Can the North Korean nuclear crisis be resolved?

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I thank Kyungnam University and the Friedrich Naumann Foundation for inviting me to present my views on the situation in North Korea. My area of expertise is in the nuclear arena and that is primarily what I will address in my paper. However, it is not possible to solve the nuclear crisis without addressing the underlying fundamental political issues, so I will offer my views, as a non-expert in this area, at the outset.

I am optimistic in the long term but pessimistic in the short term that the nuclear crisis on the Korean peninsula can be resolved. The reason for my optimism in the long term is that Northeast Asia is the most dynamic, rapidly growing economic region of the world. North Korea is an island of instability in this sea of stability and growing prosperity. There is simply too much at stake for the surrounding countries to allow the nuclear crisis to destabilize the region and descend it into chaos. This situation is very different from Iran, the other current nuclear hotspot in the world. Iran represents a much greater global challenge because it is an island of instability in a sea of instability and turmoil, namely the greater Middle East.

The reason I am pessimistic about resolving the North Korean nuclear crisis in the short term is that it will take time for Washington and Pyongyang to overcome the mistrust built up by five decades of enmity and two decades of contentious nuclear diplomacy. Moreover, the nuclear crisis cannot be resolved in isolation. It is imperative to address the long-standing problems created by the division of the Korean peninsula and the remnants of the Korean War. Pyongyang developed its nuclear program to help assure regime survival and, today, appears to be using it to forge an outcome far beyond what Pyongyang could achieve economically or through conventional military means. Pyongyang has survived by playing its poor hand to perfection in large part because the countries working to denuclearize the Korean peninsula have differing and conflicting interests in North Korea and the region.

These differences, even if acknowledged, have not been resolved and prevent a unified strategy toward North Korea from being developed. South Korea has vacillated during the past two decades between sunshine and hard-line. China continues to stress peace and stability on the Korean peninsula, regardless of how confrontational Pyongyang becomes. Japan appears to have sidelined itself from serious influence by focusing almost exclusively on the abductees issue. Russia advocates a soft approach to Pyongyang formally, but behind the scenes blames Washington for exacerbating the crisis. And the United States continues to be fixated by the nuclear issue and has handcuffed itself with domestic politics, which prevents it from taking the kind of creative approach required to resolve the crisis.

The recent agreement by Washington and Pyongyang to renew diplomatic dialogue is a positive sign of progress. On February 29, 2012 North Korea agreed to implement a moratorium on long-

range missile launches, nuclear tests and nuclear activities at Yongbyon, including uranium enrichment activities in return for nutritional aid from the United States.[1] The agreement is a small, but necessary, step to prevent the nuclear crisis from getting worse as it did during the past three years. In this paper, I provide a brief history of Pyongyang's nuclear program, review nuclear developments during the past three years, offer some suggestions of how to proceed in the near term to reduce the nuclear crisis on the Korean peninsula and some long-term suggestions of how to resolve the nuclear crisis and attain the ultimate goal of the denuclearization of the peninsula.

A brief history of the nuclear crisis

The North Korean nuclear crisis is often viewed in black and white terms – that is, Pyongyang either has or doesn't have nuclear weapons or that it will or will not give up the weapons. However, any serious attempt at resolving the nuclear crisis must recognize that the details of the nuclear program matter. The North Korean nuclear program is particularly complex – it was begun more than fifty years ago ostensibly to provide the benefits of nuclear technologies for the people of North Korea, but also because Kim Il-sung wanted to build the technological foundation for nuclear weapons.[2]

Pyongyang has pursued both nuclear energy and nuclear weapons capabilities for five decades. Much of the underlying technological base is the same. Over time, Pyongyang's emphasis on one or the other has been influenced heavily by political considerations and diplomacy, particularly as it relates to Washington. However, no matter if it was bombs or electricity that Pyongyang favored, it always kept open the option for the other. Washington, on the other hand, has continued to view North Korea strictly through a nuclear lens; first stating that it will never allow Pyongyang to obtain nuclear weapons and, once that failed, proclaiming that it will not accept Pyongyang keeping them.

Kim Il-sung laid the foundation for nuclear technology development in the early 1950s. The Soviet "Peaceful Atom" initiative, modeled after President Dwight Eisenhower's "Atoms for Peace" enabled Soviet universities and nuclear research centers to train several hundred North Korean students and researchers. The Soviets built a research reactor, the IRT-2000, and associated nuclear facilities at Yongbyon in the 1960s. North Korean specialists trained at these facilities and by the 1970s were prepared to launch a nuclear program without external assistance.

The North Koreans first used their newly acquired technical capabilities to construct an indigenous experimental gas-graphite reactor. North Korea's decision to build gas-cooled, graphite-moderated reactors was a logical choice at the time for an indigenous North Korean energy program because gas-graphite reactors can operate with natural uranium fuel and, hence, do not require enrichment of uranium.[3] Although North Korea may have experimented with enrichment technologies, commercial enrichment capabilities were beyond its reach and difficult

[1] Statement on "U.S.-DPRK Bilateral Relations." U.S. Department of State, February 29, 2012, Washington D.C. and "DPRK Foreign Ministry Spokesman on Result of DPRK-U.S. Talks." Korea Central News Agency (KCNA), February 29, 2012. Pyongyang, North Korea.

[2] See Siegfried S. Hecker, "Lessons learned from the North Korean nuclear crises," *Daedalus*, Winter 2010, pp. 44-56 for a detailed treatment of how and why North Korea developed nuclear weapons.

[3] The gas-graphite reactors were patterned after the British Calder Hall Magnox reactor, whose technical specifications were readily available because they were widely disseminated in the United Kingdom.

to acquire.[4] North Korea's ambitious program began with an experimental 5-megawatt-electric (MWe) reactor, which became operational in 1986. Construction of that reactor was followed by a scaled-up 50-MWe reactor and a 200-MWe power reactor, although neither was ever completed.

North Korea quickly mastered all aspects of the gas-graphite reactor fuel cycle. It built fuel fabrication facilities and a large-scale reprocessing facility, which enabled extraction of plutonium from spent fuel.[5] Unlike the Soviet-built research facilities, the new facilities were built and operated without being declared to or inspected by the International Atomic Energy Agency (IAEA). Pyongyang had no legal obligation to declare these facilities because it was not yet a member of the Nuclear Non-Proliferation Treaty (NPT). American reconnaissance satellites picked up signs of the reactor construction in the early 1980s and the reprocessing facility in the late 1980s. It was not until 1989, when South Korea leaked American satellite data of the reprocessing facility, that the international community first became aware of and concerned about North Korea's indigenous nuclear program. The concern stems from the fact that gas-graphite reactors are capable of producing weapons-grade plutonium while generating electrical power and heat. So, whereas Pyongyang's choice of gas-graphite reactors for its energy program was logical, it was also the best choice to develop a nuclear weapons option.

In parallel, North Korea asked the Soviets to build light water reactors (LWRs) to help meet North Korea's energy demands. North Korea joined the NPT in 1985 because the Soviets made consideration of constructing LWRs contingent upon joining the Treaty. These reactors, however, never materialized because of the demise of the Soviet Union. Pyongyang kept inspectors out of its new facilities until 1992, by which time it had all of the pieces in place for the plutonium fuel cycle. This move coincided with several diplomatic initiatives and President George H.W. Bush's decision to withdraw all American nuclear weapons from South Korea. By this time, the 5-MWe experimental reactor produced electricity and heat for the town of Yongbyong, as well as approximately 6 kilograms (roughly one bomb's worth) of weapons-grade plutonium per year. The fuel fabrication and reprocessing facilities were operational, and the two bigger gas-graphite reactors were under construction.

