Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

How many nuclear weapons does North Korea have?

Or, what is a nuclear weapon?

Matthias Englert, Öko-Institut e.V.

9.3.2018

Right Questions

How much fissile material does North Korea have?

How much fissile material is needed in a nuclear weapon?

Which type of nuclear weapon are we talking about?

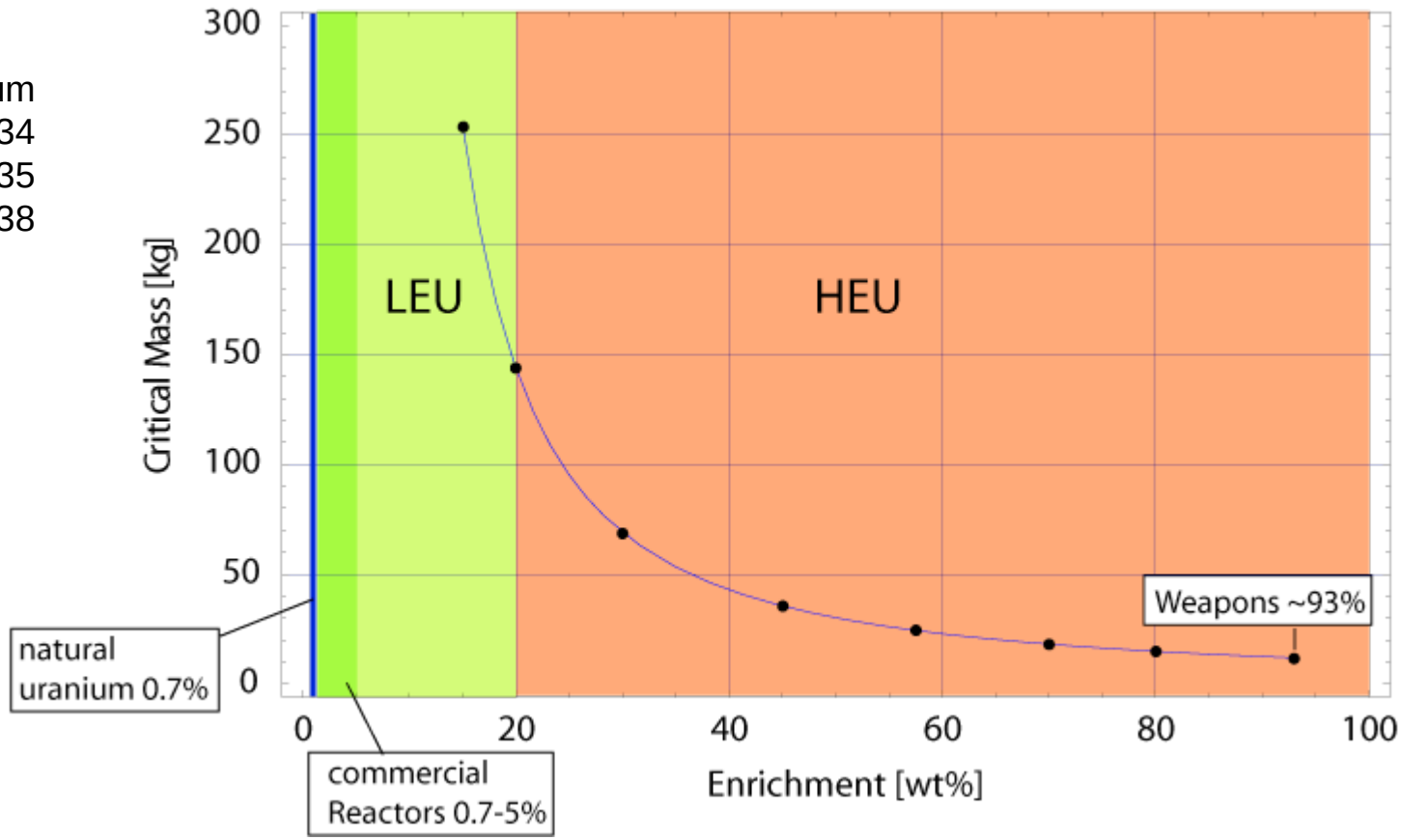
Is the nuclear device weaponized and if so, how is it delivered?

How much fissile material does North Korea have?

The Uranium Path to the Bomb
Enrichment and Weapon Capability

Increasing content of uranium Isotope U235

nat uranium
0.0055% U234
0.72% U235
99.2745% U238



Calculated critical mass for a beryllium-reflected sphere (MCNPX, ENDF/B-VII, 15 cm, 300K, 19.05 g/cc)

2010 Sig Hecker Surprises the World
North Korean Enrichment Plant Disclosed

Sig Hecker reports about his visit to North Korean Enrichment Plant at a press conference at the Center for International Security and Cooperation (CISAC), Stanford University.

Sig Hecker is a former director of the Los Alamos National Laboratory and was invited several times to visit North Korea with a US-delegation.

Source: Associated Press

Details of the disclosed centrifuge facility

Construction to fuel LWR, 3.5% enriched.

