Report on North Korean Nuclear Program

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On Oct. 31 to Nov. 4, 2006, a delegation led by Prof. John W. Lewis, Stanford University, accompanied by Siegfried S. Hecker and Robert L. Carlin of Stanford University, and Charles L. (Jack) Pritchard of the Korean Economic Institute visited Pyongyang, Democratic People's Republic of Korea (DPRK). This report summarizes the findings regarding the DPRK nuclear program based on our discussions with officials from the Ministry of Foreign Affairs, the Korean People's Army, the Supreme People's Assembly, and the Yongbyon Nuclear Scientific Research Center. Three members of our delegation made similar visits to the DPRK in January 2004 and August 2005. Before and after the current trip to the DPRK, Lewis and Hecker also had extensive discussions about the DPRK nuclear program with Chinese officials from the Ministry of Foreign Affairs, the military, the Central Party School, the China Reform Forum, the China National Nuclear Corporation, and the Institute of Applied Physics and Computational Mathematics.

Summary Observations:

This trip provided a status report of the DPRK nuclear program and yielded new, valuable insights related to the nuclear test, the plutonium production capacity, and the status of the nuclear weapons program.

Nuclear test: We were not able to meet with technical specialists responsible for the nuclear test or its design. DPRK political and military officials told us the test was fully successful and achieved its goal. We can still only speculate whether the DPRK nuclear device was designed to produce a relatively low yield with a large, simple Nagasaki-like device or if it was a sophisticated, missile-capable design with smaller dimensions. Although we cannot rule out the more sophisticated design, the more likely option is one proposed by Chinese nuclear specialists; that is, the DPRK tested a simple device of relatively low yield to make absolutely certain that they could contain the nuclear explosion in their underground test tunnel. The Chinese nuclear specialists concluded, "If the DPRK aimed for 4 kilotons and got 1 kiloton, that is not bad for a first test. We call it successful, but not perfect."

Plutonium production: Yongbyon nuclear center Director Ri Hong Sop appeared confident and satisfied with the operations of the 5 MWe reactor (which is accumulating approximately one bomb's worth of plutonium per year), and he is no hurry to unload the fuel rods currently in the reactor. However, it appears that technical difficulties associated with fuel cladding integrity and refurbishment of the fuel fabrication facility may impact the political decision as to when to unload the reactor and process more plutonium. For technical reasons, the DPRK will be able to produce at most one bomb's worth of plutonium per year for the next few years. In addition, technical difficulties are slowing down the resumption of full-scale construction of the 50 MWe reactor, which would increase plutonium production ten-fold. Although a political decision on a full construction restart apparently has not yet been made, these difficulties will put the completion of the reactor and a significant scale-up of plutonium production at least several years into the future. On the other hand, the Yongbyon nuclear center appears to have fully mastered plutonium metal production and casting, including having prepared the plutonium for the DPRK nuclear test. My best estimate is that before the test, the DPRK had separated between 40 and 50 kg of plutonium, sufficient for roughly six to eight bombs. They most likely used approximately 6 kg for their first test.

Nuclear weapons: We know very little about the DPRK nuclear stockpile and the nation's nuclear strategy. DPRK officials stated the role of their nuclear weapons is to deter the United States and defend the sovereignty of their state. The officials we met appeared to have little appreciation for the new challenges they faced for nuclear weapons safety and security that results from the possession of nuclear weapons. They stated that DPRK's commitment to denuclearize remains unchanged in spite of their nuclear test, but it will require the United States to stop threatening the DPRK state. They also pledged not to transfer nuclear weapons to other states or terrorists. Yet, my general impression is that the hurdles to convincing the DPRK to give up its nuclear weapons have increased substantially with its Feb.10, 2005 announcement of having manufactured nuclear weapons and its Oct. 9, 2006 nuclear test. It is essential for the United States to demonstrably address DPRK's security before there is any hope of denuclearization.