In 1992, Pyongyang opened the window on its nuclear program for diplomatic reasons explained below, but closed it quickly when IAEA inspectors uncovered discrepancies between their own nuclear measurements at Yongbyon and Pyongyang's declaration. Pyongyang responded to IAEA accusations by announcing its intent to withdraw from the NPT. Negotiations started in June 1993 but stalemated. In 1994, when North Korea unloaded the reactor's fuel containing an estimated 20 to 30 kilograms of plutonium, Washington and Pyongyang came close to war before former President Jimmy Carter intervened and brokered a freeze.

Intense negotiations in Geneva led to the Agreed Framework,[6] which changed North Korea's nuclear technical trajectory dramatically. Pyongyang agreed to give up its indigenous gas-

[4] The alternative path for natural uranium-fueled reactors is a heavy water reactor, such as the Canadian CANDU reactor. This was India's choice for its first reactor, which was constructed by Canada with U.S.-supplied heavy water. However, after India used the plutonium produced by that reactor for its first nuclear test in 1974, it would have been difficult for North Korea to get external assistance. North Korea required external assistance because it did not have the capacity to produce heavy water.

[5] The reprocessing facility resembles an extension of the design of the Eurochem reprocessing plant in Belgium.

[6] The Agreed Framework signed between the United States and North Korea on October 21, 1994, in Geneva agreed to have North Korea freeze its existing nuclear program. In addition to U.S. supply of LWRs and delivery of heavy fuel oil, the two sides agreed to move toward full normalization of political and economic relations, and work together for peace and security on a

graphite reactor program for the promise of two LWRs to be supplied by the United States, South Korea, and Japan. The spent fuel rods unloaded from the 5-MWe reactor were repackaged by an American technical team and stored in the cooling pool for eventual removal from North Korea. Operation of the 5-MWe reactor, the fuel fabrication plant, and the reprocessing facility was halted and monitored by IAEA inspectors per special arrangement under the Agreed Framework. Construction of the two larger reactors was stopped.

Although Pyongyang halted its plutonium program during the Agreed Framework, it continued to expand its missile program, including conducting a long-range rocket launch over Japan in 1998. It also explored uranium enrichment.[7] During its first formal encounter with Pyongyang in October 2002, the Bush Administration, which was adamantly opposed to the Agreed Framework, accused Pyongyang of covertly pursuing the alternative HEU path to the bomb. This altercation effectively ended the Agreed Framework and changed Pyongyang's technical and political trajectory again. After years of denying any uranium enrichment activities, Pyongyang showed my Stanford University colleagues and me a modern uranium centrifuge enrichment plant in November 2010.[8] It is now clear that Pyongyang was pursuing an enrichment program in the late 1990s and that the U.S. intelligence estimate was correct. Nevertheless, the Bush administration's political confrontation backfired. Washington traded a threat that would have taken years to materialize into nuclear weapons for one that took less than one year.

Following the altercation with the Bush Administration in late 2002, North Korea became the first nation to withdraw from the NPT.[9] It expelled international inspectors and announced that it would strengthen its nuclear deterrent. By the end of 2003, which also marked the invasion of Iraq and the fall of Saddam Hussein, Pyongyang was eager to have Washington believe it had the bomb. It used my first trip to North Korea, an unofficial, Track II trip led by my Stanford University colleague John W. Lewis, to send that message back to Washington. In a carefully choreographed tour of the Yongbyon nuclear complex in January 2004, Pyongyang gave me remarkable access to nuclear facilities and nuclear scientists and allowed me to hold 200 grams of plutonium bomb fuel (in a sealed glass jar), all to convince me it had a "deterrent."[10]

Over the next five years, Pyongyang built and demonstrated its nuclear weapons capabilities while it engaged off and on in the six-party talks, which it joined under pressure from the Chinese.[11] We do not know exactly when Pyongyang got its first bomb, but we know it has made

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nuclear-free Korean peninsula. See Joel S. Wit, Daniel B. Poneman, and Robert L. Gallucci, *Going Critical: The First North Korean Nuclear Crisis* (Washington, D.C.: Brookings Institution Press, 2004) for informative discussions of the Agreed Framework and North Korean crisis in the 1990s.

[7] In the late 1990s, Pyongyang is reported to have acquired centrifuge technology from Pakistan's A.Q. Khan, as reported by Pervez Musharraf in his book *In the Line of Fire: A Memoir* (New York: Free Press, 2006). Additional evidence, including the purchase of aluminum tubes suitable for centrifuge rotors from Russia and attempted purchase from Germany, is discussed in Hui Zhang, "Assessing North Korea's Uranium Enrichment Capabilities," *Bulletin of the Atomic Scientists* (June 18, 2009), http://www.thebulletin.org/web-edition/features/assessing-north-koreas-uranium-enrichment-capabilities.

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

[9] Siegfried S. Hecker, "Lessons learned from the North Korean nuclear crises," *Daedalus,* Winter 2010, p. 47

[10] Siegfried S. Hecker, "The Nuclear Crisis in North Korea," *The Bridge,* National Academy of Engineering, 17-23 (Summer 2004).

[11] The six-party talks, which were initiated in 2003, involved the United States, North Korea, and its four neighbors: South Korea, China, Japan, and Russia.

significant strides since 2003. Since the 5-MWe reactor was restarted in 2003, it operated for approximately three years before it was shut down again since July 2007. North Korea has conducted three reprocessing campaigns since 2003. The reprocessed plutonium, combined with the roughly 2 to 10 kilograms North Korea may have produced before 1994, yields an estimated plutonium production of 40 to 60 kilograms, of which we estimate 24 to 42 kilograms are available for weaponization today.

North Korea also conducted two nuclear tests of plutonium devices. Its first nuclear test in October 2006 was only partially successful; its yield was estimated at less than one kiloton. Initial estimates of the yield of the second test, which occurred in 2009, were 2 to 4 kilotons. This estimate has been revised upward to 4.6 kilotons in a recent analysis.[12] Consequently, the North may be able to design a Nagasaki-like bomb with a yield of up to 20 kilotons, but delivery is likely to be restricted to aircraft, boat, or van. For North Korea to gain enough confidence to mount a miniaturized design on a missile, it will have to test again. Hence, the technical and military driving forces for additional tests are high, even if, as Pyongyang surely knows, the political risks are also high.

