

The Nexus between Diplomacy and Nuclear Science

: The technical signatures of the uranium enrichment program
and their implications for North Korean denuclearization

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Abstract

The complete denuclearization of North Korea is mainly a diplomatic task, but at the same time geo-strategic and technical one, which calls for an interdisciplinary approach. By exploring the technical signatures of the uranium enrichment program, this article argues that diplomatic solutions alone may not deliver the goal of “final, fully-verified denuclearization.” The proliferation-prone and detection-resistant nature of centrifuge technology allowed Pyongyang secretly to build and operate modern enrichment facilities despite Washington’s supply-side efforts to combat proliferation. Also, the failure of the 1976 Symington Amendment, invoked to dissuade Islamabad from acquiring uranium bombs, attests to the fact that a demand-side approach may not work either against a fragile regime determined to “east grass” in order to be a nuclear power. Unless the

technical challenges are adequately addressed, North Korea's clandestine enrichment program, coupled with deep distrust, will complicate and even derail the whole process of denuclearization from negotiations to verifications.

Key Words: North Korea, Pakistan, Denuclearization, Uranium enrichment technology, Centrifuges, Verification,

I. Introduction

The Singapore summit on June 12, 2018 underscored the dramatic turn-around in the U.S.-North Korea relations after just a few months ago the two countries had come close to the brink of war. President Trump and North Korean leader Kim Jong-Un sat down together to discuss North Korea's denuclearization and what the U.S. can offer in return. The two leaders signed a comprehensive document which outlined a joint commitment to the denuclearization of the Korean peninsula. The summit document clearly stated: "President Trump committed to provide security guarantees to the DPRK, and Chairman Kim Jong-Un reaffirmed his firm and unwavering commitment to complete denuclearization of the Korean Peninsula."¹⁾

1) For the full text of the Trump-Kim summit agreement, see "Joint Statement of President Donald J. Trump of the United States of America and Chairman Kim Jong Un of the Democratic People's Republic of Korea at the Singapore Summit," The White House (June 12, 2018); (<<https://www.whitehouse.gov/briefings-statements/joint-statement-president-donald-j-trump-united-states-america-chairman-kim-jong-un-democratic-peoples-republic-korea-singapore-summit/>>).

Speaking at a news conference held after the summit, President Trump claimed that Chairman Kim agreed to denuclearization being verified and that economic sanctions will remain in place until “final fully-verified denuclearization (FFVD)” occurs.²⁾

Since the document lacked substance on how to reach denuclearization, the U.S. is trying to put flesh on the bones of what was agreed in the summit. The document also specified that the two countries will commit to hold follow-up negotiations to implement the outcomes of the historic summit. Reportedly, Secretary of State Mike Pompeo, in his meetings with North Korea officials, raised the issue of a timetable for denuclearization and verification and the need for a complete inventory of nuclear stockpiles, nuclear warheads, delivery systems, fissile material for nuclear weapons, and production facilities.³⁾

While each of the requirements is essential to any credible denuclearization agreement, the path to the stated goal of FFVD is expected be long and winding. Given North Korea’s unique political structure of absolute dictatorship, there is no doubt that the political decision made by the leaders of the two countries marked a crucial step toward denuclearization. However, giving too much focus on diplomatic fanfare tends to obscure the fact that denuclearization is in essence not only a political but also “technical” issue.

While numerous analyses have been presented about the prospects for

2) “Trump Kim summit: US president hails deal after historic talks,” *BBC*, 12 June 2018; (<https://www.bbc.com/news/world-asia-44450739>).

3) “North Korean Denuclearization Talks Uncertain After Pompeo Visit,” *The Wall Street Journal*, 8 July 2018.

North Korea's denuclearization, the technological aspect has yet to be considered as a major element. For example, most of the analyses that are skeptical about the prospect of North Korea giving up its nuclear arsenal are attributable to deep-seated distrust of North Korea, largely resulting from the failure of the 1994 Agreed Framework.⁴⁾ Likewise, studies that offer and compare different scenarios and strategies for denuclearization with more optimistic outlook have a tendency to overlook the unique challenges North Korea's uranium program will pose.⁵⁾ Just as nuclear ambition alone does not lead to a nuclear state, nuclear disarmament cannot be resolved without careful consideration of the technical dimension. For example, any political negotiations regarding the timeline and verification of denuclearization should carefully consider from the technical standpoint what concrete steps are required, how long each step will take, and how to verify.⁶⁾ Indeed, the denuclearization of the Korean peninsula will be a complex issue that requires a comprehensive and integrated approach to address numerous interconnected issues, ranging from strategic interests of, and political trust

⁴⁾ Evans J. R. Revere, "US policy and Pyongyang's game plan: Will we accept a nuclear-armed North Korea?" *Brookings* (August, 2018); Bruce Klingner, "U.S. Should Not Sign a Peace Declaration with North Korea," *The Heritage Foundation* (September 18, 2018); Jung H. Pak and Ryan L. Hass, *Beyond Maximum Pressure: A Pathway to North Korean Denuclearization*, Brookings Institution (December, 2017).

⁵⁾ Chang Kwoun Park, "Negotiation Strategy and a Roadmap for the Denuclearization of North Korea," *Korean Journal of Defense Analysis*, vol.30, no.2 (2018), pp. 153~170.

⁶⁾ See for a suggestion, Siegfried S. Hecker, Robert L. Carlin, and Elliot A. Serbin, "A Technically-Informed Roadmap for North Korea's Denuclearization," Center for International Security and Cooperation, Stanford University (May 28, 2018); (<https://cisac.fsi.stanford.edu/content/cisac-north-korea>).

between regional stakeholders to nuclear science and technology.

Based on this view, this article attempts to analyze the effects of uranium enrichment technology on denuclearization and verification process. By exploring the nature of the uranium route to nuclear weapons and North Korea's uranium enrichment capabilities, this article argues that the uranium enrichment program will be a key point in the following negotiations between Washington and Pyongyang. The article proceeds as follows. The next section explicates on why the uranium route is more proliferation-prone and detection-resistant than the plutonium route. Then, section III explores North Korea's uranium enrichment capabilities, which are in the Rumsfeldian domain of uncertainty—the known unknowns. Section IV examines Pakistan's case in which a combined supply-side and demand-side approach by the Carter administration failed to suspend Pakistan's clandestine uranium enrichment program. This section relies on the declassified U.S. intelligence documents to examine the case. Section V concludes with a discussion of the implications of this study for North Korean denuclearization.

II. Uranium enrichment route, more proliferation-prone and detection-resistant than plutonium route

The growing aspirations for nuclear weapons and the spread of nuclear technology are posing greater challenges to international nuclear proliferation regime. In the last couple of decades, there has emerged the gas centrifuge program, one of the enrichment technologies, as a hot potato. As for the spread of centrifuges, it has been argued that the bombing of Iraq's nuclear facility in Osirak by the Israel government in 1981, also known as Operation Opera, and the War in Iraq after 9/11 forced aspiring nuclear-weapon states to find an alternative route to plutonium route.⁷⁾ And in 2004, Abdul Qadeer Khan, Pakistan's chief atomic bomb scientist, confided the existence of the nuclear black market in which Pakistan's nuclear weapons technology was traded or sold to North Korea, Iran, Libya, and possibly a few others.⁸⁾ While how much the Khan network contributed to the proliferation of centrifuge technology remains unclear, North Korea announced that it built a light water reactor (LWR) and enrichment facility to fuel it, Iraq and Libya with centrifuge-based highly enriched uranium (HEU) production facilities

7) It was right after Osirak bombing when Libya transferred from plutonium route to uranium enrichment route. See Malfrid Braut-Hegghamer, "Revisiting Osirak: preventive attacks and nuclear proliferation risks," *International Security* (2011), pp. 101~132.

