A Return Trip to North Korea's Yongbyon Nuclear Complex

Siegfried S. Hecker
Center for International Security and Cooperation, Stanford University
November 20, 2010

Summary

On November 12, during my most recent visit to the Yongbyon Nuclear Complex with Stanford University colleagues John W. Lewis and Robert Carlin, we were shown a 25 to 30 megawatt-electric (MWe) experimental light-water reactor (LWR) in the early stages of construction. It is North Korea's first attempt at LWR technology and we were told it is proceeding with strictly indigenous resources and talent. The target date for operation was said to be 2012, which appears much too optimistic.

At the fuel fabrication site, we were taken to a new facility that contained a modern, small industrial-scale uranium enrichment facility with 2,000 centrifuges that was recently completed and said to be producing low enriched uranium (LEU) destined for fuel for the new reactor. Unlike all previously visited Yongbyon nuclear facilities, the uranium enrichment facility was ultra-modern and clean. We were also told that this facility was constructed and operated strictly with indigenous resources and talent.

These facilities appear to be designed primarily for civilian nuclear power, not to boost North Korea's military capability. That can be accomplished much more expeditiously by restarting the dormant 5 MWe gas-graphite reactor, constructing a new, larger gas-graphite reactor and conducting additional nuclear tests; but we saw no evidence of continued plutonium production at Yongbyon. Nevertheless, the uranium enrichment facilities could be readily converted to produce highly-enriched uranium (HEU) bomb fuel (or parallel facilities could exist elsewhere) and the LWR could be run in a mode to produce plutonium potentially suitable for bombs, but much less suitable than that from their current reactor.

This visit allowed us to answer some questions about Pyongyang's nuclear directions; but it also raised many more. How the United States and its partners respond to these developments may help to shape whether Pyongyang will rely more on the bomb or begin a shift toward nuclear electricity, which it wants both for economic and symbolic reasons.

Yongbyon Nuclear Scientific Research Center

This was my fourth trip to the Yongbyon nuclear complex. During my first visit in January 2004, they showed me a sample of plutonium metal that was reprocessed from the spent fuel rods that had been stored since 1994 as part of the Agreed Framework and subsequently used as bomb fuel for its nuclear test. During all six of my previous trips to North Korea, government officials and technical specialists denied the existence of any uranium enrichment activities. Following the 2009 rocket launch and second nuclear test, Pyongyang expelled the U.S. technical team and international inspectors and declared that it would build its own light-water reactor (LWR) and produce its own fuel. For this visit, I requested to see the key nuclear sites to judge their current status and to see the uranium enrichment technology that they announced in September 2009 to have been successful.[1] On Nov. 12, we were taken to Yongbyon and shown an LWR construction site and a uranium enrichment centrifuge facility.

At the new three-story Guest House, we were met by a small Yongbyon technical team and representatives of the General Bureau of Atomic Energy. The senior technical official gave the following introduction: "In the 1980s and 1990s, we agreed to give up our reactors for LWRs, 2,000 Megawatt-electric (MWe) by 2003. In the early 1990s we built 50 and 200 MWe reactors (of gas-graphite design). Now they have become ruined concrete structures and iron scrap. We have not been able to contribute to the national demand for electricity. So, we decided to make a new start. For us to survive, we decided to build our own LWR. On April 15, 2009, the Foreign Ministry stated that we will proceed with our own LWR fuel cycle. We have completed the discharge of the 5 MWe spent fuel, reprocessed it and delivered it to the military for weaponization.[2] Our nuclear program has not proceeded as expected, we have not delivered electricity and that has impacted the economic condition of our country. We will use our economic resources to solve the electricity problem. We are willing to proceed with the Six-Party Talks and the September 19, 2005 agreement, but we cannot wait for a positive agreement. We are trying our best to solve our own problems. We will convert our center to an LWR and pilot enrichment facility. It is a high priority to develop uranium enrichment. We will have some difficulties with this, but we are proceeding with the LWR fuel cycle. We have designated a site for the LWR and also for uranium enrichment – it is the first stage, so it is first priority. The construction is completed and the facility is operational. You will be the first to see this facility. We showed the LWR construction site to the Korea Economic Institute delegation (Charles L. Pritchard and colleagues)."[3] Our hosts had initially targeted our visit to the complex to last 3.5 hours, including lunch. Unlike in my previous visits to Yongbyon, the technical team clearly had instructions to show us only the basics at two facilities and answer a minimum of questions. We were hurried along at every stage. We eventually spent 3.5 hours at the site before lunch.