The six-party diplomatic process has so far failed to do much to constrain Pyongyang's nuclear ambitions. It resulted in shutting down the 5-MWe plutonium production reactor, but did not curtail its drive for uranium enrichment capabilities nor did it appear to stop its missile or nuclear exports. Not surprisingly, many observers now look at the last two decades as a dismal diplomatic failure because Pyongyang's nuclear program was not eliminated. It is important, however, take a closer look at what Pyongyang actually achieved technically–or, perhaps more importantly, what it did not achieve. It failed to get commercial nuclear power. Although Pyongyang now has nuclear weapons, its weapons program is much smaller than it would have been if left unchecked. With the capabilities it already had or was soon to complete by the early 1990s, Pyongyang today could have an arsenal of a hundred or more nuclear weapons. Instead, it has enough only enough plutonium for four to eight weapons and currently is not producing more. North Korea has the capacity to put the 5-MWe reactor back into operation and produce one bomb's worth of plutonium annually for the foreseeable future, but it has not taken steps to do so, perhaps indicating that it believes its small nuclear arsenal provides a sufficient nuclear deterrent. It apparently has a modern centrifuge facility, but it is not clear how much, if any, highly enriched uranium they may have produced for use as an alternate bomb fuel.

Pyongyang's export of missiles and nuclear technologies appears not to have been constrained. Pyongyang has pursued an extensive missile program for decades. It built its initial capability, obtained from the Soviets, into a formidable short-range missile force and developed an ambitious export business for re-engineered Soviet missiles. Its principal customers have been Pakistan, Iran, Syria, Libya, Egypt, and Burma. Pyongyang's long-range missile development has been slow and not a great technical success. After the 1998 launch, it delayed its second launch until July 2006, primarily because of the missile moratorium it declared in 1999.

[12] J.R. Murphy, B.C. Kohl, J.L. Stevens, T.J. Bennet, and H.G. Israelsson, "Exploitation of the IMS and Other Data for a Compressive Advanced Analysis of the North Korean Nuclear Test," *2010 Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technology*, Science Applications International Corporation, p. 456-465. Another recent analysis claims a minimum yield of 5.7 kilotons (E. Rougier, H.J. Patton, E.E. Knight, and C.R. Bradley, "Constraints on burial depth and yield of the 25 May 2009 North Korean test from hydrodynamic simulations in a granite medium," *Geophysical Research Letters*, Vol. 38, L16316 (30 August 2011).

However, the second launch failed instantly when the rocket apparently hit the gantry. Its third test, in April 2009, successfully lifted the first two stages over the Pacific, but the third stage failed.

We have much less information about its nuclear exports. However, evidence is overwhelming that Pyongyang built a plutonium-producing reactor for Syria that was destroyed by an Israeli air raid in September 2007. It appears quite likely that it exported to Libya uranium hexafluoride, the precursor to highly enriched uranium (HEU). There are also grounds to suspect nuclear cooperation with Pakistan and Burma.[13] Cooperation with Iran is the greatest concern because Iran is putting in place all of the pieces for a nuclear weapons option, and its nuclear capabilities complement those of North Korea.[14]

Recent nuclear developments (2010 - 2012)

The end of 2011 marked the third year of diplomatic standoff between North Korea and the United States. North Korea's third long-range missile launch in 2009 resulted in anticipated United Nations condemnation, which, in turn, triggered Pyongyang's expulsion of the international inspectors from its Yongbyon nuclear complex followed by withdrawal from the six-party talks and by a second nuclear test. The year 2010 was marked by clashes and a dangerous spike in tensions on the Korean peninsula – namely the sinking of the South Korean Corvette, the Cheonan, and the North Korean shelling of Yeongpyeon Island. In contrast, 2011 was a year of diplomatic calm and rapprochement until the death of Kim Jong-il and the leadership transition to his young son, Kim Jong-un.

With the transition barely under way, it was surprising that in late February North Korea agreed to implement a moratorium on long-range missile launches, nuclear tests and nuclear activities at Yongbyon, including uranium enrichment activities, in return for American nutritional aid.[15] Washington and Pyongyang issued independent statements describing the agreement that differed slightly, but significantly, exposing important unresolved issues that must be addressed before each party will agree to return to the six-party negotiating table. Pyongyang also agreed to allow IAEA inspectors to monitor the moratorium on uranium enrichment activities at Yongbyon.[16] This agreement was necessary to prevent the nuclear crisis in North Korea from getting worse. I will first describe the troubling nuclear developments in the past two years

[13] The evidence for North Korean assistance to Syria is strong; see David Albright and Paul Brannan, "The Al Kibar Reactor: Extraordinary Camouflage, Troubling Implications," Institute for Science and International Security (ISIS) Report, May 12, 2008, http://isis-online.org/publications/syria/index.html. Evidence of cooperation with Libya is less conclusive, yet likely; see David E. Sanger and William J. Broad, "Tests Said to Tie Deal on Uranium to North Korea," *The New York Times*, February 2, 2005. Evidence of nuclear cooperation with Burma is weak, but possible; see Julian Borger, "Burma suspected of forming nuclear link with North Korea," Guardian.co.uk, July 21, 2009, http://www.guardian.co.uk/world/2009/jul/21/burma-north-korea-nuclear-clinton.

[14] Siegfried S. Hecker and William Liou, "Dangerous Dealings: North Korea's Nuclear Capabilities and the Threat of Export to Iran," *Arms Control Today* 37 (2) (2007), http://www.armscontrol.org/act/2007_03/heckerliou; and Siegfried S. Hecker, "From Pyongyang to Tehran, with nukes," op-ed, *Foreign Policy* (May 26, 2009).

[15] Statement on "U.S.-DPRK Bilateral Relations." U.S. Department of State, February 29, 2012, Washington D.C. and "DPRK Foreign Ministry Spokesman on Result of DPRK-U.S. Talks." Korea Central News Agency (KCNA), February 29, 2012. Pyongyang, North Korea.

[16] The American statement includes the language "and confirm the disablement of the 5-MWe reactor and associated facilities, whereas the North Koreans state "while productive dialogues continue." The North Korean statement also adds "Once the six-party talks are resumed, priority will be given to the discussion of issues concerning the lifting of sanctions on the DPRK and provision of light water reactors." The American statement does not include these provisions.

before offering some suggestions on how to proceed toward the goal of the denuclearization of the Korean peninsula.

During the diplomatic calm of 2011, Pyongyang revealed very little about its nuclear progress, but all signs pointed to a continuing march toward a more threatening nuclear weapons capability. The most alarming development was a combination of two things: the operation of modern uranium centrifuge facility and the presence of road-mobile intermediate-range ballistic missiles (IRBM). An added source of stress is North Korea's likelihood of cooperating with illicit nuclear programs of other countries, such as Iran, and the likelihood of it importing and exporting nuclear technologies to expand its own programs or aid those of others.

Light water reactor

In 2010, North Korea greeted the world with the announcement that they would build an indigenous LWR and enrich uranium domestically to fuel it.[17] During my 2010 visit to Yongbyon with Stanford colleagues John Lewis and Robert Carlin, we confirmed that construction had begun on a 25-30 megawatt-electric (MWe) LWR and that the North Koreans had built a modern, sophisticated uranium enrichment facility, ostensibly to provide fuel for the reactor. Commercially available satellite imagery allows us to track progress of North Korea's LWR construction from September 26, 2010 (just prior to our visit) to February 3, 2012 -- as shown in Figure 1. Early images indicate that the construction of this new LWR began in late September 2010, near the site of the destroyed cooling tower of the 5-MWe gas-graphite reactor. One of the latest available close-up overhead images taken on February 3 (Figure 2) shows that many of the reactor's external structures are almost complete. Much progress has been made on the turbine generator hall; a traveling crane rail was installed and the roof just completed.