8) Chaim Braun and Christopher F. Chyba, "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime," *International Security* (2004), pp. 5~49.

had threatened regional security before they gave up their nuclear programs. And recent intelligence report on the existence of Iran's clandestine enrichment program, with its heavy-water reactor program, is complicating the non-proliferation effort further. Despite this looming danger of nuclear spread, the international community has yet to formulate and implement effective measures to contain the diffusion of secret enrichment program.

Against this backdrop, as a necessary step to grasp how the uranium enrichment program would affect North Korea's denuclearization, this section explicates why enrichment program is considered more proliferation-prone and detection-resistant.⁹⁾ If history is any guide, it seems evident that uranium enrichment route using gas centrifuges has become the most coveted way of acquiring nuclear technology for countries with nuclear ambition. The almost every country which had centrifuge technology in the 1970s, though with varying levels of sophistication, later became, or is considered to be, nuclear weapons states. It is also notable that late starters, such as China, South Africa, and Pakistan used HEU for their first nuclear weapons. This historical observation, however, cannot be explained without the inherent technical characteristics of enrichment technology.

⁹⁾ Major points of this section largely draw on Dr. Scott Kemp's arguments on the nuclear proliferation challenge created by the spread of the gas centrifuge technology. See Scott Kemp, "The nonproliferation emperor has no clothes: the gas centrifuge, supply-side controls, and the future of nuclear proliferation," *International Security*, vol.38, no.4 (2014), pp. 39-78; Scott Kemp, "Uranium Enrichment: a new era of proliferation," Nonproliferation Policy Education Center, London (November 4, 2011); Scott Kemp, "The End of Manhattan: How the Gas Centrifuge Changed the Quest for Nuclear Weapons," *Technology and Culture*, vol.53, no.2 (2012), pp. 272-305.

The gas centrifuge-based uranium enrichment route is more proliferation-prone than reprocessing route for the following reasons: (1) A centrifuge program is relatively easy to build and hide; (2) the technical possibility of dual use—peaceful purpose and nuclear weapons purpose—provides strong incentives for non-nuclear states to pursue enriched uranium route; and (3) there is no need for nuclear weapons testing. Because of these intrinsic features of enrichment, the diffusion of centrifuges technology poses greater challenges to the NPT regime than plutonium reprocessing technology.¹⁰⁾ In the following, each reason will be explained separately in detail.

1. Relatively easy to build and hide

Uranium enrichment by centrifugation can be the basis for relatively easy and, more importantly, secret production of nuclear weapons. There are key factors that make centrifuge program easy to build and hide and thus attractive to countries with nuclear ambition.

¹⁰⁾ Arguing that uranium enrichment route is more proliferation-prone, however, does not necessarily mean that reprocessing route is more proliferation-resistant in absolute terms. No nuclear energy systems, such as all kinds of reactors and fuel cycles, are proliferation proof. For example, the proponents of Pyroprocessing technology argue that Pyroprocessing will be more proliferation-resistant since there is little possibility of clearly separating plutonium from other radioactive materials like ultra-uranium. However, many nuclear experts have been critical of that optimistic view. See Frank Von Hippel, "Plutonium and reprocessing of spent nuclear fuel," *Science*, vol.293 (2001), pp. 2397~2398; Frank Von Hippel and Jungmin Kang, "Limited proliferation-resistance benefits from recycling unseparated transuranics and lanthanides from light-water reactor spent fuel," *Science and Global Security*, vol.13, no.3 (2005), pp. 169~181.

First of all, centrifuge facilities are relatively easy to build. That is because, when compared to plutonium reprocessing, technological barrier for mastering enrichment technology has become relatively low for late starters. The most difficult step in making a nuclear weapon is the production of chain-reacting fissile materials. Most of the \$10 billion budget in the Manhattan Project was spent for the production of two nuclear fissile materials: highly enriched U-235, the fissile isotope of uranium, and Pu-239, the fissile isotope of plutonium. However, the easing of the technical hurdles involved in the production made enrichment route an easy way to produce fissile materials. In particular, as new enrichment technology—the gas centrifuge—became available in the early 1960s, basic information required to build gas centrifuge became widely available. Since 1975, seven countries—Brazil, Iran, Iraq, Libya, North Korea, Pakistan, and South Africa—have at some point with varying levels acquired centrifuge technology with little or no direct external support, and all of them are considered to be potential nuclear weapons states today.¹¹⁾

Black market transfer, albeit limited, also helped facilitate the diffusion of centrifuge technology even further. Despite numerous multilateral instruments, multilateral oversights, and initiatives that are designed for the purpose of non-proliferation, the existence of the Khan network—proliferation ring—revealed the limits of those institution.¹²⁾ North Korea, for

¹¹⁾ World Nuclear Association, “Uranium Enrichment,” (<http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx>).

¹²⁾ David Albright and Corey Hinderstein, “Unraveling the AQ Khan and future proliferation networks,” *Washington Quarterly*, vol.28, no.2 (2005), pp. 109~128.

example, sold its missile technology to Pakistan in exchange for the transfer of centrifuge technology. Nuclear rogue states with the means of long range delivery would be the worst thing to happen to the NPT regime.

Exaggerating the role of the Khan network, some argue that countries that aim to build centrifuges should rely on external support for core technology and key components. According to such view, it is one thing to acquire the detailed drawing of cascade design, and it is quite another to have an enrichment program in operation since operating enrichment program requires tacit knowledge that can only be gained by learning-by-doing.

However, technological barrier is relatively low that centrifuges can be made indigenously. Nuclear experts argue that countries with a certain level of expertise and resources can easily make simple Soviet-style centrifuges with endogenous materials and technology.¹³⁾ To exaggerate, any countries with enough motivation and organizational capacity can acquire centrifuge program in a couple of years. Building basic Soviet-style centrifuges does not require high levels of technology, and, more importantly almost every part can be produced domestically without relying on risky imports.¹⁴⁾ Historically speaking, average time that took for a government to master enrichment technology and have a centrifuge program in operation was less than three years.

13) Matthew Bunn and Anthony Wier, "Terrorist nuclear weapon construction: how difficult?" *The Annals of the American Academy of Political and Social Science*, vol.607, no.1 (2006), pp. 133~149.

14) If basic centrifuges capable of producing weapon-grade HEU can be fabricated indigenously, it means that the existing supply-side measures for export control and proliferation security are irrelevant at least for centrifuge technology. This observation calls for filling a gap in the nuclear proliferation regime.