Nuclear test:

On Oct. 9, 2006, the DPRK conducted a nuclear test in the northeastern part of the DPRK. On Oct. 16, the U.S. Office of Nuclear Intelligence issued the statement: "Analysis of air samples collected Oct. 11, 2006 detected radioactive debris which confirms that North Korea conducted an underground nuclear explosion in the vicinity of P'unggye on Oct. 9, 2006. The explosion yield was less than 1 kiloton." Reports of seismic signals from around the world ranged from a magnitude of 3.5 to 4.2 on the Richter scale. There is uncertainty in translating these measurements to explosion yield because of lack of knowledge of the exact geology at the test site. Most of the yield estimates reported to date range from 0.2 to 1.0 kiloton.[1,2] Subsequent press reports suggested that there was evidence that the test was of a plutonium bomb.[3] However, such information would be difficult to obtain and has never been officially confirmed.

The director of the Yongbyon nuclear center did not discuss the test results beyond the fact that his facility produced the plutonium metal for the test device. He told us that plutonium metal was used and it was of the type that they allowed me to hold (in a sealed glass jar) during my January 2004 visit to Yongbyon.[4,5,6] He indicated that his responsibilities end with plutonium metal production. The technical specialists associated with nuclear weapons design and testing were not made available for discussion during our visit. So, our questions regarding technical details of the test – such as the type of device, the yield, test diagnostics, and post-explosion diagnostics – remained unanswered.

The diplomatic officials and military officials were not reluctant to discuss the nuclear test. They declared the nuclear test “powerful and fully successful.” Their comments included “the test has given us hope for the future; we are confident and full of pride.” When we inquired about press reports that the nuclear test may have been a failure or only partially successful, they indicated that they are aware of the criticism, but “the criticism does not conform to reality.” They reiterated, “The test was successful. We don’t care what others say. We are confident the test achieved our goals.” All of our DPRK hosts projected an attitude of pride and confidence during this visit.

When asked about why the DPRK decided to test and why now, they responded that the test was “a result of U.S. political pressure. The test is an active self-defense measure.” They also indicated that the nuclear test was legal because the United States withdrew from the Agreed Framework and the DPRK withdrew from the Nuclear Nonproliferation Treaty (NPT). “Without this pressure there would have been no test.” They also indicated that it is quite natural for a nuclear weapons state to test. The United States should not have been surprised. None of the officials we met gave us the impression that they are planning a second nuclear test. We told our hosts that they are the first country to announce its first nuclear test. Moreover, the apparent DPRK explosion yield is much lower than those of the first tests conducted by other countries. Why did they announce their test? The military official answered, “We could either not announce, or announce and make certain that the test is carried out safe and secure. Which is more beneficial and reasonable?” To summarize the DPRK nuclear testing discussions, their officials declared it a successful test of a plutonium nuclear device.

We were told that the DPRK gave both the Chinese and Russian embassies two hours advance notice of the test. We received no definitive response to our question of whether or not this notice included an estimate of the expected explosion yield of the test. We were subsequently told in China by officials from the Ministry of Foreign Affairs and other organizations that China was given the following advance notice about the test: time, location, and an estimated explosion yield of approximately 4 kilotons.

Based on independent seismic measurements around the world, the test had an explosion yield between 0.2 and 1 kiloton. It was confirmed to be a nuclear test based on radioactive air sampling results reported by the United States. A plutonium device is consistent with the DPRK plutonium production program. That is all we know for certain at this time. The explosion yields of the first nuclear test conducted by the seven declared nuclear weapons states range from approximately 10 to 60 kilotons. The Nagasaki bomb yielded approximately 21 kilotons. So, by comparison, the DPRK explosion yield was low.