Using overhead images from Figure 2, a 3-D model (Figure 3) of the LWR was constructed.[18] Our analysis confirms Pyongyang's plan to use this experimental reactor for electricity production. The rapid progress of construction also demonstrates that North Korea still has impressive manufacturing capabilities, in spite of the last two decades of economic downturn. However, we view this progress with alarm given the safety concerns associated with building and operating an LWR. What is especially troubling is that this is a new endeavor for North Korea and its technical specialists have not been part of the global nuclear safety community. These concerns were exacerbated by the nuclear accident at the Fukushima Daiichi Nuclear Power Plant in March 2011.

Uranium enrichment

During our November 2010 visit to Yongbyon, we were stunned to find a newly constructed, modern 2,000-centrifuge uranium enrichment plant.[19] Our visit answered some questions regarding the North's nuclear facilities at Yongbyon, but it raised many more. Though the

[17] "N.Korea to Build Light Water Reactor Soon: State Media," Agence France-Presse, 29 March 2010. The North Korean's MOFA announced that they would build an indigenous LWR in April 2009 as well, but the 2010 pronouncement was considered more significant.

[18] See N. Milonopoulos, S. Hecker and R. Carlin, "North Korea from 30,000 feet," *Bulletin of the Atomic Scientists*, 6 January 2012 [http://thebulletin.org/web-edition/features/north-korea-30000-feet]

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

Yongbyon uranium centrifuge enrichment facility looked complete, we were unable to verify that it was operational. We were told that the facility was producing low enriched uranium (LEU) destined for the small, experimental LWR under construction; the facility appeared to house sophisticated centrifuges (apparently of the P-2 or G-2 design) and was sized properly for production of fuel for the experimental LWR.[20] We were also told that the facility became operational just a few days before our arrival, but we were unable to corroborate that. Whatever its status during our visit, the facility may be fully operational now, more than a year later. They may also have run into the typical difficulties of getting centrifuge cascades to operate smoothly, so we don't know how much LEU has been produced to date, what the current production rates are, or what is the disposition of any LEU that has been produced to date. Although the facility is likely producing LEU for the reactor, it could conceivably be producing HEU bomb fuel. And if it is configured to do this, the reactor could produce roughly 40 kilograms of HEU annually, enough for at least one bomb.

As far as I know no foreigners have been given access to the facility since our November 2010 visit. Our requests for a return visit have so far been denied. By tracking the construction of the Yongbyon centrifuge plant via overhead imagery, however, we conclude that North Korea must also have an undisclosed, pilot-scale centrifuge facility elsewhere to have made it possible for such rapid installation progress at Yongbyon. Figure 4 is a rough schematic of the interior layout of the Building 4, which was renovated from the former fuel rod fabrication plant to a centrifuge hall. In the November 2010 visit, we observed approximately 2,000 centrifuges, divided into six cascades, from the second-floor observation platform identified in the diagram. Figure 5 represents a 3-D model of the exterior of the Building 4 renovated centrifuge building. Unless Pyongyang allows access to this facility as part of the new agreement, however, the world will not know if it is fully operational or much else about its sophistication or that of other undisclosed centrifuge facilities.

The Yongbyon centrifuge facility could not have been constructed from scratch and made operational in only 18 months, between April 2009 and November 2010, as Pyongyang has claimed. It is likely that the North had one full cascade (about 340 centrifuges) operational at a separate site long before it moved into the renovated Yongbyon fuel fabrication building and revealed their centrifuge program in November 2010. The size of any clandestine program is likely constrained, but constrained or not, North Korea may be producing some HEU now, and may have been doing so for some time.

Plutonium

The Yongbyon plutonium facilities remained dormant in 2011. The 5-MWe plutonium production reactor, operational since 1986, was shut down in July 2007 and has not been restarted. The reprocessing facility ceased operations in 2009, but remains in stand-by status. Presently, North Korea is not producing any plutonium and there is no plutonium in the pipeline. The key facilities could be reactivated if necessary; it would take approximately six months to do

[20] Yongbyon officials claimed an annual throughput capacity was 8,000 separative work units (the measurement of the separation during the enrichment process), indicating that the centrifuges were second generation, or so-called P-2 s; first generation centrifuges, by comparison, produce an annual throughput capacity of about 2,000 separative work units (Hecker, 2010).

so.[21] Therefore, my estimate that North Korea has roughly 24 to 42 kilograms (approximately four to eight bombs worth) of plutonium still holds today.

The decision to pursue uranium enrichment instead of plutonium production is puzzling – *if* Pyongyang simply wants to make more bomb fuel.[22] The missing piece of the puzzle, however, is that Pyongyang has long sought LWRs for electricity production, first from the Soviet Union and then from the United States[23] – and this type of reactor fuel requires enrichment, which, in turn, opens the door to the weapons option since the centrifuge facilities needed for the reactors can also be converted to produce weapon-grade HEU bomb fuel. Thus, choosing the uranium route provides Pyongyang with a viable dual-track option – LEU for nuclear electricity with LWRs and HEU for the second route to the bomb to augment its small plutonium bomb inventory.

Nuclear weapons and delivery systems

Pyongyang has the bomb but not much of a nuclear arsenal. We have reasonable confidence in the number of bombs – roughly four to eight – because plutonium inventories are easy to assess, but we simply don't know their sophistication. Since it has shut down its plutonium facilities, Pyongyang apparently is not planning to increase the number of plutonium bombs significantly.

We assume the North is working on missile-capable nuclear systems, but employing miniaturized nuclear warheads will require more nuclear tests. Satellite imagery captured in 2011 showed preparations for what possibly could be another test tunnel, which is located near the two previous tests in the Kilju region.[24] Hence, the nuclear test moratorium agreed to in the February statements is particularly important to halt Pyongyang's drive toward more sophisticated, smaller nuclear weapons that could be mounted on their missiles. If Pyongyang breaks the test moratorium, it will almost certainly be a test of a miniaturized design, but we don't know if it will be with plutonium or HEU.

In October 2010, North Korea publicly exhibited, for the first time, a road-mobile intermediate-range ballistic missile at a military parade in Pyongyang. Dubbed the "Musudan" by US intelligence services, the IRBM can travel an estimated 3,000 to 5,000 kilometers, apparently farther than any other missile in the North Korean arsenal.[25] Although never flight-tested, the missile represents a big step forward for Pyongyang, because it is road mobile and, hence, difficult to find. In June 2011, then-Defense Secretary Robert Gates expressed concern that North Korea had also been developing a road-mobile intercontinental ballistic missile (ICBM).[26]

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[21] If reactivated, the reactor is capable of producing only six kilograms of plutonium, roughly one bomb's worth, per year.

[22] Plutonium is used in all states with nuclear weapons. China switched from HEU to plutonium early on in its program, and Pakistan has begun to employ plutonium in addition to HEU.

[23] See Siegfried S. Hecker, Chaim Braun, and Robert L. Carlin, "North Korea's Light-Water Reactor Ambitions," *Journal of Nuclear Materials Management*, Vol. 39, No. 10 (Spring 2011).

[24] "North Korea Prepared to Detonate Third Nuclear Device, South Says," *Global Security Newswire*, 19 April 2011, available at http://gsn.nti.org/gsn/nw_20110419_5975.php.

[25] "North Korea Rolls out Ballistic Missiles," *Global Security Newswire*, 13 October 2010, available at http://gsn.nti.org/gsn/nw_20101013_1452.php.