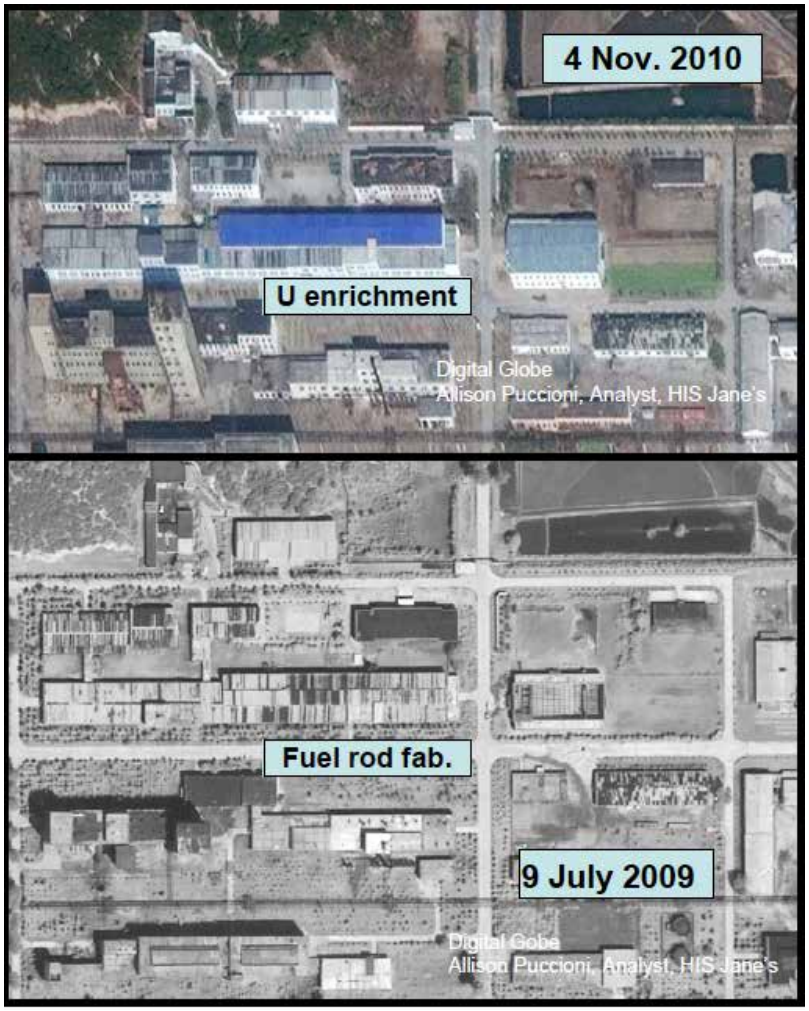
Construction April 2009 - Nov. 2010

Building 120 x 18 m

2000 centrifuges
6 ft high
8 in diameter
Steel rotors
Sep. Capacity of plant 8000 kg SWU/y
2.3 t 3.5% LEU from 15.3 t nat. U
41 kg 90% HEU from 9 t nat. U
112 kg 90 % HEU from 3.1 t 3.5% LEU

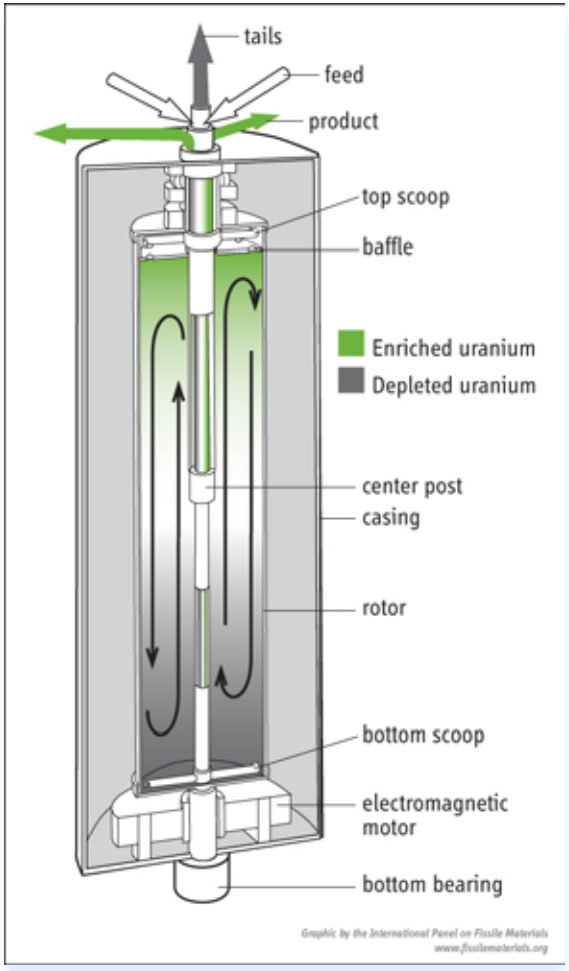
LEU output fits specs for planned LWR

Modern Control Room



Hecker, S. (2020), North Korea's Yongbyon Nuclear Complex: A Report by Siegfried S. Hecke, CISAC 2010.

The Centrifuge



Left Picture: Presentation Mohammed Saeidi http://www.world-nuclear.org/
Right Picture: www.ipfm.org

Centrifuge Separative Capacity

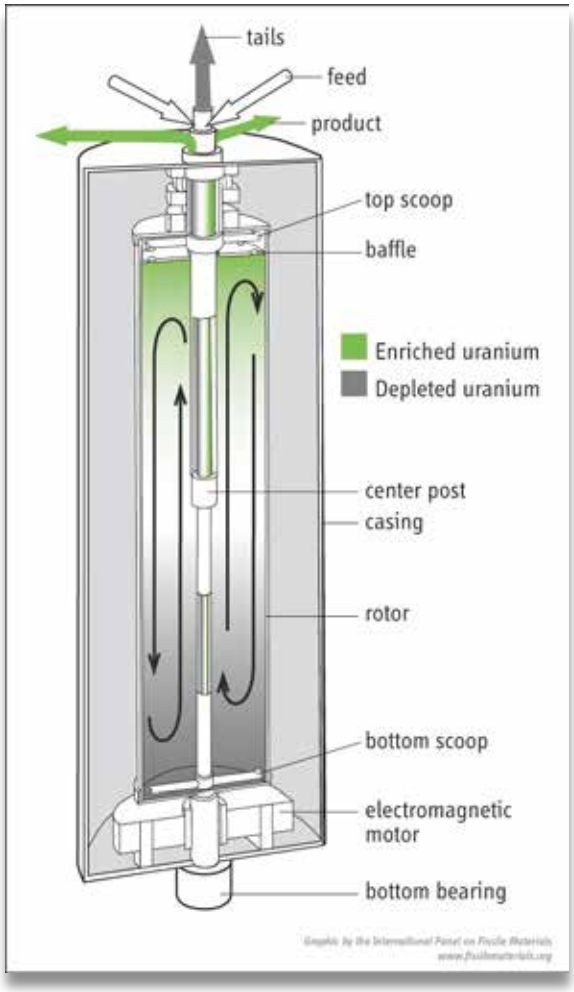
SWU: Separative Work Units
(kg SWU/year)

$$\delta U_{max} = \frac{\pi}{2} L D \rho \left(\frac{\Delta M v^2}{2RT}\right)^2$$

$$\delta U = V(N_p)P + V(N_w)W - V(N_F)F$$

Value Function

$$V(N) = (2N-1)ln\left(\frac{N}{(1-N)}\right)$$



www.ipfm.org

Right picture: www.ipfm.org

Some Centrifuges

Name	Material	D [cm]	L [m]	V [m/s]	δU [kg-SWU/y]
Zippe	Aluminum	7.4	0.3	350	0.44
Early Urenco	Aluminum	10	2	350	2-3
North Korea	Steel	20?	1,5-1,8	<450	4
G2	Steel	15	1	450	5-6
TC-10	Carbon	15	3.2	500	21
TC12	Carbon	20	3	620	40