Secondly, because centrifuge facilities are relatively small and easy to hide, covert operation is possible. The poor record of detection supports the difficulty of identifying undeclared enrichment program. Despite intensive intelligence effort, the US had not been aware of the Soviet Union's centrifuge program until it declared in 1991. And this helps explain why China's centrifuge program was kept secret for almost two decades. Even at this point, the international community does not have clear and detailed information on the capability, size, numbers, location of enrichment facilities of the most two troubling nuclear states—North Korea and Iran.

The difficulty of detecting enrichment activities is derived from the fact that there are limitations of the means of detection. First, optical means of detection is limited, which makes centrifuge plants easy to hide. Centrifuge facilities are much less distinguishable than normal nuclear reactors. Nuclear reactors, both LWRs and HWRs, usually have noticeable facilities, in particular the row of cooling towers, and the reactor dorm itself is too big to hide. Therefore, nuclear reactors, that have clear visual signatures, can be easily identified using satellite imagery. It is virtually impossible for nuclear aspirants to operate covert reactor program once the US and other majors with satellites run air intelligence operation.¹⁵⁾

In contrast, centrifuge facilities are much less visible when seen from above. That is because, unlike reactors, centrifuges program does not require massive plants, and centrifuge cascades are small and modular. The low energy use of gas centrifuge plants makes them more difficult to detect.

¹⁵⁾ Kemp (2012); Scott Kemp and Alexander Glaser, "The Gas Centrifuge and the Nonproliferation of Nuclear Weapons," Proceedings of the Ninth International Workshop on Separation Phenomena in Liquids and Gases (2006).

Running on low energy, a centrifuge facility does not require separate power plants to supply energy, nor emit heat that can be identifiable through thermal infrared image. For that reason, it is argued that even a proliferation-scale gas-centrifuge program could be housed in a small warehouse or office building.¹⁶⁾ Technically speaking, centrifuge program can go underground, making satellite reconnaissance irrelevant. Thanks to the limitation of optical detection, clandestine operation is possible when it comes to enrichment route.

Besides the limitation of optical means, centrifuge program also denies detection by other means—effluent and electromagnetic—because it does leave few radioactive or chemical tracers.¹⁷⁾ Both LWRs and HWRs emit radioactive and chemical tracers that can be detected in the environment. However, there is no reliable technical means of detecting a covert centrifuge programs unless we set up detectors within the range of some hundred meters from the suspected facility.

In sum, gas centrifuge-based uranium enrichment is more proliferation-prone and detection-resistant because of the insurmountable gap between the ease of building gas centrifuges and the difficulty of detecting centrifuge plants

¹⁶⁾ Allegedly, North Korea painted the roof of its enrichment facility blue. Without the colored roof, the facility from above would look like a normal warehouse and thus not be noticeable in a satellite image.

¹⁷⁾ Kemp (2014), pp. 48-55.

2. Dual use providing strong incentives to pursue enriched uranium route

One important technical aspect of the gas-centrifuge system is that it can be used for both peaceful and military purpose. The flexibility of centrifuge program provides strong incentives for states with nuclear ambition. First of all, the peaceful purpose of centrifuge-based enrichment is to provide fuel for nuclear reactors, which will eventually generate electricity. An enrichment program can serve as a means for self-reliant fuel supply because enriched uranium extracted from indigenous enrichment facilities can be used as a fuel for light water reactors, the predominant nuclear fuel-cycle, to operate.¹⁸⁾ Therefore, for those countries whose genuine interest is to operate nuclear reactors for peaceful use only, uranium-enrichment technology might be regarded as an essential component of a sustainable and self-sufficient nuclear energy program.

However, what makes enrichment technology less proliferation-resistant than reprocessing technology is that a centrifuge program is flexible for dual use. Because of its flexibility, enrichment route is preferred by aspiring nuclear weapon states. Centrifuge programs that are designed for peaceful purposes can rapidly be reconfigured for the military purpose of producing highly enriched, weapons-grade U-235 without significant modification or

¹⁸⁾ The light water reactor (LWR) is the most common type of nuclear reactor and uses U-235, enriched to approximately 3 percent, as a fuel, and normal water (H₂O) as its coolant and neutron moderator. The heavy water reactor (HWR) uses un-enriched, natural U-235 (0.72 percent) as a fuel and heavy water (D₂O) as its neutron moderator; (<http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx>).

delay.¹⁹⁾ Nuclear experts posit that reconfiguration can be completed only in a matter of weeks, or less than that.

Given that making nuclear fissile material is the most difficult part of producing a nuclear weapon, the duality of gas centrifuge technology provides strong incentive for both those countries who want to have nuclear weapons and those countries who just keep the door to nuclearization open. Iran's case is a stark example here. Iranian government officials have repeatedly asserted that the country's nuclear program is exclusively for peaceful purposes. President Mahmoud Ahmadinejad asserted that nuclear weapons have no benefit but high costs to keep them and that accumulating nuclear weapon is a backward idea.²⁰⁾ However, the US and other states have argued that Iran may be pursuing nuclear weapons capability. Discerning a peaceful nuclear program from a nuclear weapons program can be difficult because of much of the technology's dual-use nature. For that reason, one should not accept the Iranian government's official announcement at face value. What matters most is whether Iran has the potential for nuclear weapons' capability or not.²¹⁾ Once Iranian's

¹⁹⁾ Alexander Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation," *Science and Global Security*, vol.16 (2008), pp. 1-25.

²⁰⁾ Paul K. Kerr, "Iran's nuclear program: status," DTIC Document, *Congressional Research Service* (December 29, 2009).

²¹⁾ Jose Goldemberg, Brazil's former secretary of state for science and technology, observed that a country developing the capability to produce nuclear fuel does not have to make an explicit political decision to acquire nuclear weapons. In some countries, such a path is supported equally by those who genuinely want to explore an energy alternative and by government officials who either want nuclear weapons or just want to keep the option open. See Paul K. Kerr (2009),

government is determined to have nuclear weapons, the same centrifuges that produce civilian power-reactor fuel could be quickly converted to produce HEU for nuclear weapons with little or no modification.

Once the reconfiguration is completed, uranium enrichment by centrifugation can be the basis for the quick and efficient production of nuclear weapons.²²⁾ Centrifuge technology allows speed of action, which means a state with centrifuges can accumulate enriched uranium enough for a nuclear weapon as fast as it can produce with a plutonium route. By connecting more centrifuges in series and parallel, the enrichment level and the product flow rate can be increased.²³⁾

3. No need for nuclear weapons testing

The last reason why uranium enrichment route is more attractive for non-nuclear states is that centrifuges produce highly enriched uranium, which is much easier to handle and use in nuclear weapons than plutonium. Although its critical mass for nuclear fission is about three times larger, HEU is more relevant in military terms since a nuclear weapon design with enriched uranium is much simpler than that with plutonium.²⁴⁾

p. 2.

²²⁾ Houston G. Wood, Alexander Glaser, and R. Scott Kemp, "The gas centrifuge and nuclear weapons proliferation," *Physics Today* (September 2008).