[26] In June 2011, then-U.S. Secretary of Defense Robert Gates noted, "With the continued development of long-range missiles and potentially a road-mobile intercontinental ballistic missile and their continued development of nuclear weapons, North Korea is in the process of becoming a direct threat to the United States," available at http://www.iiss.org/conferences/the-shangri-la-dialogue/shangri-la-dialogue-2011/speeches/first-plenary-session/qa/. Also available at

Nuclear cooperation, imports, and exports

Though 2011 cast little light on North Korea's nuclear relationships with outside countries, there is certainly cause for increased concern, considering developments like the Musudan and the new uranium enrichment facilities at Yongbyon. North Korea has a history of being a quick study (it became self-sufficient for the entire plutonium fuel cycle after initial help from the Soviets) and enterprising (Pyongyang almost certainly built a plutonium production reactor for Syria).[27]

North Korea has historically relied on importing key materials and components for its uranium centrifuge program. I believe it still does not have all the requisite capabilities today and has to rely on imports to expand its program. The centrifuge facility we were shown in 2010 apparently benefited from imports from Europe, Russia, Japan, and the A. Q. Khan network prior to 2003. It also profited from training and consultation with Pakistani enrichment specialists in the Khan Research Laboratories (KRL).[28] Today, the most likely acquisition route for key materials and components is through China.[29]

Over the past 10 years, North Korea has developed a uranium export business, supplying Libya with 1.8 metric tons of uranium hexafluoride before Muammar Qaddafi terminated the program in 2003.[30] The reactor built for Syria by North Korea at Dair Alzour also would have provided a lucrative fuel export business for North Korea had it not been bombed by Israel in 2007.[31] In 2011, Pyongyang may have continued to export nuclear technologies, knowhow, and precursor materials like uranium hexafluoride or, potentially, HEU itself to dangerous states. None of these are easy to detect or easy to stop. The footprint for uranium centrifuge activities is small, detection is difficult, and Pyongyang could claim exports are for civilian applications.

Virtually all North Korean missiles are copies or derivatives of Soviet missiles. More than 20 years ago, Pyongyang turned from import to export, becoming the major supplier of missiles and the means to manufacture them to the most unstable parts of the world. Their export business has slowed down considerably,[32] but it appears that North Korea is now collaborating closely with Iran's missile establishment.[33] Nuclear cooperation between North Korea and Iran, including the export and import of sensitive nuclear and missile technology, could greatly benefit both

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http://www.thedailybeast.com/articles/2011/06/21/robert-gates-interview-his-lingering-concerns-about-u-s-supremacy-nuclear-proliferation-and-more.html.

[27] There is little chance that North Korea has done this anywhere else. Additionally, reactors are difficult to hide and are vulnerable to foreign intervention, as was demonstrated by Israel's destruction of the Syrian reactor in 2007.

[28] Siegfried S. Hecker, Chaim Braun, and Robert L. Carlin, "North Korea's Light-Water Reactor Ambitions," *Journal of Nuclear Materials Management*, Vol. 39, No. 10 (Spring 2011): pp. 18-25.

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

[30] International Atomic Energy Agency Board of Governors General Conference, "Application of Safeguards in the Democratic People's Republic of Korea," GOV/2011/53-GC(55)/24, 2 September 2011, pg. 10, Sec. 50.

[31] International Atomic Energy Agency Board of Governors, "Implementation of NPT Safeguards Agreement in the Syrian Arab Republic," GOV/2011/30, 2 May 2011, pgs. 1-9. http://www.iaea.org/Publications/Documents/Board/2011/gov2011-30.pdf

[32] Joshua Pollack, "Ballistic Trajectory: The Evolution of North Korea's Ballistic Missile Market," *Nonproliferation Review*, Vol. 18, No. 2 (July 2011): p. 411-429.

[33] See *Iran's Nuclear and Missile Potential: A Joint Threat Assessment by U.S. and Russian Technical Experts*, (East-West Institute, May 2009), available at http://docs.ewi.info/JTA.pdf; Also see Mark Fitzpatrick, ed. *North Korean Security Challenges: A net assessment*, A IISS Strategic Dossier (London: The International Institute for Strategic Studies, July 2011): p. 179-182.

countries – reactor, plutonium, and weapons technologies from North Korea to Iran; centrifuge technologies and missile technologies in both directions.[34]

Prospects of resolution of the North Korean nuclear crisis

In the short term

The centrifuge revelations in 2010 complicated an already gridlocked diplomatic six-party process, particularly reinforcing the hardliners' stance in Washington and Seoul against diplomatic engagement with Pyongyang. At the same time, events in Libya reinforced Pyongyang's conviction that ceding ground on the nuclear front is dangerous and possibly fatal.

Despite these negative developments, in February 2012 North Korea and the United States agreed on a moratorium on nuclear and missile testing and suspension of the enrichment plant in Yongbyon. North Korean – U.S. negotiating history, and the fact that the two sides issued statements with somewhat different language, suggest that this new negotiation will be difficult and drawn out. Both sides reaffirmed their commitment to the September 19, 2005 Joint Statement (for realizing the denuclearization of the entire Korean peninsula) and recognized that the 1953 Armistice Agreement is the cornerstone of peace and stability on the Korean peninsula until the conclusion of a peace treaty. But they have different views of what denuclearization means and what will be required to verify and monitor it.

In the short term, preventing Pyongyang from substantially enhancing its nuclear program is the best that we can hope to achieve. Denuclearization remains the long-term goal; but the six parties must be prepared to address broader political, security and economic issues in North Korea and Northeast Asia.

Although the American and North Korean statements have significantly different language reflecting their different expectations, the basic bargain – a nuclear moratorium for nutritional aid – should allow them to get back to the six-party table and begin to take meaningful steps to reduce the nuclear risks and address Pyongyang's broader concerns. Below, I outline some potential steps that should be considered early in the next round of negotiations.

Uranium enrichment. While I believe the existence of a clandestine uranium enrichment facility is highly likely, I do not know how large and how sophisticated such a facility (or facilities) may be – and if these facilities are producing LEU or HEU, or both. This undeclared facility is unlikely, however, to house a large number of centrifuges, because I believe North Korea must still import some of the key materials and components (such as high-strength maraging steel and aluminum alloys) in order to construct large numbers of centrifuges. Since it is highly unlikely that Pyongyang will admit the existence of such facilities (and even less likely to allow access), the most important near-term step is for the IAEA or a U.S. technical team to get access to the known Yongbyon centrifuge facility. Access will likely be a major point of contention in the next round of discussions; Washington will argue for full access and intrusive inspection, Pyongyang will likely try to keep inspectors stationed outside the centrifuge hall with no access claiming that it, like all other centrifuge plant operators in the world, has a right to protect its proprietary technologies. Washington should press to get access at least as intrusive as what the

[34] These concerns were previously expressed by Siegfried S. Hecker in 2009 (Foreign Policy) and have been reinforced by the recent IAEA report by the Board of Governors (IAEA Board of Governors, 2011b).

IAEA currently has at other centrifuge facilities it inspects, including those at Iranian plant in Natanz and the Brazilian enrichment plant in Resende.