Experimental 25 to 30 MWe LWR construction

At the 5 MWe reactor site we were taken to a construction site that had been identified previously from overhead imagery.[4] The chief engineer of the 5 MWe reactor showed us the site and answered questions, but only when pressed. The large excavated pit was roughly 40 meters by 50 meters by 7 meters deep. A concrete foundation 28 meters square with round concrete preforms for the reactor containment vessel was visible. The containment vessel was about one meter high at the time we saw it. We were told it will be 22 meters diameter, 0.9 meters thick and 40 meters high. It is designed for a power level of 100 MW (thermal). He chose not to specify the electrical power, but said

[1] In a September 4, 2009 letter to the President of the UN Security Council, the North Korean permanent representative to the United Nations stated that North Korea's "experimental uranium enrichment has successfully been conducted to enter into completion phase." (Korean Central News Agency – KCNA).
[2] A reference to North Korean action following the expulsion of the U.S. technical team and international inspectors.
[3] This quote is based on our notes of the interpreter's version of the technical official's comments.
[4] David Albright and Paul Brannan,

that the conversion efficiency is typically 30 percent. Therefore, I estimate the electrical power to be roughly 25 to 30 MWe.

This, of course, is much smaller than the two 1,000 MWe LWRs that were being constructed as part of the KEDO project at the Kumho site.[5] They explained that the LWR design is different from their experience base of gas-graphite reactors; hence they are building this small prototype first. Once they have mastered this technology, they will build a bigger LWR. However, even with the 25 to 30 MWe reactor, they will build two electrical generators that will supply electricity to the local communities and be hooked into the national grid. The chief engineer said the construction was started on July 31, 2010. He said the target date for operations is 2012 (which is unreasonably optimistic, but coincides with the centenary of Kim Il-sung's birth and is the target date for most current major projects). There were nearly 50 workers on the floor – all of them dressed in dark blue coveralls and hard hats. We enquired about reactor safety analysis and practices. They claimed to have excavated down to the bedrock and that they had performed seismic analysis of the site.

The pressure vessel will be fabricated out of high-strength steel, possibly with a stainless steel liner. The chief engineer said that they will be able to manufacture it domestically. They will make all the pumps and other reactor components domestically and have the requisite welding capabilities. In addition to the standard propaganda signs, they displayed the following safety sign at the site: "Safety first – not one accident can occur!" I asked if they have a nuclear regulatory agency. The chief engineer said that the National Nuclear Safety Commission has oversight. They submitted their plans to the Commission. They inspect the site. They have nuclear specialists at the Standing Committee and have inspectors on the site.

The reactor will be fueled with uranium dioxide fuel enriched to 3.5%, typical of LWR fuel, but very different from the metallic uranium alloy fuel rods used in the gas-graphite reactor. A full load of fuel is comprised of four tonnes of uranium. In a separate discussion, they reiterated that they had ample domestic uranium ore resources. They were not certain what cladding material would be used, stating that they are still working on many of the details. The reactor design team is a new, young team without reactor design experience. However, they assured us that they would be mentored by the experienced gas-graphite reactor designers. The new designers are in their 40s, graduated from North Korean universities and have spent their careers at Yongbyon. They have not brought any of the North Korean KEDO LWR team members to Yongbyon at this time, but may do so for the operational phase.

Uranium enrichment facility – called the "Uranium Enrichment Workshop"

[5] The Korean Peninsula Energy Development Organization (KEDO) project was to have the United States and other parties build two 1,000 MWe LWRs for North Korea at the Kumho site. It was established in March 1995 as part of the Agreed Framework. The LWR project was terminated in 2006. http://www.nti.org/e_research/official_docs/inventory/pdfs/kedo.pdf

At the fuel fabrication plant we entered what appeared to be a new building about 100 meters long, across from the tall uranium oxide production building. We later identified it as the former metal fuel rod fabrication building, which I had visited in Feb. 2008 to verify their disablement actions. We walked up polished granite steps to the second-floor control room and observation area. The first look through the windows of the observation deck into the two long high-bay areas was stunning. Instead of seeing a few small cascades of centrifuges, which I believed to exist in North Korea, we saw a modern, clean centrifuge plant of more than a thousand centrifuges all neatly aligned and plumbed below us. There were two high-bay areas on each side of the central island. The high-bay areas were two stories high and we were told 50 meters long each. We estimated the width of the bays to be 12 to 15 meters. There were three lines of centrifuge pairs, closely spaced, the entire length of each hall. We were told that they began construction in April 2009 and completed the operations a few days ago. Overhead imagery now shows a building with a blue roof about 120 meters long.