²³⁾ The separative power of a normal P-2 type centrifuge is about 5 SWU/year, which means that a centrifuge with 250 kWh power can produce around 30 grams of uranium per year. Therefore, when enrichment facility with 1,700 centrifuges is in operation for a full year, it can produce about 50 kg of enriched uranium. Alexander Glaser (2008), p. 8.

²⁴⁾ The critical mass of a plutonium bomb is around 10kg while that of HEU bomb

Major advantage of HUE weapon is that it can be used to make relatively simple gun-type bomb, a.k.a. Little Boy or the Hiroshima bomb.

Basically there are two kinds of nuclear weapon designs: gun assembly and implosion. When the active material is HEU, it can be assembled into a chain-reacting critical mass by gun assembly method. In gun assembly, one separated piece of fissile uranium is fired at a fissile uranium target at the end of the gun, achieving critical mass when two-separated uranium pieces are combined. Gun-type nuclear weapons work with so simple a detonation device that they do not even need explosive testing. Another method of making nuclear fission weapons is implosion. While the gun-type method only uses HEU, the implosion method can use HEU, Pu-239, or a combination of both as fuel. In implosion method, fissile material is surrounded by high explosives that when exploded compress the mass, resulting in criticality. In contrast to gun type assembly, implosion method requires high levels of weapon techniques and detonation test to prove its working.²⁵⁾

is around 50kg when enriched at the level of 90%. Hans M. Kristensen, "The Basics of Nuclear Weapons: Physics, Fuel Cycles, Effects and Arsenal," Federation of American Scientists.

²⁵⁾ Matthew Bunn, "What types of nuclear material require what levels of security?" Belfer Center, Harvard Kennedy School (February 2014); (<https://www.belfercenter.org/index.php/publication/what-types-nuclear-material-require-what-levels-security>).

III. North Korea's secret HEU programs : *the Known Unknown*

While all assessments of North Korea's nuclear weapons capabilities, that include intelligence on the number of nuclear warheads, amount of weapons-grade fissile materials, development of detonation device, and delivery system, remain unclear, it gets even murkier when it comes to North Korea's HEU weaponization program.²⁶⁾ Because of the secrecy of the regime and, more importantly, technical nature of uranium enrichment technology, it is difficult to assess and quantify the advancement of its enrichment program. Even nuclear experts and U.S. intelligence agencies have different assessments of the North Korea's enrichment capacity, and thus the estimates of HEU stockpile are highly speculative. There is also mounting suspicion that North Korea might have built a second and third clandestine enrichment facilities.²⁷⁾ To paraphrase the former U.S. defense

²⁶⁾ Assessments of the North Korea's plutonium stockpile are believed to be relatively more accurate because governments with support from nuclear experts can estimate plutonium production levels from satellite imagery. According to 2015 estimates, North Korea's current stockpile is composed of 6-8 plutonium-based war heads and 4-8 devices fashioned from uranium. Joel S. Wit and Sun Young Ahn, "North Korea's Nuclear Futures: Technology and Strategy," *In North Korea's Nuclear Futures Series* (February 2015), p. 17; (<http://38north.org/2015/02/nukefuture022615>).

²⁷⁾ In a 2011 Senate hearing, Director of National Intelligence James Clapper testified North Korea likely has additional undeclared uranium enrichment facilities. James R. Clapper, "Statement for the Record on the Worldwide Threat Assessment of the U.S. Intelligence Community for the House Permanent Select Committee on Intelligence," Office of the Director of National Intelligence (February 10, 2011).

secretary Donald Rumsfeld, North Korea's HEU capability falls in the domain of *the Known Unknown*: We know that there are things we do not know.

Although North Korea's isolationist policy, coupled with the technical properties of centrifuge program addressed in the previous section, makes it extremely difficult to gauge its HEU capability, there have been indications and evidence that North Korea has actively pursued enrichment route. As demonstrated with six nuclear tests, North Korea has acquired expertise on how to process plutonium for the creation of nuclear weapons, and North Korea's nuclear arsenal depends primarily on its ability to expand its uranium enrichment program.

The issue of North Korea's centrifuge program first surfaced in October 2002. In response to allegations made by James Kelly, assistant secretary of state for East Asian and Pacific affairs, North Korean First Deputy Foreign Minister Kang Seok-Ju acknowledged the existence of a uranium enrichment program. But ever since North Korean officials had consistently denied that. The US intelligence agencies, largely based on procurement related evidence, reported that North Korea had pursued secret efforts to acquire a uranium enrichment capability. A CIA estimate provided to Congress on 19 November 2002 stated, "North Korea embarked on the effort to develop a centrifuge-based uranium enrichment program about two years ago ... the North is constructing a plant that could produce enough weapons-grade uranium for two or more nuclear weapons per year when fully operational —which could be as soon as mid-decade"²⁸⁾ The U.S. government accused

²⁸⁾ North Korean Nuclear Weapons, CIA Estimate for Congress (November 19, 2002); <<https://fas.org/nuke/guide/dprk/nuke/cia111902.html>>; "Threats and Responses: Alliances; In North Korea and Pakistan, Deep Roots of Nuclear Barter." *New York*

North Korea of developing a program to enrich uranium to weapons grade, in violation of the Agreed Framework. In January 2003, North Korea announced its withdrawal from the NPT.

Meanwhile, some analysts were not convinced of the public disclosure of North Korea's HEU program. In 2012, a researcher concluded that while North Korea's nuclear capability was much lower than it looks, it was inflated by the higher ranks of the regime.²⁹⁾ Selig Harrison, an American reporter and author, underlined the lack of evidence and posited the Bush administration's accusation of Pyongyang was inspired by the growing fear over the appeasement approach by South Korea and Japan toward North Korea.³⁰⁾

The cooperation between Pakistan and North Korea in the nuclear sphere came to light with the exposure of A. Q. Khan's network in 2004. According to western intelligence agents, the Khan network played a significant role, providing North Korea with centrifuge designs and a small number of complete centrifuges, which could serve as an alternative way of manufacturing nuclear fissile material after it agreed to freeze reprocessing facilities under the 1994 Agreed Framework.³¹⁾ More importantly, the evidence that North Korea secretly provided Libya with nearly two tons of

Times, November 24, 2002; <<https://www.nytimes.com/2002/11/24/world/threats-responses-alliances-north-korea-pakistan-deep-roots-nuclear-barter.html>>.

²⁹⁾ Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," in RAND Technical Reports (2012), p. 16; <http://www.rand.org/pubs/technical_reports/TR1268.html>.

³⁰⁾ Selig S. Harrison, "Did North Korea Cheat?" *Foreign Affairs* (2005), pp. 99-110.

³¹⁾ "Evidence is cited linking Koreans to Libya uranium," *New York Times*, May 23, 2004; <<https://www.nytimes.com/2004/05/23/world/evidence-is-cited-linking-koreans-to-libya-uranium.html>>.

uranium served to confirm U.S. charges that North Korea had long pursued a uranium-based nuclear program that can turn raw uranium into uranium hexafluoride and produce weapons-grade uranium.³²⁾ The degree of progress, however, remains unknown.