The greatest risk posed by North Korea's centrifuge program is that it may be configured to produce large quantities of HEU that could greatly increase the number of nuclear weapons it could field. I do not believe this is currently possible. Highly enriched uranium does offer the simplest and most assured route to a primitive bomb – the so-called "gun assembly" used for the Hiroshima device. However, Pyongyang has already demonstrated a simple plutonium bomb, so there is no obvious benefit for North Korea to produce a simple HEU bomb, unless they build many of them (which they cannot do with plutonium since no more plutonium is currently being produced in North Korea). Using HEU can offer some benefits, including its use for building a more sophisticated, miniaturized nuclear warhead, but such a design would have to be tested before Pyongyang could have any confidence to mount one on a missile. Information on such design(s) was distributed to various clients of the A.Q. Khan network and may also be available to North Korea.

It is crucial, therefore, to stop Pyongyang from importing large quantities of key centrifuge materials and components in order to prevent North Korea from building large additional centrifuge facilities now that it has apparently mastered the art of manufacturing and operating such facilities. Whereas previous supply routes for such materials and components likely originated in Europe and Russia or via the A.Q. Khan network in Pakistan and Malaysia, the most likely routes today go through the enormous and ill-controlled Chinese industrial sector. It should be our first order of discussion with China to help shut down such potential routes. Additionally, as part of the moratorium process, Washington should also attempt to place all LEU that may already have been produced at Yongbyon under IAEA safeguards to prevent potential subsequent conversion to HEU in undeclared North Korean enrichment facilities.

The light-water reactor. There is no mention in the February statements of the fate of the experimental LWR being constructed at Yongbyon. The North Korean statement hints at the potential prospect that it may be willing to abandon that project since it asks for the provision of an LWR, which indicates Pyongyang is willing to get assistance and financial support in constructing a new LWR. The Agreed Framework had provisions for two modern, commercial LWRs of 1,000 MWe (compared to the Yongbyon experimental LWR designed for 25 to 30 MWe). The LWR issue need not be addressed at this time. Even if North Korea continues with the construction of the experimental LWR, it will take at least a couple of additional years before it can become fully operational. Moreover, as long as operation of the Yongbyon centrifuge plant remains suspended, the reactor cannot be fueled because it is highly unlikely that sufficient fuel has already been produced or that a clandestine facility has the capacity for sufficient LEU fuel.

In the longer term, it could well be that a provision of a modern, moderately-sized LWR may be the best way of keeping Pyongyang from completing and operating its own reactor with questionable safety credentials. An LWR reactor could be provided with guaranteed fuel supply and take-back arrangements. This, in turn, would eliminate the need for North Korea to have its own enrichment and reprocessing facilities, thereby removing the primary proliferation concerns. Pyongyang was prepared to accept this kind of arrangement a few years ago. However, it may be

more difficult to get Pyongyang to agree to give up its modern centrifuge plant now that it has shown the world that it can build one.

Currently, it is politically impossible to consider providing an LWR unless it is part of a bargain in which Pyongyang agrees to give up its nuclear weapons and consents to intrusive monitoring and verification mechanisms. If such a bargain can be worked out, Washington and its partners should consider revisiting the KEDO arrangement.[35] Alternatively, either China or Russia could supply a moderate size LWR for North Korea. Another possibility for long-term consideration in a weapon-free Korean peninsula is to help Pyongyang convert its HEU-fueled IRT-2000 research reactor to LEU fuel to produce medical isotopes that North Korea's medical community could use and/or sell to neighboring countries. An even better solution may be to have South Korea build a version of its world-class research and isotope production reactor, the HANARO Reactor, for North Korea to produce medical isotopes. Seoul has just signed a deal to build such a reactor for Jordan.

The Yongbyon plutonium production complex. Our 2010 visit to Yongbyon confirmed the fact that the 5-MWe reactor and the reprocessing facility were not operational and a key building in the fuel fabrication facility used for fuel rod fabrication for that reactor was converted into the centrifuge hall. The chief engineer told us that these facilities are in stand-by, but they could be reactivated.[36] One of the first orders of return to six-party negotiations should be to have Pyongyang take the steps necessary to permanently shut these facilities. These steps should involve permanently disabling the core of the reactor (that can be done by a number of means), selling the roughly 14,000 natural uranium metal fuel rods (which make up more than one full core load of new fuel) and dismantling the front end of the plutonium reprocessing facility so that it would no longer be able to accept spent fuel. These actions will effectively and irreversibly shut Yongbyon's plutonium production facilities. To date, the facilities have been frozen several times, but never permanently taken out of commission. Eventually, Pyongyang must address the decommissioning and decontamination of the buildings and site.

Nuclear weapons and delivery systems. The nuclear test and long-range missile launch moratorium was the most critical step to take. Another positive step would be for Pyongyang to agree to permanently destroy the test tunnel that has been prepared for a third nuclear test, and completely abandon the test site. It is also imperative that North Korea not share its nuclear testing facilities or data with Iran. In due time, a complete declaration of fissile materials and nuclear weapons inventories must be put on the negotiating table. In the longer term, Pyongyang must declare its entire nuclear program and be willing to have its dismantlement monitored and verified. Likewise, an accounting of the number of Musudan road-mobile missiles and other long-range missiles must be addressed.

Nuclear exports and imports. North Korea's exports of nuclear technologies or fissile materials can destabilize other parts of the world, like the Middle East. In our discussions with Pyongyang diplomats, we were told that they are prepared to discuss halting all "horizontal and vertical"

[35] The Agreed Framework negotiated in three substantive sessions (July 1993, August 1994, and September/October 1994) produced an agreement to construct two modern 1000-MWe LWRs in North Korea as part of a consortium eventually known as the Korean Peninsula Energy Development Organization (KEDO).

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

proliferation – meaning no export and limiting the size of their own arsenal. The export issue must be addressed early on once negotiations resume. It will be one of the most difficult concessions to achieve because it is difficult to verify and shutting down exports potentially represents a significant loss income of foreign currency for the regime.

Although I expect the negotiations to be difficult and drawn out, the process has begun. At this point, the most important first steps have been taken by the new Kim regime with the February 29 agreement. It is difficult to predict which twists and turns the process of negotiations will take, but at least the process of negotiations has resumed. The steps that I outline above are ones that I believe will enhance the security of South Korea and the United States, and should be acceptable to the other parties. It will be up to the negotiators to determine what it takes to address Pyongyang's concerns – food aid alone won't suffice. Washington will have to address Pyongyang's fundamental insecurity and future energy and economic needs. Washington and Seoul will have to overcome domestic politics to do so. The young North Korean leader will have to be willing to seek a better future for his destitute people.

In the long term – will Pyongyang give up its nuclear weapons?

Although Pyongyang continues to claim that it is committed to the September 19 Joint Statement on the denuclearization of the Korean peninsula, it has made it clear that it is not prepared to give up its nuclear weapons any time soon. Nuclear weapons have become central to Pyongyang's projection of military might. North Korea views them as crucial to the regime's survival. They also appear to play a supportive role domestically for the regime and provide it with international diplomatic leverage.[37] The reasons why the regime believes it needs the bomb are deeply rooted in history and, hence, are unlikely to be resolved by alliances with its neighbors, each of which, North Korea believes, to have ulterior motivations. With its great mistrust of the United States, the regime will require much more than another security guarantee from Washington to make it feel secure.