We estimated the centrifuges to be about 8 inches (20 cm) in diameter and approximately 6 feet (1.82 meters) high. They looked like smooth aluminum casings (no cooling coils visible) with three small stainless steel tubes emanating from the top to the central plumbing that ran the length of the facility. The highest horizontal line appeared to be an insulated pipe about 10 cm diameter. The chief process engineer told us (in response to persistent questioning[6]) that the facility contained 2,000 centrifuges in six cascades (one thousand centrifuges and three cascades on each side). He would not provide us with the physical dimensions, stating that the United States would also not release such proprietary information. When asked if they were P-1 centrifuges,[7] he said no. When pressed, he said the rotors were made of alloys containing iron.[8] In response a subsequent question, the chief process engineer implied that the rotors had single bellows. The casings, he said, were made from an aluminum alloy. He claimed all components were manufactured domestically, but modeled after the centrifuges at Almelo and Rokkasho-mura.[9] We were able to extract the most important detail, that is, the enrichment capacity, which he said was 8,000 kg SWU/year.[10] The average enrichment level is 3.5% and the tails are 0.27%. The reactor designers told him to target enrichment levels from 2.2 to 4%.

The control room was astonishingly modern. Unlike the reprocessing facility and reactor control room, which looked like 1950s U.S. or 1980s Soviet instrumentation, this

---

[6] The chief process engineer told us at the outset that they did not want to show us this facility, but their superiors told them to do so. Consequently, they showed us as little as possible, did not volunteer any information, and hurried us along as much as possible.
[7] The P-1 designation refers to the Pakistani design copied from the least advanced URENCO centrifuges. These contain high-strength aluminum alloy rotors and high-strength aluminum alloy casings.
[8] This most likely makes them P-2 centrifuges (which were based on the German G-2, that was developed by the Germans as part of the URENCO consortium), which typically have high-strength maraging steel rotors that can by spun much faster than the aluminum rotors, thereby increasing the throughput.
[9] URENCO's enrichment facilities are located in Almelo, Netherlands and Japanese Nuclear Fuels Limited operates a uranium enrichment facility in Rokkasho-mura.
[10] The kg SWU is an acronym for kg of separative work units. It refers to the amount of isotope separation achieved (separating the fissile U-235 isotope from the non-fissile U-238 isotope).

control room would fit into any modern American processing facility. They had five large panels in the back that had numerous LED displays of operating parameters. They had computers and four flat-screen monitors (similar to ones we saw at the e-Library at Kim Il-sung University in Pyongyang). The monitors had flow diagrams and lots of numbers displayed, but they ushered my past so quickly that I was not able to tell what they signified.

We went into the recovery room, in which we saw two operators, two flat screen panels, and lots of tanks and plumbing. There was a set of steps leading down to the ground floor. There were many small, galvanized steel panels and small tanks, and one big tank in the back. We did not get a good look, but it may have been about one meter diameter and two meters long, horizontally positioned. We were ushered outside as quickly as possible, but continued to ask questions.

I expressed surprise that they were apparently able to get cascades of 2,000 centrifuges working so quickly, and asked again if the facility is actually operating now – we were given an emphatic, yes. We were not able to independently verify this, although it was not inconsistent with what we saw. We probed more deeply into their claims of indigenous fabrication. For example, do they have flow-form machines to make the rotors, and what about the bearings? We received no concrete answers. He claimed that they produce uranium hexafluoride, the feed material for gas centrifuges but which they had never admitted having produced in the past.[11] They said they have sufficient throughput for the size of the centrifuge facility.

I asked again about the fuel – will it be UO_2 and how will they make it? He said the process for learning how to make UO_2 had begun. It is difficult and we will have problems. We cannot get help from the outside, so we have to do it by ourselves. So, he said, we will get started now. Before being whisked away back to the Guest House for a late lunch and departure, in response to my question, the senior Yongbyon official confirmed that they are enriching uranium now in the facility. When I pointed out that the outside world will be concerned about their ability to convert the facility to make HEU, he stated that anyone can tell by looking at the monitors in the control room that the cascades are configured for LEU. Besides, he said, they can think what they want.