North Korea: P2 design. Two rotors single bellow, Grade 350 maraging steel not likely to be fabricated in NK. Grade 250 easier.
(Hecker et al. 2017)

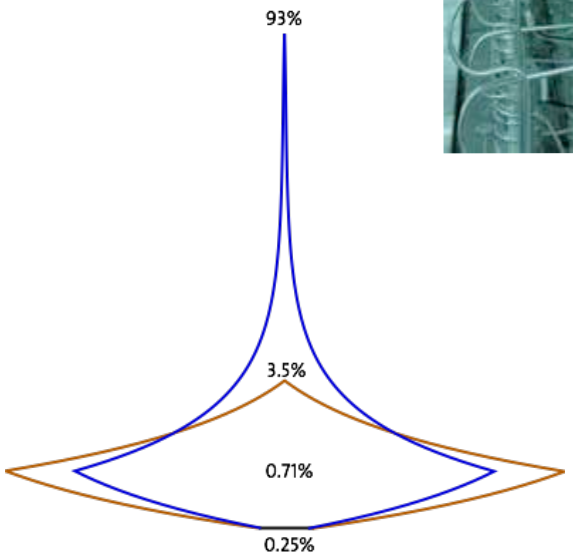
Table 3 *Maximum peripheral speeds for thin-walled cylinders*

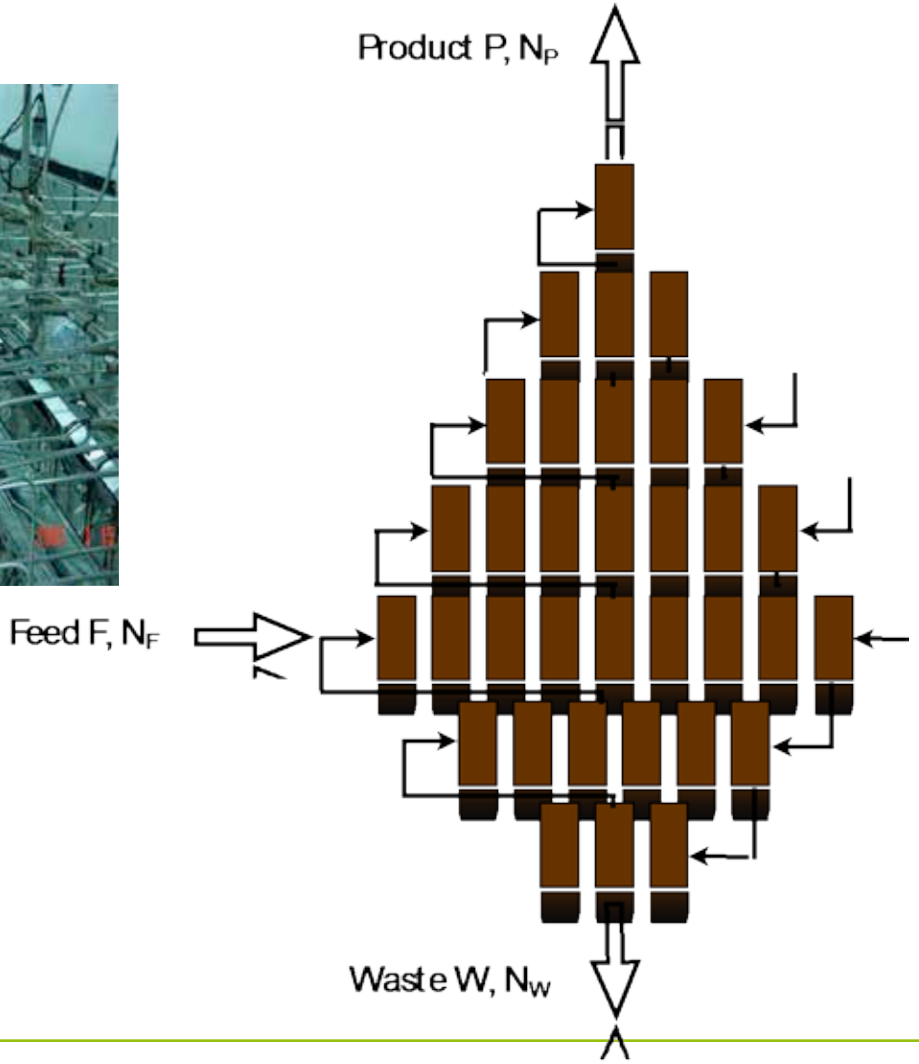
Material	*Tensile strength,* T (kg cm^{-2})	*Density* ρ (g cm^{-3})	T/ρ ($\times 10^3$)	*Approximate maximum peripheral speed* (m s^{-1})
Aluminium alloy	5 200	2·8	1·9	425
Titanium	9 200	4·6	2·0	440
High-strength steel	17 000	8·0	2·1	455
Maraging steel	22 500	8·0	2·8	525
Glass fibre/resin	7 000	1·9	3·7	600
Carbon fibre/resin	8 500	1·7	5·0	700

Siegfried Hecker and Chaim Braun, "North Korea's Stockpiles *of* Fissile Material," *Korea Observer*,. *Vol. 47*, Iss.*4*, (*Winter 2016*): *721-749*
Whitley ,Physics in Technology 1978