Even if North Korea's security fears are assuaged, domestic factors may favor keeping the bomb. The external threat environment is used by the regime to justify the need for the bomb and the sacrifices North Korea's people continue to be asked to make. That threat also helps keep its people submissive and isolated from the international community. It also helps the regime control all information and to blind its people to progress in the rest of the world, especially south of the Demilitarized Zone. However, the recent exponential growth of cell phone ownership in North Korea, which now tops around one million, will eventually undermine the regime's rigid control.[38]

It is unlikely that North Korea can be forced to give up the bomb. Realistically, military options are off the table unless North Korea initiates a conflict. Additionally, sanctions are mostly ineffective without China's support, but China will not support sanctions that bring Pyongyang to its knees. It wants peace and stability on the Korean peninsula, which Beijing believes is best achieved if Pyongyang reforms its economy and opens up along the lines of what China did some thirty years ago.

[37] Siegfried S. Hecker, "Lessons learned from the North Korean nuclear crises," *Daedalus*, Winter 2010, pp. 44–56.
[38] Alexandre Mansourov, "North Korea on the Cusp of Digital Transformation." The Nautilus Institute Special Report, October 20, 2011

Pyongyang will give up its nuclear weapons only if the benefits of giving them up outweigh the cost of keeping them. The cost of its nuclear program has been, and continues to be, enormous. The resulting isolation from international commerce along with its military-first policy and centrally controlled economic system has led it to a state of abject poverty in contrast to its free market southern neighbor. Ironically, Kim Jong-un may be trying to protect his regime against imagined external enemies while its primary threats are internal and economic – a situation perhaps not unlike that in the dying days of the Soviet Union.

North Korea's nuclear choice and current economic status stand in stark contrast to that of South Korea. Although South Korea explored the development of nuclear weapons,[39] it abandoned its fledgling weapon program because of heavy pressure from Washington and strengthened U.S. security guarantees. As part of South Korea's drive to become an international economic powerhouse, it began to build a robust nuclear power program, initially with western technology and assistance, but eventually developing an impressive indigenous capability. South Korea has developed its nuclear program in a transparent manner with good cooperation with the IAEA.[40]

Today, South Korea has 23 modern LWRs producing 31 percent of its electricity.[41] It has a strong nuclear research establishment in the Korean Atomic Energy Research Institute (KAERI). Together with industrial giant Daewoo, KAERI recently signed a contract to build a research reactor for Jordan. South Korea now harbors realizable ambitions of becoming one of the world's leading exporters of nuclear power plants. The December 2009 award of a $20.4 billion contract to build the first power plants in the United Arab Emirates stands as an example of this budding global role.[42] Now, South Korea has too much to lose economically to consider developing a nuclear weapons option. In fact, it tries to be especially transparent and compliant so as not to jeopardize its export business. By contrast, the North has no nuclear electricity today and little prospect for indigenously developing any significant amounts for the next decade. North Korea's scientists and engineers are cut off from the rest of the world. Their exports have all been illicit and are drying up. They have a handful of bombs, but at a large price.

I draw the contrast between the North and South not to suggest that North Korea could have done as well if it had pursued nuclear electricity instead of bombs, but to demonstrate that North Korea could have much to gain in the future by trading its military program for a civilian one. Given its sorry economic state, North Korea has few other opportunities than to give up its nuclear weapons program to improve its dire economic condition.

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[39] South Korea first explored the plutonium route by conducting experiments to irradiate uranium rods in a research reactor and reprocessing them in a hot cell laboratory in 1981. This was likely a precursor to designing a reprocessing plant, after U.S. pressure stopped an attempted acquisition of such a plant from France. These experiments were disclosed and that activity stopped. Past activities thus imply that the South Koreans were interested in obtaining fissile material separation capability either through the uranium or the plutonium route. See, for instance NTI: South Korea Profile; Nuclear Overview. Available at: http://www.nti.org/e_research/profiles/SKorea/Nuclear/index.html

[40] In 2004, South Korean scientists from the KAERI, however, conducted experiments in laser isotopic enrichment of various elements including uranium. These experiments were conducted without informing Korean Ministry officials or IAEA safeguards inspectors. This activity was stopped and fully reported to the IAEA later in 2005.

[41] World Nuclear Association states that South Korea plans to provide 59% of electricity from 40 nuclear plants by 2030. http://world-nuclear.org/info/inf81.html

[42] Margaret Coker, "*U.A.E. awards $20.4 billion contract for four reactors in breakthrough on world stage for Korea Electric Power,"* Wall Street Journal, Dec. 28, 2009.
http://online.wsj.com/article/SB10001424052748704905704574621653002992302.html

I remain optimistic in the long term. To stay in power Kim Jong-un will have to improve the livelihood of his people. He will have to open up his country and reform the North's economy. If his security concerns can be assuaged by China, the United States and South Korea, he may find that the nuclear card gives him significant bargaining leverage. Paradoxically, compared to a more democratic country, an autocracy like North Korea may find it easier to give up its weapons if doing so is seen to help the regime survive, because it does not have to deal with domestic opposition. The challenge for Washington and Seoul will be to focus on how to improve regional security while dealing with their own contentious domestic politics to encourage the North's transition.

Figures

Figure 1 – A time sequence of overhead images of the light water reactor site tracking its development from September 2010 to February 2012. Image Credit: DigitalGlobe and GeoEye

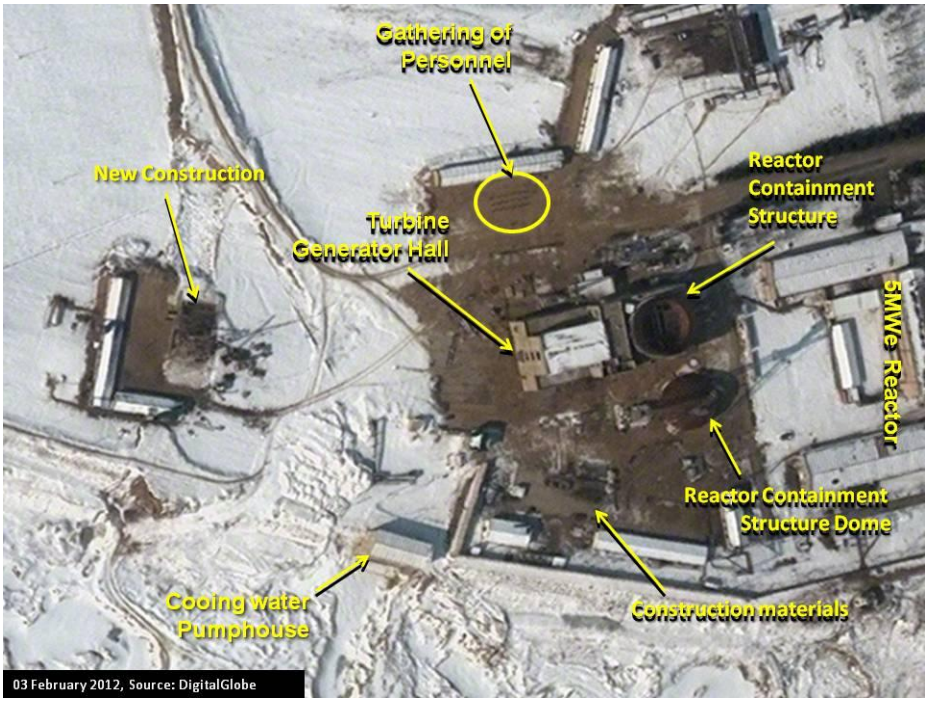

Figure 2 – Image of the experimental light water reactor as of February 3, 2012. Image Credit: DigitalGlobe

