrifuge plant.
- Certainly, North Korea can make centrifuge components domestically and would be expected to be seeking independence from foreign supply. But **there is a wide range of materials and equipment that North Korea must import** in order to produce these components and then make and operate centrifuge plant(s).
- Bottom line: North Korea is not producing indigenously all the major components, materials, and equipment for its centrifuge program.

North Korean Illicit, Foreign Procurements for Centrifuges
(non-Pakistani supply)

- **Materials**: Aluminum tubes (low strength for outer casings), ring magnets for use in a centrifuge upper bearing, epoxy resins used in assembling centrifuge parts (sold commercially as Araldite), raw materials and additive alloys;
- **Vacuum Equipment:** A range of equipment important to operating centrifuges individually or in cascades, such as vacuum pumps, valves, specialized uranium hexafluoride resistant oils. Also pressure transducers, which are used to measure the vacuum pressure in individual centrifuges and cascades;
- **Other Equipment:** Uranium hexafluoride cylinders, uranium hexafluoride flow meter, He leak detectors, and whole frequency converters and their key subcomponents, implying that North Korea assembles frequency converters from subcomponents purchased abroad. Also computerized control equipment, including software and updates, used to run a plant composed of centrifuge cascades. (The equipment is the same as that acquired by Iran to control its centrifuges.)
- **Manufacturing Equipment:** Flow-forming machine usable to make centrifuge rotors. an electron beam welder for centrifuge assembly, equipment to make ring magnets. State-of-the-art computer numerically controlled (CNC) machines for making centrifuge parts, and measuring equipment;
- **Spare parts** for centrifuge-related equipment.

North Korean Illicit Foreign Procurements for the 5 MWe Reactor

- During the last several years, North Korea has procured goods for its 5 MWe reactor and spent considerable funds on this endeavor;
- The intention appears to be the restoration and upgrading of the aged reactor;
- In China, it procured carbon dioxide blowers for the primary cooling system, a Japanese emergency generator, and Sulzers water pumps for the secondary cooling system
- North Korea also procured aluminum-magnesium powder for making cladding of fuel for this reactor.

Example: Lithium 6 Enrichment Plant

- Most likely site is at the Hungnam Fertilizer Complex, near Hamhung on North Korea's east coast. This site is involved in ammonia processing, fertilizer production, and other chemical processing.
- Evidence of location is primarily procurement related, although this type of complex would be a logical choice for such a plant.
- Very difficult to locate the site visually via commercial satellite images or ground photos of the site. There are numerous ground photos of the site, particularly because Kim Jong Il visited the site in the late 2000s, which help narrow the possiblities.
- Procurement evidence includes a 2012 North Korean contract to arrange the purchase of a wide range of industrial and lab-scale equipment and materials abroad in China. The purpose of the contract is not included but the list of goods implies they are for a lithium 6 enrichment plant using mercury-based lithium exchange. The contract had handwritten notes stating that the goods were needed urgently and the procurements involved the Hamhung complex.
- What was procured? Most of the procurements were for industrial-scale equipment. Included in the order was metric tonne quantities of mercury and tens of kilograms of lithium hydroxide.
- The Plant appears based on the U.S. COLEX process. This process needs electrolytical cells, which are already located in the Hamhung fertilizer plant.
- Procurements/construction started in about 2012.

Shenyang Machine Tools Company

http://isis-online.org/isis-reports/detail/shenyang-machine-tools-company

- Shenyang Machine Tools Company, headquartered in northeast China, allegedly supplied sophisticated 6-axis machine tools to North Korea containing controlled subcomponents. The subcomponents were provided by a European company under the condition that they would not be re-exported.
- This company imports a range of subcomponents from major Western supplier nations. It sells its machine tools in China and globally, including in Europe and the United States.
- Government officials gathered evidence that at least two 6-axis machine tools, containing controlled, imported subcomponents, were exported to North Korea in about 2015 without authorization from the supplier country, a requirement of the original supply of the goods.
- Although Shenyang company officials have stated that the exports were inadvertent, other evidence suggests that the company did know about the end destination of the controlled goods being North Korea.
- The Chinese government refused to cooperate with a foreign criminal investigation to determine the actual situation, backing the company's claim that the exports were inadvertent or uncontrolled re-exports.
- As a result, legal options to investigate the company's exports are limited.
- However, we have recommended that this company should be considered a candidate for U.S. sanctions. In addition, the United States should take other measures to ensure that U.S. companies' and other suppliers' goods are not re-exported to North Korea, in part by obtaining verified assurances from Chinese companies.

Successes and Opportunities

- Procurements from abroad allow for the detection and characterization of North Korea's expanding nuclear programs;
- Export controls, sanctions, and interdictions remain important tools to slow down North Korea's nuclear programs and better characterize them;
- Policies based on more effectively thwarting North Korean procurements remain fruitful and have great potential for becoming more effective;
- Procurements can provide useful baseline information for future efforts to verify denuclearization.
- Lack of Chinese action against illicit procurement has stimulated efforts to find ways to press them to better enforce their export control laws, e.g. applying secondary sanctions to Chinese companies and banks engaged in illicit trade with North Korea.
- Trump administration actions?