Importance of cascade forms

One centrifuge not enough



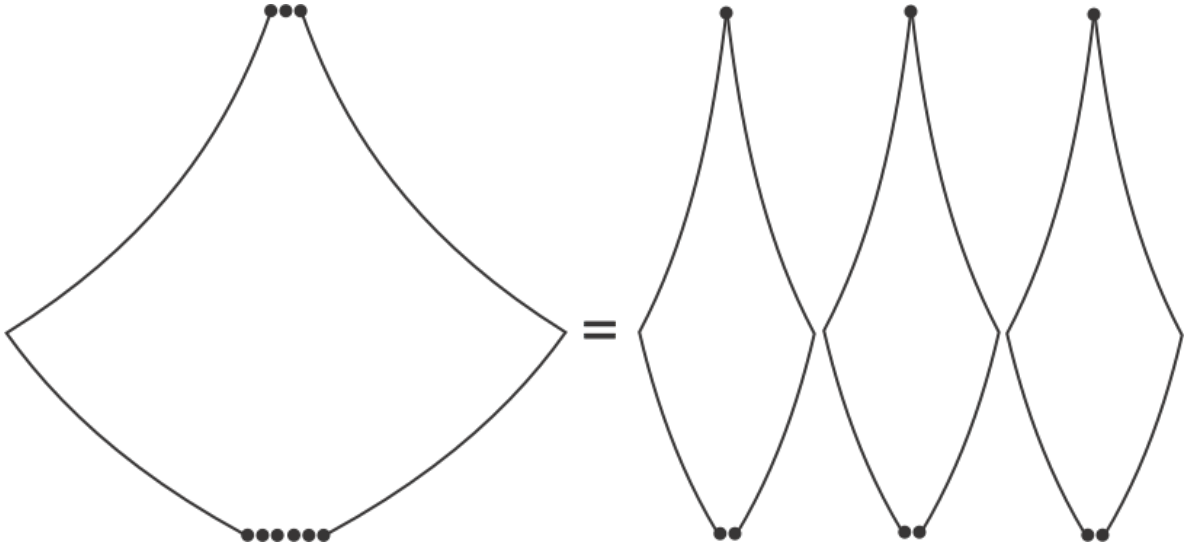


Left Pictures: Presentation Mohammed Saeidi http://www.world-nuclear.org

Cascades

North Korea: 1,8 t LEU/y 3,5% (small Reactor)
6x330 cascades. Like Pakistani layout. (Hecker et al. 2017)

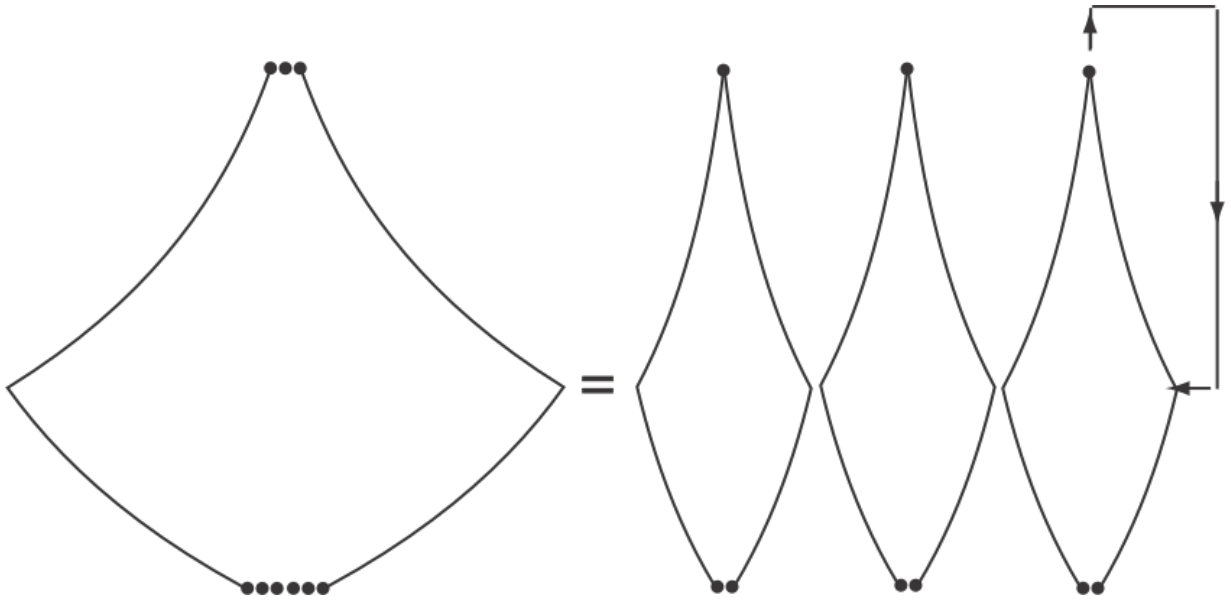
Cascade can be operated with several identical sub-cascades



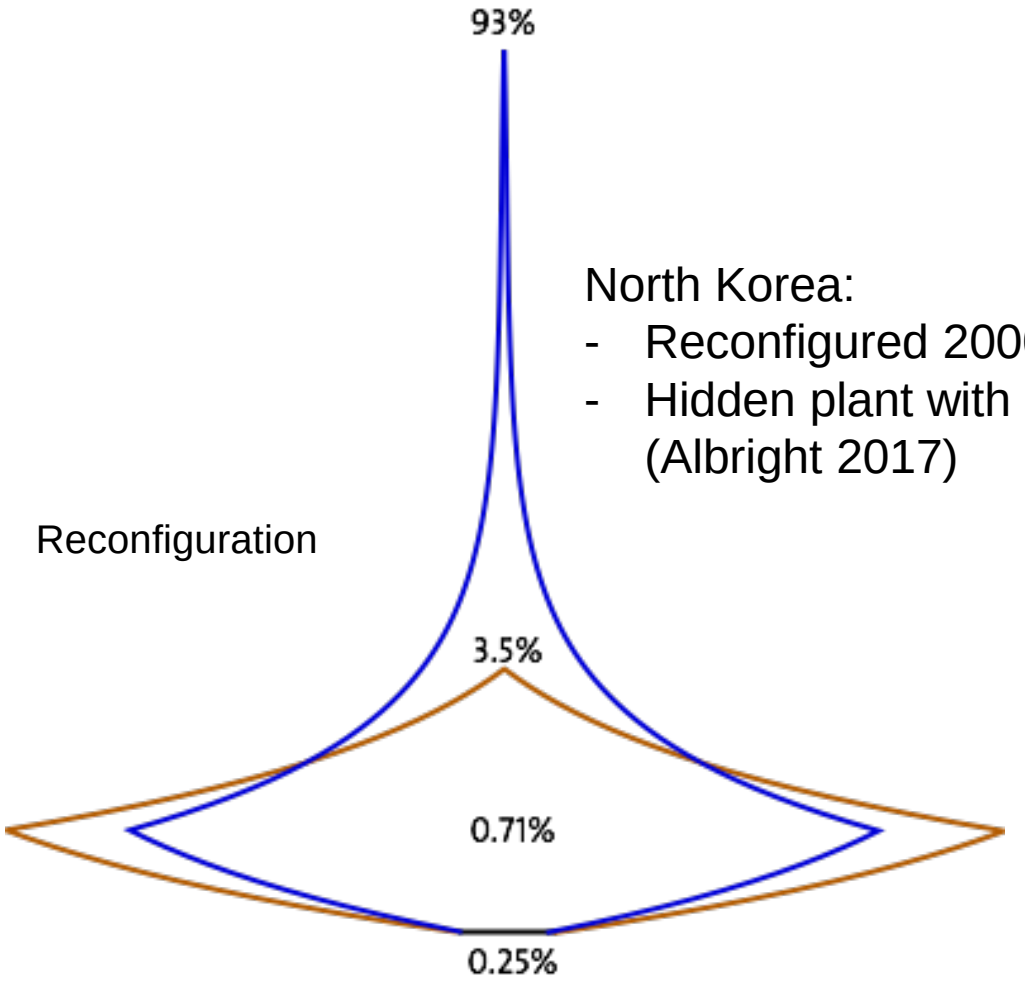
Siegfried Hecker and Chaim Braun, “North Korea's Stockpiles *of* Fissile Material,” *Korea Observer*,. *Vol*. *47*, Iss.*4*, (*Winter 2016*): *721-749*