More evidence on North Korea's HEU program came in 2009. In February 2009, despite North Korea's denial, U.S. and South Korean intelligence reportedly discovered underground facilities in Sowi-ri, a district of Yongbyon that can produce highly enriched uranium.³³⁾ In June 2009, North Korea publically announced that it was operating uranium enrichment program. In response to U.N. sanctions imposed following the second nuclear test, the North Korean Foreign Ministry stated "North Korea has had enough success in developing uranium enrichment technology, and the enrichment process will be commenced."³⁴⁾

Yet, the most conclusive evidence came to light in 2010. Much to the surprise of many experts who underestimated North Korea's centrifuge technology, North Korea revealed its uranium-based nuclear program. On 12 November 2010, North Korea unveiled to a team of U.S. officials and academics its enrichment facility in Yongbyon. According to Dr. Siegfried Hecker, the "astonishingly modern" facility contained some 2,000 centrifuges to enrich uranium.³⁵⁾ While North Korea claimed that the facility was

32) "North Korean nuclear trade exposed: IAEA team finds Pyongyang sold uranium to Libya for bomb," *The Guardian*, 24 May 2004; (<https://www.theguardian.com/world/2004/may/24/northkorea,libya>).

33) "NK Has Built Uranium Enrichment Facilities," *The Dong-a Ilbo*, February 18, 2009; (<http://english.donga.com/List/3/all/26/261399/1>).

34) "N,K, says it will start enriching uranium," *The Korea Herald*, June 15, 2009.

35) Siegfried Hecker, "A Return Trip to North Korea's Yongbyon Nuclear Complex,"

producing low-enrichment uranium (LEU) for a light-water reactor, it can be reconfigured for HEU production. When reconfigured, the facility is capable of producing up to 40 kg of HEU, which is enough for one or two nuclear weapons.³⁶⁾ He also said that the centrifuges must have been relocated from another location, indicating that North Korea could possibly have other enrichment facilities.³⁷⁾

There still remains a high degree of uncertainty about the scale and level of sophistication of North Korea's enrichment program. Researchers and Western intelligences have pointed out North Korea probably had been pursuing enrichment capability long before it publicly acknowledged. The 2011 IAEA report concluded that the uranium hexafluoride (UF₆) cylinders found in Libya was "very likely" originated in North Korea, which indicate that North Korea had an undeclared uranium facility prior to 2001.³⁸⁾ Lee Chun-keun, a Korean researcher, argues that North Korea's UF₆ production—the pre-enrichment phase—started as early as in the mid to late 1980s after years of national effort.³⁹⁾ Meanwhile, some experts suggest that the

Center for International Security and Cooperation, Stanford University (November 20, 2010).

³⁶⁾ Olli Heinonen, "North Korea's Nuclear Enrichment: Capabilities and Consequences," Belfer Center, Harvard Kennedy School (June 22, 2011). According to Hecker's recent estimate, North Korea's HEU inventories are estimated to be in the range of 200 to 450 kg, sufficient for 10 to 25 HEU bombs. See Siegfried S. Hecker, Chaim Braun, and Chris Lawrence, "North Korea's Stockpiles of Fissile Material," *Korea Observer* (2016), p. 721.

³⁷⁾ "North Korea Reveals Uranium-Enrichment Plant," Arms Control Association; (https://www.armscontrol.org/act/2010_12/NorthKorea).

³⁸⁾ Report by the Director General, "Application of Safeguards in the Democratic People's Republic of Korea (DPRK)," United Nations, IAEA (September 2, 2011), p. 10.

third test conducted in February 2013 with the yield of 6 to 9 kilotons was a HEU test. It is possible that North Korea has more than one facility capable of producing and weaponizing HEU, and even if North Korea invites IAEA inspectors, it would not show them the facilities. After all, the full nuclear capability of the isolated regime lies in the domain of the “known-unknown.” The fundamental challenge in verifying North Korean denuclearization is that the only reliable source of information is the North Korean government itself, whose reliability can be questioned.

IV. Pakistan’s case: America’s unsuccessful efforts to roll back secret uranium–enrichment program

While there had been a direct linkage between Pakistan and North Korea—the “nuke-for-missile” deal that facilitated North Korea’s nuclear development—Pakistan’s path to a nuclear-armed state has also significant implications for America’s effort to denuclearize North Korea.³⁹⁾ Despite America’s efforts toward non-proliferation, Pakistan conducted nuclear tests in May 1998 and

³⁹⁾ Lee Chun-keun, “Assessing North Korea’s Nuclear Weapons Capability,” NAPSNet Special Reports (May 11, 2015), pp. 4–6.

⁴⁰⁾ Notwithstanding, it should be noted that Pakistan’s case differs from North Korea’s case in that while in the former the U.S. attempted to dissuade Pakistan from acquiring enrichment technology, in the latter the U.S. is demanding North Korea to abandon established enrichment programs.

declared itself a nuclear weapon state. Pakistan currently possesses a growing nuclear arsenal, remaining outside both the NPT and the CTBT. As discussed in the following, declassified U.S. intelligence documents published by the National Security Archive reveal the Carter administrations' unsuccessful efforts to roll back Pakistan's secret uranium enrichment program.⁴¹⁾

Following India's May 1974 nuclear test, Islamabad embarked upon an aggressive effort to acquire a nuclear weapons capability. For the Pakistani leadership, a nuclear weapons program was an essential tool to shift the regional balance of power in their favor. Zulfikar Ali Bhutto, former Prime Minister and architect of Pakistan's nuclear program once famously said, "If India builds the bomb, we will eat grass or leaves, even go hungry, but we will get one of our own."⁴²⁾ Pakistan turned to France for purchase and installation of reprocessing facilities, but the Ford administration forced France to cancel the proposal.⁴³⁾

While US intelligence efforts were exclusively focused on the plutonium route to nuclear weapons, America's non-proliferation effort entered a new stage as Pakistan began resorting to the uranium route to nuclear weapons. Until the late 1970s, the possibility that Pakistan would take the uranium route had not been in the scope of the U.S. intelligence analysis.⁴⁴⁾ During

⁴¹⁾ Declassified documents from the National Security Archive, "The United States and Pakistan's Quest for the Bomb," The George Washington University; <<https://nsaarchive2.gwu.edu/nukevault/ebb333/>>.

⁴²⁾ Khushwant Singh, "Foreign Affairs: Pakistan, India and the Bomb," *The New York Times*, July 1, 1979.

⁴³⁾ Central Intelligence Agency, "Pakistan Nuclear Study,"; <https://www.cia.gov/library/readingroom/docs/DOC_0000252641.pdf>.

the 1970s, however, Pakistan, under the leadership of A. Q. Khan, acquired gas-centrifuge-based technology. Having brought blueprints for a gas centrifuge design from the Netherlands, Pakistan avoided export controls and acquired necessary equipment to build enrichment facilities. Reportedly, Pakistan also received extensive assistance in the production of the facilities from Europe and China. Since 1978, evidence mounted that Pakistan was operating a uranium enrichment program. Yet, largely thanks to the secret nature of the program, different intelligence agencies presented different assessments.⁴⁵⁾ For example, a report from the Netherlands stated Pakistan established a pilot program with a very small enrichment capacity. An Australian assessment indicated that it would take three to five years for Pakistan to acquire nuclear weapons capability. A 1978 U.S. intelligence report stated that Pakistan attempts to build a clandestine uranium enrichment plant.