Update on status of existing plutonium production facilities

Although we were not specifically taken to the plutonium production facilities, the facilities that we visited were located in the same areas. The 5 MWe reactor, which is adjacent to the new LWR construction site, appeared dormant. There were at least two long barrack-style buildings between the new construction site and the river. We were told that the 5 MWe reactor is in stand-by status with regular maintenance. We were reminded that the cooling tower was destroyed (June 2008) but the chief engineer was confident that they could the reactor should they decide to do so (my previous estimate

[11] In spite of prior North Korean denial, the nuclear materials recovered in Libya in 2003 when Col Gadaffi relinquished his nuclear weapons program were reputed to include a shipment of uranium hexafluoride from North Korea.

was that it would require approximately six months to do so). We were told the fresh fuel, which could be used to refuel the reactor, was still stored in the same warehouse in which I last saw it in 2008 (at the fuel fabrication facility). I was told that there was insufficient time to visit the warehouse.

The 50 MWe reactor, which was near completion in the mid-1990s but abandoned during the Agreed Framework was being dismantled with large cranes. It looked just like the senior Yongbyon technical official described it: "a ruined concrete structures and iron scrap." No activity was apparent at the reprocessing facility as we drove past it. There are several new buildings at the fuel fabrication site, including the one containing the centrifuge cascade halls. That building was previously designated as Building 4, which housed the uranium metal fuel rod fabrication. Its interior was completely reconstructed and its exterior appeared freshly renovated.

To summarize the status of the plutonium facilities; the 5 MWe reactor has not been restarted since it was shut down in July 2007. The spent fuel rods were reprocessed following North Korea's termination of the Six-Party talks in April 2009. No new fuel has been produced and the fresh fuel produced prior to 1994 (sufficient for one more reactor core) is still in storage. Pyongyang, has apparently decided not to make more plutonium or plutonium bombs for now. My assessment is that they could resume all plutonium operations within approximately six months and make one bomb's worth of plutonium per year for some time to come.

Discussion

The findings from this trip answer many questions about the North's nuclear directions, but they also raise at least as many. I will give a preliminary analysis here. Clearly much more will have to be done by many more analysts to understand the implications of these developments in North Korea.

The plutonium program remains frozen, and has perhaps even taken another step backward. They converted the metal fuel rod fabrication facility into the centrifuge cascade halls, thereby making it more difficult to make fuel for the plutonium production reactor. The LWR will produce plutonium, but it is much less suitable for bombs than that from the 5 MWe reactor. In addition, the reprocessing facility operations would have to be reconfigured to reprocess the LWR fuel. My previous estimate of the North Korean plutonium inventory from its 5 MWe reactor of 24 to 42 kilograms (sufficient for four to eight primitive nuclear weapons) still stands.[12]

A North Korean uranium enrichment program has long been suspected. I believe they started early, perhaps in the 1970s or 1980s, but then did not try to accelerate the effort until their dealings with A.Q. Khan in the 1990s. However, the 2,000-centrifuge

[12] Siegfried S. Hecker, "Lessons learned from the North Korean nuclear crises," *Daedalus*, Winter 2010, pp. 44-56.

capability significantly exceeds my estimates and that of most other analysts.[13] We were not able to confirm that the facility is fully operational. It typically requires much more time to bring cascades of this size into full operation.[14] Nevertheless, they have either done it as they claim, or are most likely capable of doing so shortly. With the 8,000 kg-SWU/yr capacity, North Korea could produce up to 2 tonnes of LEU or, if the cascades are reconfigured, up to 40 kg HEU. The LEU capacity is consistent with the requirements of the LWR under construction. It would have to be expanded significantly if North Korea eventually builds a large LWR. Whether LEU or HEU is produced in the facility is easy to monitor with on-site presence or on-site instrumentation. However, the greatest concern is that a facility of equal or greater capacity, configured to produce HEU exists somewhere else. Such a facility would be difficult to detect as demonstrated by the fact that this facility was undetected in the middle of the Yongbyon fuel fabrication site. The only factors that would limit North Korea's ability to build more are the procurement or production of many of the specialty materials and pieces of equipment – such as maraging steel, high-strength aluminum alloys, ring magnets, frequency converters, special bearings, vacuum equipment, flow meters, etc. We have little knowledge of what the North's indigenous fabrication capabilities are. If North Korea claims its uranium program is strictly peaceful, then the burden of proof is on it, especially since they continued to deny it during the Six-Party negotiations.