Cascades – Batch Recycling

North Korea: unlikely to use batch recycling – very inefficient



Cascades - Reconfiguration



Reconfiguration

North Korea:

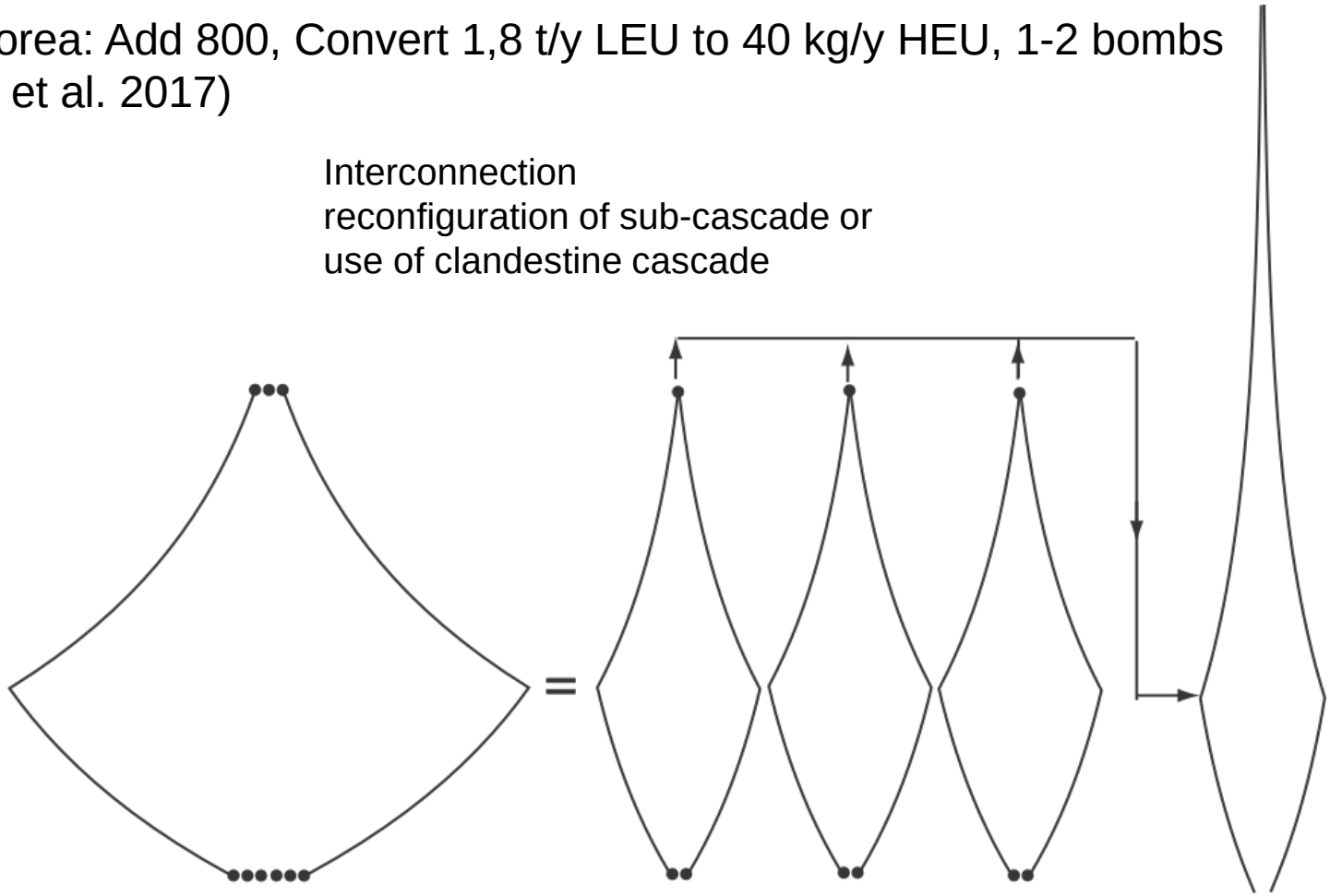
- Reconfigured 2000 centrifuges (Hecker et al. 2017)
- Hidden plant with additional 2000 centrifuges (Albright 2017)

Siegfried Hecker and Chaim Braun, “North Korea's Stockpiles *of* Fissile Material,” *Korea Observer*,. *Vol*. *47*, Iss.*4*, (*Winter 2016*): *721-749*
David Albright (2017): North Korea’s Nuclear Capabilities: A Fresh Look, presentation.

Cascades

North Korea: Add 800, Convert 1,8 t/y LEU to 40 kg/y HEU, 1-2 bombs (Hecker et al. 2017)

Interconnection
reconfiguration of sub-cascade or
use of clandestine cascade



Siegfried Hecker and Chaim Braun, “North Korea's Stockpiles *of* Fissile Material,” *Korea Observer*,. *Vol*. *47*, Iss.*4*, (*Winter 2016*): *721-749*

Some Calculations

Examples for first generation centrifuges in small facility 8000 kgSWU/y

Scenario	Feed	Waste	Centrifuges	Production per year
civil LEU quick	12.7 t nat. U	11 t (0,27%)	2000	1.7 t LEU 3,5%
civil LEU few resources	9.5 t nat U	8 t (0,2%)	2000	1,5 t LEU 3,5%
Reconfig cascade quick	8 t nat U	8 t (0,27%)	2000	38 kg HEU
Reconfig low reouces	6 t nat U	6 t (0,2%)	2000	34 kg HEU
Reconfig cascade 4x	32,2 t nat U	32,2 (0,27%)	8000	153 kg HEU
Hidden cascade full	4.7 t Reactor Fuel	4.5 (nat U)	2000	140 kg HEU
Hidden cascade topping	1.7 t Reactor Fuel	1,65 (nat U)	720	50 kg HEU
Hidden cascade quick	12,7 t Reactor Fuel	12.5 (2%)	2000	210 kg HEU