Even the Carter administration was aware that Pakistan was purchasing technology for gas centrifuges and tightened up export controls through the introduction of the 1978 Nuclear Non-Proliferation Act, the declassified intelligence documents reveal that U.S. failed to bring Pakistan's bid for an

⁴⁴⁾ Central Intelligence Agency, "Pakistan Nuclear Study," (April 26, 1978). Top Secret, excised copy; <<https://nsarchive2.gwu.edu/nukevault/ebb333/doc05.pdf>>.

⁴⁵⁾ "Pakistan's Nuclear Program," *Congressional Research Service*, p. 3. In October 1978, assistance secretary of state Joseph Nye reported that "we had indications that Pakistan is attempting to acquire an indigenous centrifuge enrichment capability." See Memorandum of Conversation, prepared by Assistant Secretary of State Joseph Nye, "Consultations on Pakistan: Details on Indigenous Nuclear Capabilities (Supplement to Memcon Prepared by Ambassador Hummel)," U.S. Department of State (October 6, 1978); <<https://nsarchive2.gwu.edu/nukevault/ebb333/doc19.pdf>>.

uranium bomb to a halt. In December 1978, US intelligence belatedly learned that Pakistan's technology acquisition network was "more extensive and sophisticated than previous indicated."⁴⁶⁾ In less than a month, new information was presented. By January 1979, an intelligence report estimated Pakistan "may already have succeeded in acquiring the main missing components for a gas centrifuge plant and ancillary facilities that are probably being built to produce HEU for weapons, perhaps even by 1982."⁴⁷⁾ These evidence shows that the U.S. intelligence agencies have failed to track Pakistan's development of uranium enrichment technology.

After recognizing that supply-side measures failed to disrupt Pakistan's purchase of uranium enrichment technology, the Carter administration sought diplomatic pressure to dissuade Pakistan, but to no avail. In January, as a part of the diplomatic actions, US Ambassador to Pakistan, Arthur Hummel directly met with Pakistan's President General Mohammed Zia ul-Haq to discuss about the Khan research laboratories at Kahuta. Ambassador Hummel briefed him on what the U.S. knew about Pakistan's secret uranium program and presented satellite images of Kahuta facilities suspected to be producing enriched uranium. President Zia responded with a straight face, "That's absolutely ridiculous. Your information is incorrect.

⁴⁶⁾ John Despres, National Intelligence Officer for Nuclear Proliferation via Deputy Director for National Foreign Assessment [and] National Intelligence Officer for Warning to Director of Central Intelligence, "Monthly Warning Report-Nuclear Proliferation," (December 5, 1978); (<https://nsarchive2.gwu.edu/nukevault/ebb333/doc21.pdf>).

⁴⁷⁾ John Despres, NIO for Nuclear Proliferation, to Interagency Intelligence Working Group on Nuclear Proliferation, "Monthly Warning Report," Top Secret (January 18, 1979); (<https://nsarchive2.gwu.edu/nukevault/ebb333/doc22.pdf>).

We have to clear this up. Tell me any place in Pakistan you want to send you experts, and I will let them come and see.”⁴⁸⁾

However, it was soon turned out to be a strategy to buy time, and no inspections ever took place. President Zia had twice affirmed his willingness to accept inspections on January 24 and February 9; however, when the U.S. called on to Pakistani officials to follow, they refused to accept inspections on the grounds that India also refused. Expressing deep regret for Pakistan’s reversal, Ambassador Hummel noted to Foreign Secretary Shahnawaz that “serious discrepancies between our information about Pakistan’s nuclear programs and Pakistan’s assurances thereupon, which could have serious impact on our relations if unresolved.”⁴⁹⁾ Such diplomatic move, however, did not yield results. In the subsequent meetings, when Ambassador Hummel asked Pakistan officials about nuclear intentions, “They did not deny that both reprocessing and enrichment programs are building, nor would they agree to discontinue their movement toward weapons-grade material production.”⁵⁰⁾

As Pakistan’s relentless pursuit of nuclear weapons continues, the Carter administration in April 1979 invoked the 1976 Symington Amendment and

48) Dennis Kux, *The United States and Pakistan, 1947-2000: Disenchanted Allies* (Washington D.C.: Woodrow Wilson Center Press, 2001), p. 236.

49) U.S. Embassy Islamabad to cable 2413 to State Department, “Pakistan Nuclear Program: Technical Team Visit,” (February 27, 1979) Secret (Source: National Archives, Record Group 59, Department of State Records, Records of Warren Christopher, 1977-1980, box 56, Pakistan II); (<https://nsarchive2.gwu.edu/nukevault/ebb333/doc25.pdf>).

50) U.S. Embassy Islamabad cable 2769 to State Department, “Nuclear Aspects of DepSec Visit Discussed with UK and French Ambassadors,” (March 7, 1979); (<https://nsarchive2.gwu.edu/nukevault/ebb333/doc26a.pdf>).

prohibited U.S. assistance to Islamabad.⁵¹⁾ It was a major U.S. non-proliferation effort, demand-side approach designed to exert pressure on and eventually encourage Islamabad to forgo its enrichment program. The U.S. understood that while assenting to Pakistan's nuclear program was unacceptable, cutting aids alone was insufficient. Therefore, even after the implementation of the amendment, Washington tried to keep the dialogue open and find inducements for Islamabad and at same time sought a regional solution—the assurance of “mutual restraint” between Pakistan and India—to resolve the India-Pakistan dilemma.

Despite the U.S. efforts, there was no improvement in the situation. In June 1979, National Security Adviser Zbigniew Brzezinski asked Secretary of State Cyrus Vance to “set up a small interagency working group, ... charged with the task of a complete rethinking of our approach to South Asian nuclear issues,”⁵²⁾ and yet he admitted that finding a new solution would never be an easy task. In the memorandum, he wrote:

In view of the impasse in our dealings with Pakistan and India, both our political relationships and our non-proliferation goals are in great jeopardy in the near term. We must at least consider alternative positions even if, in the last analysis, we come to the conclusion that our present courses must be pursued for policy reasons.⁵³⁾

⁵¹⁾ The 1976 Symington Amendment was an amendment to the Foreign Assistance Act and the Arms Export Control Act of 1961. It banned U.S. economic, and military assistance, and export credits to countries that deliver or receive, acquire or transfer nuclear enrichment technology when they do not comply with IAEA regulations and inspections.

⁵²⁾ Brzezinski to the Secretary of State, “The South Asian Nuclear Problem,” Secret (June 19, 1979); <<https://nsarchive2.gwu.edu/nukevault/ebb333/doc37.pdf>>.