We can only speculate whether the DPRK nuclear device was designed to produce a relatively low yield with a large, simple device along the lines of a Nagasaki design or if it was a sophisticated design with smaller dimensions and mass so as to fit onto a Nodong medium range missile. A test of a sophisticated device could readily explain the low yield since it is very difficult to get all technical parameters correct the first time. Opting for testing a sophisticated device would represent a big step for a first test. I should add that given the low yield results and without further tests, it is highly unlikely that they have gained sufficient confidence to field such a device on a missile. Although we cannot rule out their willingness to take such a step, I find it more likely that they opted for the more conservative approach of a simple design. Our discussions with Chinese nuclear specialists provided some interesting insight. First, they told us that the Chinese seismic stations close to the DPRK test location recorded a magnitude of 4.1 to 4.2, from which they estimate an explosion yield close to 1 kiloton. They believe that the DPRK opted for a simple design at 4 kilotons to make absolutely certain that they contain the nuclear explosion in their underground test tunnel without massive radioactive leakage.[7] We were told, "If the DPRK aimed for 4 kilotons and got 1 kiloton, that is not bad for a first test. We call it successful, but not perfect." This appeared to be a technical judgment, not one related to the utility of a nuclear weapon of similar design. In my opinion, that is a reasonable assessment based on the facts we have at this time. The availability of plutonium may also affect test decisions in the DPRK. As noted below, the DPRK's weapons-usable plutonium inventory is limited to 40 to 50 kg. Therefore, they will keep the number of tests to a minimum. However, for the first test, I do not believe the amount of available plutonium influenced the decision to test a simple vs. a sophisticated design.

Plutonium production:

The director of the Yongbyon nuclear center, Dr. Ri Hong Sop, met us in Pyongyang to present a status update of Yongbyon nuclear activities. During our January 2004 visit to Yongbyon, he took us to the 5 MWe reactor, the spent-fuel storage pool, and the plutonium reprocessing facility (called the Radiochemical Laboratory). We also drove by the construction site for the 50 MWe reactor and discussed its status. In August 2005, the director provided us a status report on all of these facilities in a meeting in Pyongyang.

The 5 MWe reactor[8]: Director Ri informed us that the reactor was operating but with some restrictions. Although the reactor is operating at its full 25 MWt (thermal power), the output temperature has been reduced to 300°C from 350°C. He indicated that the lower temperature produces higher weapons-quality plutonium, but it reduces the efficiency of the electrical power output. However, the principal reason for lowering the temperature was to avoid fuel cladding failures.[9] "The reactor operators decide the operating temperature based on what is best for the safety of the fuel rods. Replacing fuel rods is time consuming, so running at a lower temperature is more advantageous."

We asked if they had many on-off cycles in reactor operations in the current campaign.[10] He claimed not. They have removed damaged fuel rods a couple of times. They inspect the fuel rods carefully before loading, and they examine them periodically while in the reactor. This is the only time they have lowered the power. He stated, "There have been no big fluctuations in power over the past year. We only did this during planned inspections." He said that in 2005 they were concerned about the fuel rods, but that reprocessing campaign demonstrated that the fuel rods and cladding were generally in good shape. The fuel rods for the third campaign were also all fabricated before the 1994 shutdown prompted by the Agreed Framework. He was not particularly concerned about the current load of fuel rods because these were inspected before loading. Only a small number of rods had corroded. They found replacements for these rods. His overall assessment of reactor operations was that he is happy with reactor operations during the past year. They had to lower the temperature and do some minor maintenance and fuel rod replacements.

We asked about plans to unload the reactor, which has been operating with the current fuel load since June 2005. Director Ri said that from a technical standpoint they would do so sometime next year. However, there are other factors that he does not decide. "The political situation may change. So, sometimes we unload the reactor earlier even though it is less favorable for us technically." When asked about the availability of another reactor core load of fuel rods, he said that at this point they still have a number of fuel rods from the pre-1994 inventory that was inspected by the International Atomic Energy Agency (IAEA). There were insufficient fuel rods for a full reactor core load of 8000 fuel rods.

Fuel fabrication facility: We inquired about the status of the fuel fabrication facility.[11] He stated, "We are finalizing facility preparations now." He indicated that although parts of the original line had collapsed, they were in the final stages of refurbishment now. They expect to begin new fuel fabrication in 2007. It will take them approximately one year to fabricate an entire reactor core of fresh fuel rods. Since they still have spare fuel rods from the previous inventory, they can replace fuel rods as necessary. So, when they shut down the reactor, they plan to have a fresh charge ready to go. If it is decided to shut down the reactor earlier, they will consider doing a partial unloading, replacing the rods in the center of the reactor core first. They would use the remaining spare rods and whatever fresh rods they had fabricated by then. In response to our question of whether or not they had all the materials they needed for the refurbishment, including stainless steel, indigenously, he replied, "Yes we do."