North Korean Production Estimates - SWU

Table 3. Summary of Estimates for North Korea's Enrichment Capacity

Author(s)	Assumptions	Estimated current centrifuge numbers	Estimated total enrichment capacity by 2014	Projected total enrichment capacity by 2020
Albright et al.	• Numerous technical and economic constraints (low estimate)	P-2: 2,000	8,000 kg-SWU /yr	12,000-16,000 kg-SWU /yr
	• Continuation of current trajectory; "political commitment" (medium)	P-2: N/A	8,000 kg-SWU /yr	24,000-28,000 kg-SWU /yr
	• Nuclear weapons progress is steady and successful (high estimate)	P-2: 4,000-5,000	16,000-20,000 kg-SWU /yr	48,000-58,000 kg-SWU /yr
Bistline et al.	• Constraints: procurement of maraging steel; high-strength aluminum; pivot bearings	N/A	Most likely is 35,000 kg-SWU /yr	N/A
Braun	• Known capacity is mirrored at covert production-scale plant;	P-2: 8,700	34,600 kg-SWU /yr	N/A
	• P-2 centrifuge production rate of 2,000 every 2 years	P-2: 8,000	26,660 kg-SWU / yr	34,660 kg-SWU / yr

Assumptions: SWU per Machine, machine number, cascade scheme, tails enrichment, feed material …

Siegfried Hecker and Chaim Braun, "North Korea's Stockpiles *of* Fissile Material," *Korea Observer*,. *Vol. 47*, Iss.*4*, (*Winter 2016*): *721-749*

North Korean Production Estimates - Stockpiles

Table 4. Estimates of Highly Enriched Uranium Stockpile in North Korea by 2015

Reference	HEU Stockpile by end of 2016 Annual production rates
Albright[38]	133-502 kg (1) 24-170 kg/yr by 2020
Hecker (based on Bistline et al.)[39]	300 to 450 kg (2) 150 kg/yr
Braun in Braun et al.	~200 kg (3) 100 kg/yr

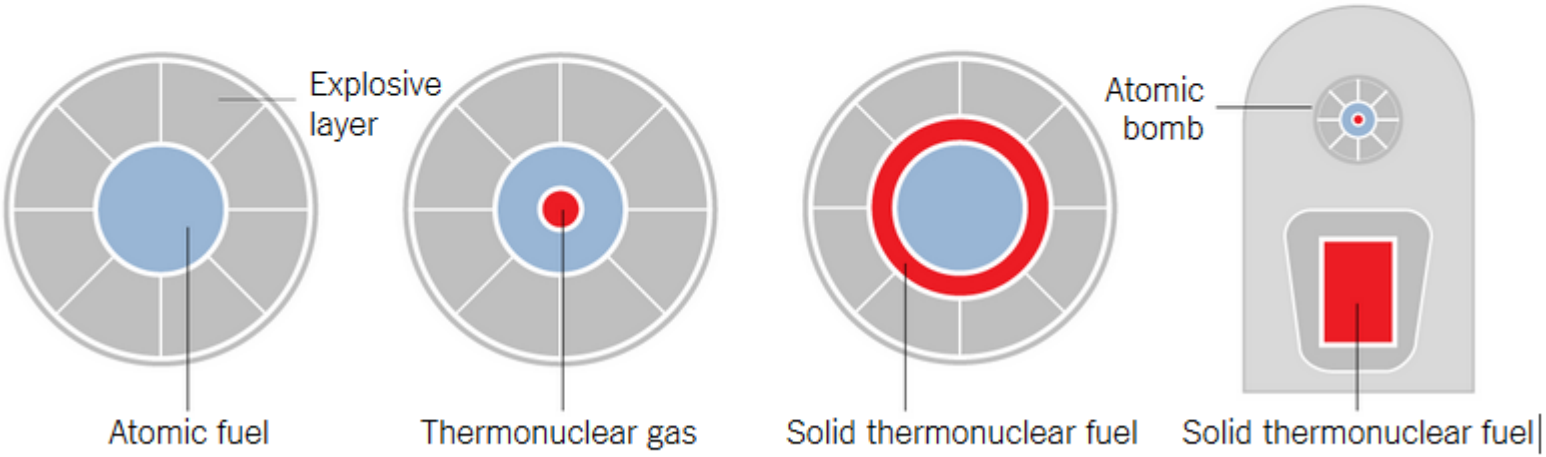
Low estimate: single plant
Middle estimate: small hidden topping cascade
High estimate: second hidden plant

Siegfried Hecker and Chaim Braun, "North Korea's Stockpiles *of* Fissile Material," *Korea Observer*,. *Vol. 47*, Iss.*4*, (*Winter 2016*): *721-749*

Which type of nuclear weapon are we talking about?

Types of Nuclear Weapons

STAGE 1	STAGE 2	STAGE 3	STAGE 4
Implosion Atomic Bomb uses conventional explosives to compress and ignite atomic fuel	**Boosted Atomic Bomb** uses a bit of thermonuclear fuel inside the atomic core	**Layered Atomic Bomb** uses more thermonuclear fuel outside the atomic core	**Hydrogen Bomb** uses lots of hydrogen fuel that the nearby atomic core ignites
1	3	25	1,000
Equal to Hiroshima			

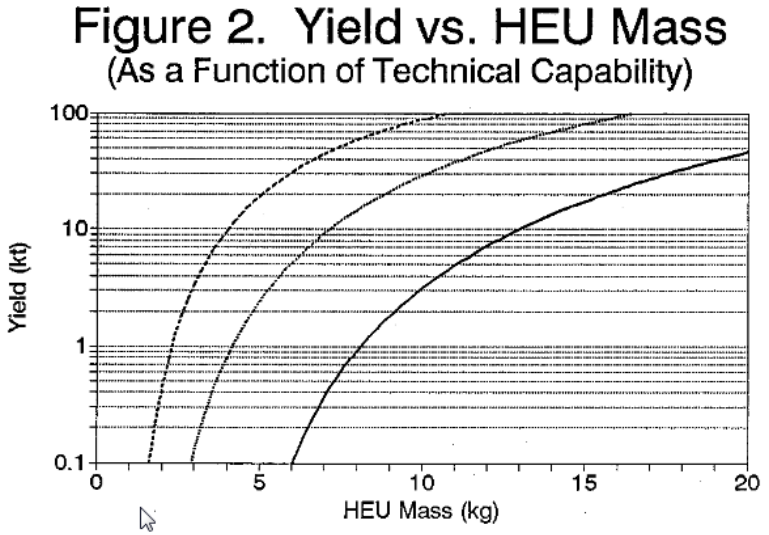


Note: Destructive power for each stage is based on early tests in the U.S. and U.S.S.R., not on current stockpiles.