With more disturbing intelligence coming to light regarding Pakistan's enrichment program, U.S. was at a loss to find a solution. In August 1979, the New York Times reported that Carter administration officials had received unconfirmed reports that Pakistan was preparing an underground test site for a nuclear detonation.⁵⁴⁾ In September Charles Van Doren, assistant director of Non-Proliferation Bureau at the Arms Control and Disarmament Agency (ACDA), provided a briefing on Pakistan's nuclear development to the General Advisory Committee (GAC) consisted of a group of former officials and scientific experts advising the Carter administration. While discussing a variety of solutions to the nuclear deadlock, Van Doren likened Pakistan's case to "the makings of another Indian disaster" and stated that "we're all deeply concerned about it and most of us are scratching our heads about what is the best thing to do."⁵⁵⁾

While Pakistan officials repeatedly asserted that they would not develop nuclear weapons, their actions were inconsistent with that. In September 1979, President Zia, appealing Washington to review its policy, said in an interview, "Pakistan is not in a position to make a bomb and has no intention of making a bomb."⁵⁶⁾ Even though he confirmed that Pakistan had embarked on a uranium enrichment program, he insisted that the program

⁵³⁾ Ibid.

⁵⁴⁾ Or Rabinowitz, *Bargaining on Nuclear Tests: Washington and its Cold War Deals* (Oxford: Oxford University Press, 2014), p. 143.

⁵⁵⁾ "Friday Morning Session: General Advisory Committee on Arms Control and Disarmament," Secret (September 14, 1979); (<https://nsarchive2.gwu.edu/nukevault/ebb333/doc42.pdf>).

⁵⁶⁾ "Zia Denies Pakistan Builds Nuclear Bomb and Urges U.S. to Resume Aid," *New York Times*, September 23, 1979; (<https://www.nytimes.com/1979/09/23/archives/zia-denies-pakistan-builds-nuclear-bomb-and-urges-us-to-resume-aid.html>).

was designed to provide needed source of energy. For the Pakistan's leadership, the Soviets invasion of Afghanistan in December 1979 brought a window of opportunity for Pakistan, a neighboring state with crucial supply routes, to be a nuclear weapons state. During the 1980s while the Symington and Glenn amendments were in place, but the U.S. relaxed pressure and largely turned a blind eye to the Pakistan's nuclear program.⁵⁷⁾ Even in 1982, General Zia was invited to meet President Reagan at the White House. "He [Zia] is a good man," wrote President Reagan in his diary, and "He gave me his word they were not building an atomic or nuclear bomb,"⁵⁸⁾ While a 1986 ACDA memorandum indicated that Pakistan had violated the pledge and produced enough high enriched uranium for one or more nuclear devices, reportedly US officials maintained "we don't have enough information" to conclude that Pakistan was not making weapons-grade HEU.⁵⁹⁾ However, as A.Q. Khan confirmed, Pakistan had never stopped making bomb-grade HEU during the 1980s and 1990s. In 1987, Pakistan's HEU production capacity was sufficient to produce one nuclear bomb per year. In May 1998, Pakistan carried out a series of underground nuclear tests, signaling the failure of Washington's effort for the past 30 years to deter Pakistan from acquiring nuclear weapons.

⁵⁷⁾ In December 1979, the Soviets invaded Afghanistan and U.S. relations with Pakistan soon began to improve. The top policy priority became working with Islamabad to check the Soviet invasion. Richard S. Cleary, "Persuading Countries to Forgo Nuclear Fuel-Making: What History Suggests," In Henry Sokolski (Ed.), *Nuclear Nonproliferation: Moving Beyond Pretense* (Carlisle, P.A.: U.S. Army War College Press, 2014), pp. 212-13.

⁵⁸⁾ Douglas Brinkley, "Reagan, Unscripted," *Vanity Fair* (June 2012); (<https://www.vanityfair.com/news/2007/06/reagan200706>).

⁵⁹⁾ Paul K. Kerr and Mary B. Nikitin, "Pakistan's Nuclear Weapons: Proliferation and Security Issues," *Congressional Research Service* (July 20, 2011), pp. 3~4.

V. Implications for North Korean denuclearization

President Donald Trump's diplomatic engagement with Kim Jung-Un led to the historic summit in which they pledged to look for ways to end a nuclear stand-off on the Korean peninsula. The joint agreement certainly marked a first step towards denuclearization, but the diplomatic breakthrough, however meaningful, does not necessary guarantee "final, fully verified" denuclearization of North Korea. No one knows at this point where the next steps will lead.

While the negotiators from the two sides are struggling to put flesh on the bones of the agreement, two different approaches have been presented: one a short-term "grand bargain"; the other long-term, trust-building. Based on the technical properties of the uranium enrichment program and the analysis of Pakistan case discussed earlier, each approach is reviewed in turn, with an assessment of their opportunities and risks.

For the first approach, the Trump administration could opt for a short-term strategy in which the two countries strike a sweeping deal that will cause a sort of big-bang denuclearization to happen. Advocated by the hard-liners in Washington who tend to view a long-term approach as Pyongyang's old game to cheat and buy time,⁶⁰⁾ the strategy will press

⁶⁰⁾ John Bolton, president Trump's national security adviser, insisted the U.S. be focused squarely on how to eliminate North Korea's nuclear weapons as quickly as possible. "Trump should insist on Libya-style denuclearization for North Korea: Bolton," *Reuters*, March 24, 2018; (<https://www.reuters.com/article/us-usa-trump-bolton-northkorea/trump-should-insist-on-libya-style-denuclearization-for-north-korea-bolton-idUSKBN1GZ37A>).

North Korea to take drastic, meaningful, and irreversible steps to dismantle its nuclear program. To that end, North Korea would have to submit the full inventory of nuclear warheads, fissile materials and production facilities; ship its nuclear stockpile out of the country; dispose of nuclear weapons infrastructure, including delivery systems and platforms; and allow unprecedented monitoring and inspections to verify its compliance. In return, the U.S. would grant concessions to North Korea, ranging from the declaration of the end of the Korean War, to a firm security guarantee, to formal diplomatic recognition and the opening of embassies and consulates, and to economic assistance and the lifting of sanctions.

However desirable the strategy may be, it is unlikely that North Korea would easily abandon its hard-won nuclear deterrent. As was the case with Pakistan, North Korea has repeatedly stated nuclear weapons are critical to its survival. Henry Kissinger, known to have advised President Trump on North Korea issues, noted that “North Korea acquired nuclear weapons to assure its regime’s survival; in its view, to give them up would be tantamount to suicide.”⁶¹ With nuclear arsenal, the regime can maintain balance of military power against its neighbors, deter possible U.S. military actions, and preserve its existence. North Korea has offered occasional concessions—freezing nuclear program or blowing up a cooling tower—but retained and even pursued vertical proliferation at the expense of economic and energy problems.

Besides, the denuclearization process could drag if both countries

⁶¹ Joseph Bosco, “The Trouble with Kissinger’s North Korea Advice,” *The Diplomat*, January 29, 2018.

continue to test the waters to see who will act first, blaming each other for lack of progress.⁶²⁾ During the Bush and Obama administrations, the U.S. maintained the position that North Korea should act first, and only when North Korea takes concrete and verifiable actions toward denuclearization, the U.S. would reciprocate.⁶³⁾ The underlying logic of “maximum pressure” campaign is no different. Even after the summit, President Trump reaffirmed that the sanctions would remain in place until denuclearization occurs. More importantly, from the North Korean perspective, it may be rational to refuse such unilateral nuclear abandonment since the deal is to trade “the irreversible” for “the reversible.” North Korea may find the inducements—from security guarantee to economic aid—offered by the U.S. to be appealing; however, they are reversible in nature while the dismantlement of nuclear weapons infrastructure is not. The perceived imbalance of nuclear trade will provide strong incentives for North Korea to keep its easy-to-hide enrichment program undisclosed as a nuclear weapons hedge. Therefore, pressing North Korea to accept a unilateral denuclearization could be nothing more than forcing it to lie.