One of the most puzzling issues is how they got this far? Albright and Brannan[13] recently presented a detailed analysis of the status of North Korea's uranium enrichment program. They demonstrate a clear pattern of cooperation and exchange with Pakistan, including crucial elements such as on-site training of North Korean technical specialists at the Khan Research Laboratory. They also show troubling procurement scheme, particularly with commercial entities in China. I have previously stated my concern about potential cooperation and exchanges in uranium technologies between North Korea and Iran. However, a detailed analysis and reevaluation taking into account the findings from this trip is now in order. A better understanding is important because it will help us better judge the capacity of current and planned North Korean enrichment capacity.

Understanding North Korea's motivation is even more difficult. In the Daedalus essay,[12] I showed how an initially security-driven motivation for the bomb took on important domestic and international dimensions. Pyongyang has clearly stated that it will retain its nuclear weapons as a deterrent so long as U.S. hostile policies persist. North Korean officials with whom we met on this trip made it abundantly clear that there will be no denuclearization without a fundamental change in U.S. – North Korean relations. In the Daedalus article and a subsequent article,[15] I make the case that Pyongyang has seriously pursued nuclear electricity; it has both practical and symbolic importance. It views LWRs as the modern path to nuclear power. It was prepared several

[13] For example, see Hui Zhang, "Assessing North Korea's uranium enrichment capabilities," *Bulletin of the Atomic Scientists,* 18 June 2009 and David Albright and Paul Brannan, "Taking Stock: North Korea's Uranium Enrichment Program," http://isis-online.org/uploads/isis-reports/documents/ISIS_DPRK_UEP.pdf
[14] It took Iran about 20 years to procure, build and operate cascades of this size. Iran has roughly 8,000 centrifuges installed with 4,000 P-1s working for a total capacity of ~ 4,000 kg SWU.
[15] Siegfried S. Hecker, Sean C. Lee and Chaim Braun, "North Korea's Choice: Bombs over Electricity," *The Bridge,* Vol. 40, No. 10, Summer 2010, pp. 5-12.

times in the past to trade its bomb-fuel producing reactors for LWRs. This time we were told, “We have given up; we will do it on our own.” We were reminded that in April 2009 they announced their intention to build an LWR and to make their own fuel, including enrichment. They said, “no one believed us, including you, Dr. Hecker.” They can claim with some justification that the uranium enrichment program is an integral step toward an LWR and nuclear electricity.

I believe that although this peaceful program can be diverted to military ends, the current revelations do not fundamentally change the security calculus of the United States or its allies at this time. Pyongyang has gained significant political leverage already from the few plutonium bombs they have. Building more sophisticated bombs that can be mounted on a missile is better done with plutonium than HEU. However the production of large quantities of HEU and additional nuclear tests would allow them to increase the size of their arsenal. Even more troubling would be the potential of export of fissile materials or the means of producing them, which now include centrifuge technologies. For these reasons, the United States and North Korea should not sit by idle.

Where do we go from here?

Is Pyongyang really pursuing a modern nuclear electricity program? If so, what are its chances of success without outside help? Has Pyongyang decided to abandon its plutonium production complex (or at least keep it dormant)? Does it have additional uranium centrifuge facilities that could easily be dedicated to producing HEU bomb fuel? How did North Korea acquire centrifuge technology at such a level of sophistication and when? Why did Pyongyang decide to show us the facilities now and how does this fit into their broader strategy of how to deal with its domestic and international challenges?

These and other questions will take more time and more people to answer. One thing is certain: these revelations will cause a political firestorm. Some will use them to prove that Pyongyang can’t be trusted. Some will use them to justify the October 2002 U.S. decision to confront Pyongyang about uranium enrichment, which terminated the Agreed Framework. Some, most likely China and Russia, will claim that North Korea is within its sovereign rights to develop nuclear energy. The issue is complicated by the inherently dual-use nature of nuclear technology. It is possible that Pyonyang’s latest moves are directed primarily at eventually generating much-needed electricity. Yet, the military potential of uranium enrichment technology is serious. It is clear that waiting patiently for Pyongyang to return to the Six-Party talks on terms acceptable to the United States and its allies will exacerbate the problem. A military attack is out of the question. Tightening sanctions further is likewise a dead end, particularly given the advances made in their nuclear program and the economic improvements we saw in general in Pyongyang. The only hope appears to be engagement. The United States and its partners should respond to the latest nuclear developments so as to encourage Pyongyang to finally pursue nuclear electricity in lieu of the bomb. That will require addressing North Korea’s underlying insecurity. A high-level North Korean government official told us that the October 2000 Joint Communiqué, which brought Secretary Madeleine Albright to Pyongyang, is a good place to start.