By The New York Times

David E. Sanger, Choe Sang-Hung (2017), North Korean Nuclear Test Draws U.S. Warning of 'Massive Military Response', New York Times, 3.9.2017

Simple Fission Weapon – Disco Ball



Masses needed for one fission weapon (compression)

	Weapons Pu (kg)			Highly Enriched Uranium (kg)		
	Techn. Capability			Techn. Capability		
Yield (kt)	low	middle	high	low	middle	high
1	3	1.5	1	8	4	2.5
5	4	2.5	1.5	11	6	3.5
10	5	3	2	13	7	4
20	6	3.5	3	16	9	5

Thomas B. Cochran, Christopher E. Paine (1995), The amount of Plutonium and Highly-Enriched Uranium Needed for Pure Fission nuclear Weapons, NRDC.
Picture leftt: KCNA/Handout/European Pressphoto Agency, Taken from NYT, https://www.nytimes.com/interactive/2017/02/24/world/asia/north-korea-propaganda-photo.html

Simple Fission Weapon – „Disco Ball“

Or is Disco Ball already a fission-fusion design, either:
- Tritium boosted or
- Mixed-fuel (composite)

Assumption by Albrigth
2 kg of plutonium and 6-10 kg of HEU

Small Composite Designs	Yield (kt)	Weapons Pu (kg)	Highly Enriched Uranium (kg)
Russia RDS-4	28 kt	4,2	6,8
Wee Gwen unboosted composite	<1kt	1,6	2,42
Tony primary boosted	2-10 kt	2,25	1,4

Picture leftt: KCNA/Handout/European Pressphoto Agency, Taken from NYT, https://www.nytimes.com/interactive/2017/02/24/world/asia/north-korea-propaganda-photo.html
David Albright (2017): North Korea's Nuclear Capabilities: A Fresh Look, presentation.

Simple Fission Weapon – „Disco Ball“

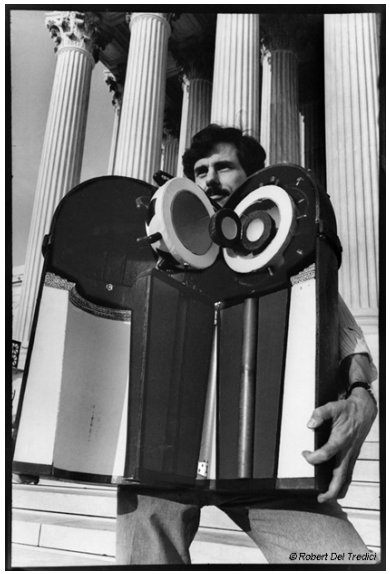
Or is Disco Ball already a Fission-fusion design, either:
- Tritium boosted or
- Mixed-fuel (composite)

Or even layered cake design (thermonuclear)

RDS-5 Russian Design
several hundred kt
fissile material unknown

Picture leftt: KCNA/Handout/European Pressphoto Agency, Taken from NYT, https://www.nytimes.com/interactive/2017/02/24/world/asia/north-korea-propaganda-photo.html
David Albright (2017): North Korea's Nuclear Capabilities: A Fresh Look, presentation

Thermonuclear Design – „The Peanut“



2017 nuclear test 140-250 kt (Norris 2018)
US Intelligence “advanced nuclear device”
Experts devided if composite or thermonuclear.
Was it the peanut? We do not know.

Fissile Material ? (Research! But not that much different from above)

Left Picture: Howard Morland with his Thermonuclear Design. Copyright Robert Del Tredici.
http://nonuclear.se/deltredici.e5.morland.html
Right Picture: KCNA, via DPRK Today. https://www.popsci.com/north-korea-working-theromonuclear-bomb.
Hans M. Kristensen & Robert S. Norris (2018) North Korean nuclear capabilities, 2018, Bulletin of the Atomic Scientists, 74:1, 41-51