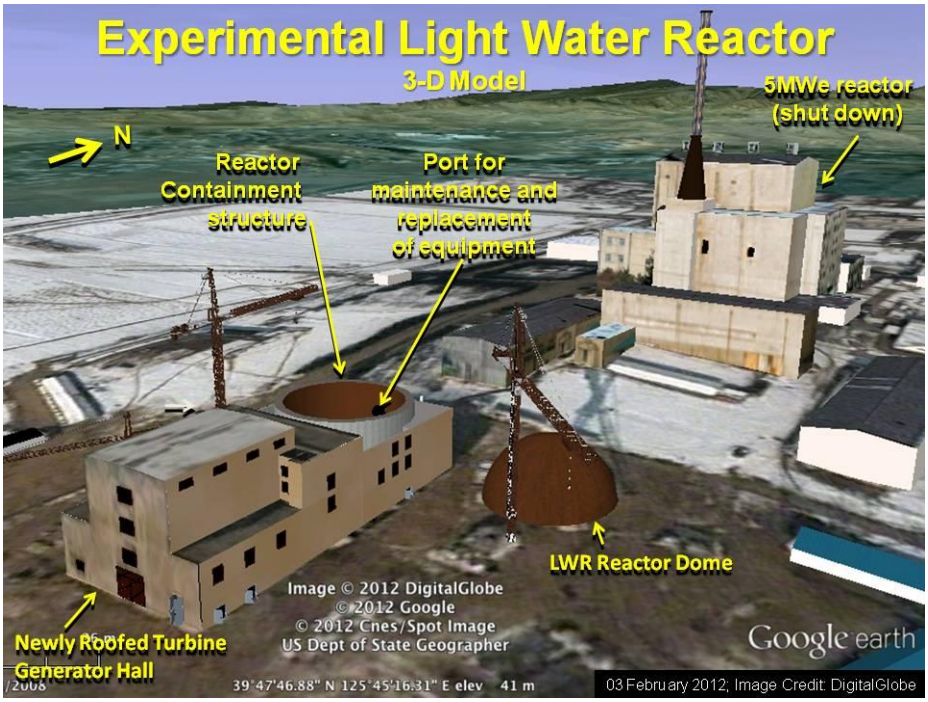

Figure 3 – Three-dimensional model of the light water reactor based on latest satellite images

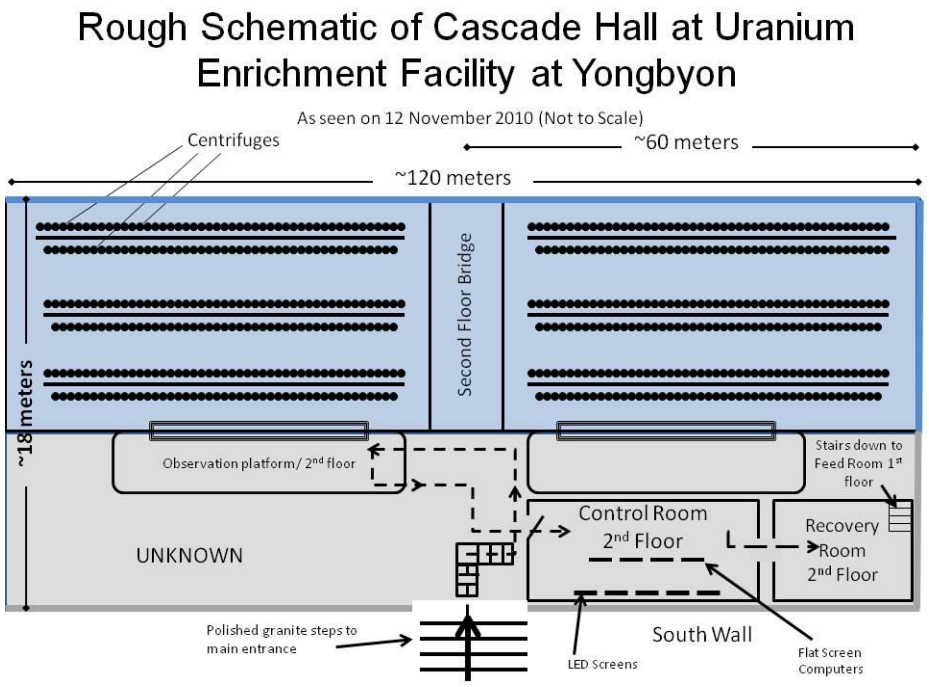

Figure 4 – A rough schematic of the floor plan for the cascade hall at the uranium enrichment centrifuge facility (Building 4) in Yongbyon, as of Nov. 12, 2010.

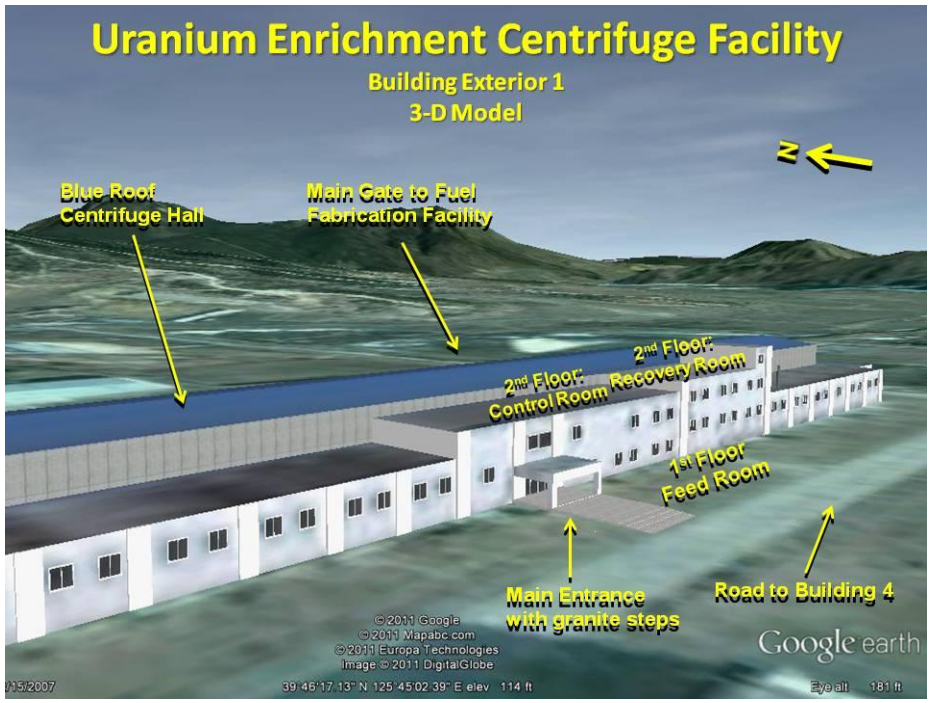

Figure 5 – Three-dimensional model of Building 4 (the new uranium enrichment centrifuge plant) in the fuel fabrication plant, created using the latest satellite images.