After all, even when North Korea would accept the across-the-board deal, the technical signatures of uranium programs could further complicate and derail the denuclearization process. The U.S. will demand that North Korea

⁶²⁾ David Kang points out that while waiting North Korea to take the next step, the U.S. has actually done little in return in the two months after the summit. David Kang, “Why Should North Korea Give Up Its Nuclear Weapons?” *The New York Times*, August 22, 2018; <<https://www.nytimes.com/2018/08/22/opinion/north-korea-nuclear-trump.html?action=click&module=Opinion&pgtype=Homepage>>.

⁶³⁾ Evans JR. Revere, “Facing the facts: towards a new US North Korea policy,” The Brookings Institution Center for North-East Asian Policy Studies (2013).

provide a full inventory of its nuclear arsenal and facilities. Given the trust deficit with Pyongyang, however, Washington might not be assured that it is disclosing all its nuclear weapons and facilities.⁶⁴⁾ And if the U.S. confronts North Korea with all available intelligence on enrichment programs, North Korea, following Pakistan's steps, will repudiate the findings of the U.S. intelligence community. The danger is that if for that reason nuclear talks stall, North Korea is very likely to walk away and resume nuclear and missile testing.

Tantalized by the idea of solving the North Korea problem during his term, president Trump could seek a quick denuclearization deal; however, a second, and more reasonable, scenario would be a long-term, step-by-step approach whereby each time North Korea takes actions to denuclearize in a verifiable manner, the U.S. offers compensation. Initial steps could include freezing nuclear facilities or dismantling missile test sites.⁶⁵⁾ Divided up into several steps, realizing this formula will take a very long time—The Iran nuclear deal took thirteen years to bring about. However, if the U.S. could offer positive economic inducements which make it reasonable for North Korea to forgo its hard-earned nuclear weapons,⁶⁶⁾ the slow-but-sure rolling

⁶⁴⁾ William Perry said, "Over the last two and a half decades, we've learned we cannot really trust North Korea. ... Therefore I'd put a high premium on verification. If we can't get verification, don't value too highly the agreement." William Perry, "America 'Blew the Opportunity' to Denuclearize North Korea," *The Atlantic* (March 2018); (<https://www.theatlantic.com/international/archive/2018/03/bill-perry-north-korea/555239>).

⁶⁵⁾ On May 24, 2018 North Korea in front of foreign journalists claimed to have destroyed a nuclear test site in Punggye-ri. However, it is difficult to verify whether North Korea actually did since experts have yet permitted to analyze the location.

back of nuclear might not only serve the U.S. security interests but help stabilize the region.

However, verifying North Korea's uranium enrichment program will be the key to successful implementation of the step-by-step formula. In a low-trust relationship, North Korea will have strong incentives to use its "known-unknown" enrichment program as a wild card, conceal clandestine enrichment facilities, and opt for the strategy of "engage-and-hedge" whereby North Korea takes modest actions while at the same time hedges against the failure of negotiations and compensations.⁶⁷⁾ In order to prevent the denuclearization process from being mired in the suspicion trap, the U.S. will have to create conditions for trust building. At the same time, as nuclear experts point out, there are major technical gaps in the scientific capability to detect secret centrifuges and verify a freeze of enrichment activities,⁶⁸⁾ and the U.S. must act quickly to address the gaps.

The Final, fully-verified dismantlement of North Korea's nuclear program is a lofty goal that can only be achieved through sustained commitment,

⁶⁶⁾ For suggestions on guiding principles in nuclear negotiations with North Korea, see Bradley O. Babson, "Positive Economic Inducements in Future Nuclear Negotiations with North Korea," US-Korea Institute, SAIS (December 2015).

⁶⁷⁾ It is often argued that Washington's renegeing on its promises is also responsible for the failure of the 1994 Agreed Framework. Maria Ryan, "Why the US's 1994 deal with North Korea failed and what Trump can learn from it," *The Conversation* (20 July 2017). For theoretical analysis on the failure of the 1994 Agreement Framework, see Curtis H. Martin, "Rewarding North Korea: Theoretical Perspectives on the 1994 Agreed Framework," *Journal of Peace Research*, vol.39, no.1 (2002), pp. 51~68.

⁶⁸⁾ Scott Kemp, "North Korean disarmament: build technology and trust," *Nature* (June 7, 2018); <<https://www.nature.com/articles/d41586-018-05383-8>>.

pooling of resources, and sustained efforts to build trust, from all the parties involved. A diplomatic approach alone, however, may not deliver the goal. Given the deep suspicion each harbors toward the other, the technical signatures of the uranium enrichment program will complicate or even derail the whole process of denuclearization from negotiations to verifications unless we find ways to add a valuable layer of confidence.

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외교와 핵 과학의 연계

: 우리늄 농축 프로그램의 기술적 속성이 북한의 비핵화에
주는 함의

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국문요약

북한의 비핵화는 기본적으로 외교적인 과제이지만, 동시에 지정학적이고 기술적인 과제이기도 하다. 북핵문제 해결을 위한 학제간 접근은 선택이 아닌 필요이다. 본 논문은 북핵 문제에 내재된 '기술적 속성'에 주목함으로써, 완벽한 비핵화가 북미정상 간 외교적 타협만으로는 쉽게 도달 할 수 없는 목표임을 주장한다. 플루토늄과 구별되는 우리늄 농축 프로그램의 '확산용이적'이며 동시에 '탐지 및 검증 저항적'인 속성은 북한이 비확산을 위한 미국의 '공급식 접근'을 우회해 비밀리에 우리늄 농축 시설을 가동할 수 있게 하였다. 또한 파키스탄의 우리늄 농축 프로그램을 저지하기 위해 구상된 1976년 사이밍턴 수정안의 실패는 '핵무기를 위해서는 풀도 먹기로 작정'한 국가를 상대로 한 미국의 '수요적 접근' 역시 근본적인 해결책이 될 수 없음을 방증한다. 기술적 요소가 제기하는 난제들이 해소되지 않는 한, 우리늄 농축 프로그램은 하나의 와일드 카드로 작용해 북한에게 다양한 전략적 선택지를 제공하고 결과적으로 협상에서 검증에 이르는 전 과정에 걸쳐 미국의 비핵화 노력을 복잡하고 어렵게 만들 것으로 예상된다.

주제어: 북한, 파키스탄, 비핵화, 우리늄 농축, 원심 분리기, 검증.

양희용(Yang, Hee-Yong)

서울대학교 국제대학원에서 박사학위를 취득하였고, 현재 육군사관학교 부교수로 재직 중이다. 최근의 주요논문으로 "Japan's Search for a New Security Role after the Persian Gulf War"(2017)와 "2003년 이라크전 유지연합 참가 동기에 대한 연구"(2017) 등이 있다.