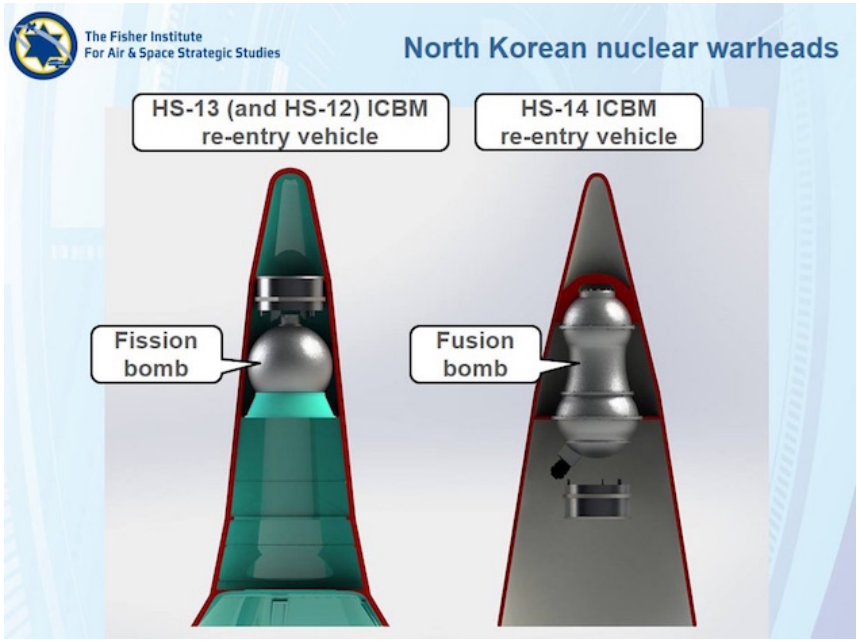
Number of Nuclear Weapon Estimates

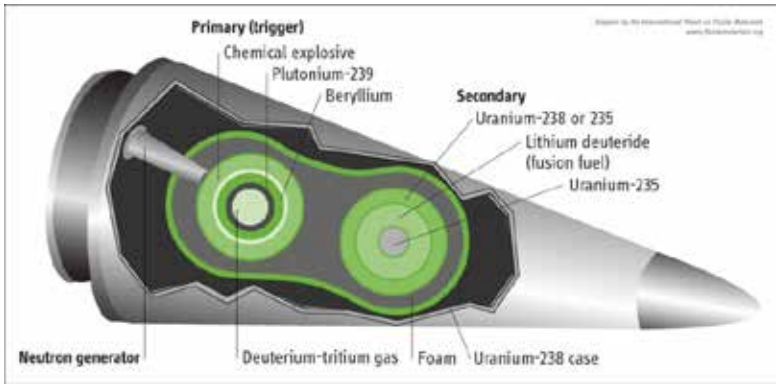
Source	Fissile Material	Nuclear Weapons
Hecker 2017	~ 20-40 kg Pu, 250-400 kg HEU	20-25 -
Hecker et al. 2017	~ 20-40 kg Pu, 250-500 kg HEU	16-32 „Hydrogen“ +7/y
Albright 2016	33 kg Pu, 175-645 kg HEU 30% of fissile material wasted	13-30 Fission +3-5/y 12 composite
Albright 2017 Estimate for 2020 Max	~ 48 kg Pu, 409-1120 kg HEU 30% of fissile material wasted	24-49 Fission 17 Composite core
Albright 2017 Estimate for 2020 Median	~ 33 kg Pu, 175-645 kg HEU 30% of fissile material wasted	13-30 (17-32) Fission 12 Composite core
Albright 2017 Worst case with LWR		60 fission
Washington Post 2017 Leaked Intelligence		60 warheads

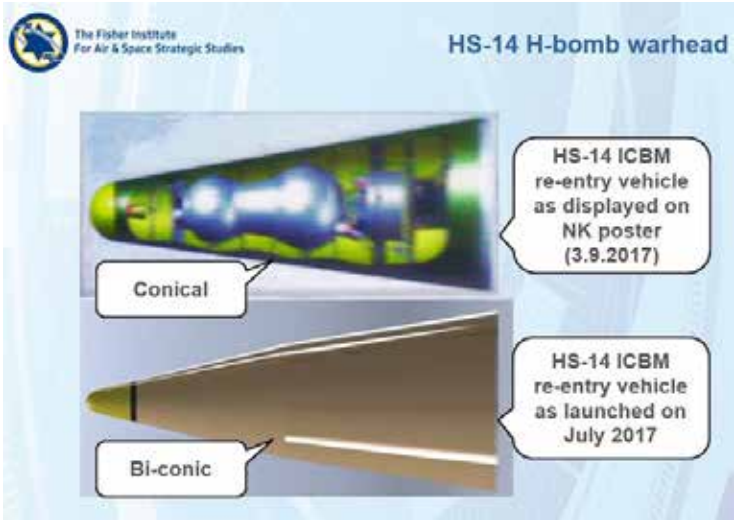
Hans M. Kristensen & Robert S. Norris (2018) North Korean nuclear capabilities, 2018, Bulletin of the Atomic Scientists, 74:1, 41-51
Siegfried Hecker and Chaim Braun, “North Korea's Stockpiles *of* Fissile Material,” *Korea Observer*,. *Vol. 47*, Iss.*4*, (*Winter 2016*): *721-749*
David Albright (2017): North Korea's Nuclear Capabilities: A Fresh Look, presentation
Warrick, J., E. Nakashima, and A. Fifield. 2017. “North Korea Now Making Missile-Ready Nuclear Weapons, US Analysts Say.” The Washington Post, August 8.
https://www.washingtonpost.com/world/national-security/northkorea-now-making-missile-ready-nuclear-weapons-us-analysts-say/2017/08/08/e14b882a-7b6b-11e7-9d08-b79f191668ed_story.html.

Is the nuclear device already weaponized (warhead design)? How is it delivered?

Warhead Design



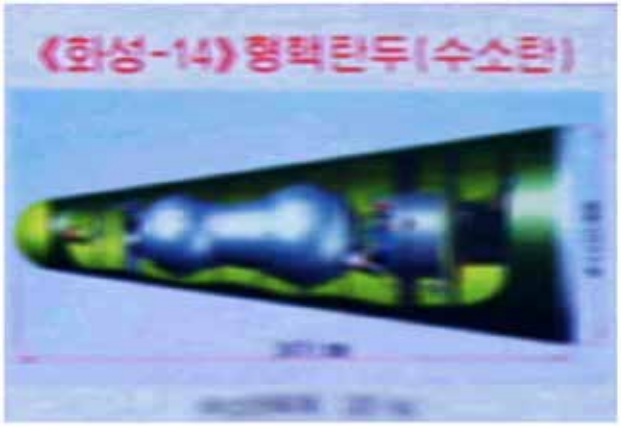




www.ipfm.org
The Fisher Institute For Air and Space Strategic Studies
https://www.sofmag.com/korea-nuclear-test-furthers-emp-bomb/
http://www.jewishpress.com/news/us-news/israel-condemns-sixth-north-korean-nuclear-test-as-unsc-meets-in-emergency-session/2017/09/04/

Reentry Vehicle

Mock up? Or real design.
We do not know.
S. Hecker: Learned not to underestimate North Korean engineers.



Close-up of concept diagram from above KCTV photo. (Source: Nathan J. Hunt, https://twitter.com/ISNJH)

KRT via AP Video. http://www.concordmonitor.com/North-Korea-claims-leader-inspects-new-H-bomb-12257715
KCNA via REUTERS https://www.reuters.com/article/us-northkorea-missiles-thermonuclear-ana/possible-two-stage-hydrogen-bomb-seen-game-changer-for-north-korea-idUSKCN1BE0PT
Sixth Nuclear Test Detected at Punggye-ri, Declared to be a Hydrogen Bomb. https://www.38north.org/2017/09/nuke090317/

Steps to Weaponization - ICBM

Steps to Weaponization	Difficulties and assessment
Miniaturization	Hecker: Yes for middle range ballistic missiles
Guidance and Stability	Different for long range missiles We do not know. (JCoS)
Reentry Vehicle	- stresses extreme on flatter trajectory. Difficulties during last test. We do not know (JCoS). - " … did not appear to be a technical barrier to building a working RV (Wright 2017h). 2 more years (Hecker)
Weapon survivability	Extreme conditions for delicate materials. We do not know. (JCoS)

My opinion already manufactured weapons?
Maybe 10.

Hans M. Kristensen & Robert S. Norris (2018) North Korean nuclear capabilities, 2018, Bulletin of the Atomic Scientists, 74:1, 41-51

FIN