Reprocessing facility and plutonium metal production:[12] Director Ri told us that when they conducted the second reprocessing campaign in 2005, they decided to postpone the waste treatment activity to 2006. That is what they are doing now at Yongbyon, and because of the resulting high radiation levels during this operation, they do not allow outsiders to visit. He confirmed that the 30 percent improvement in throughput in plutonium reprocessing that he mentioned in August 2005 was obtained by replacing some of the mixer-settlers with pulsed columns. He indicated that they made this change only for the uranium – plutonium co-extraction line, not for the entire line because of the complexity of changing an operating line. If they could do it all over again, they would use pulsed columns instead of mixer-settlers in the entire line. When we expressed surprise they were able to make this change at all noting how difficult it is to do in our facilities, he said, "Well we did it. Maybe it shows our technicians are more advanced than yours." Our rejoinder was that, nevertheless, it is a big deal to make these kinds of changes in an operating facility.[13] To this he answered, "Yes, but because of the nuclear threat (meaning the threat from the United States), we had to do this in spite of the risk." We asked again if they had all the necessary equipment indigenously, and the reply was yes. He said they can produce corrosion-resistant steels in the DPRK and all the chemicals are produced domestically, including the tributyl phosphate used in the separations process.

Director Ri also stated with pride that they have mastered the entire plutonium production cycle. They initially designed the Radiochemical Laboratory for a commercial nuclear fuel cycle; that is, “We make plutonium oxalate and plutonium oxide. However, following the U.S. cutoff of heavy fuel oil in Nov. 2002, we decided to resume reactor operation and changed the design of the Radiochemical Laboratory to go from plutonium oxalate, to plutonium oxide, to plutonium tetrafluoride, to plutonium metal, which is then electrorefined, alloyed and cast.” The electrorefining step is to purify the plutonium metal. He stated: “Since we completed the (entire) process and in Feb. 2005, we announced that we have produced nuclear weapons.”

We inquired about the nature of the plutonium metal and shape used for the nuclear test and if it was manufactured at Yongbyon. Director Ri indicated that the metal is of the nature I touched in Jan. 2004. He can’t tell me anything about the shape. They cast the gross plutonium shapes at Yongbyon, the device is fabricated elsewhere beyond his jurisdiction. He also indicated that most of their plutonium research is focused on ensuring a sound cast product. They do extensive examination of the purity, density and uniformity of the plutonium castings. They do little plutonium properties research because most properties of plutonium are well known.

50 MWe and 200 MWe reactors.[14] In Jan. 2004, we drove by the 50 MWe reactor in Yongbyon. The outside of the reactor building looked in bad repair. Apparently, nothing had been done to the site during the Agreed Framework freeze. In August 2005, Director Ri told us that they had completed a design study that concluded that construction of the reactor could continue on its original site with much of its original equipment. He said that the core of the reactor and other components were not at the Yongbyon site. He said their workers are ready to go back to reactor construction, although he did not give us an expected completion date.

During this visit, we were told that virtually nothing had been done at the 50 MWe reactor site and that they have run into some difficulties. Director Ri stated, “We are now in a partial preparation, not in full swing.” The current effort is directed at “recovering the original state of the equipment; for example, removing rust from the steel.” He said, “The main problem is the preparation by other industries, recovery in other factories, not on site at Yongbyon. This is not a simple job, nor a small job. The problem is in outside industrial facilities.” Responding to our question about having all materials for this construction job available within the DPRK, he answered, “It is difficult to import, so we must do everything ourselves. It will take longer.” When asked about the timing of resuming full operations, he said, “I have sent a schedule to the higher level, but have not yet received instructions. I expect to get instructions soon.”

The 200 MWe construction site is at Taechon, about 20 km from Yongbyon. Nothing has been done at the site since the Agreed Framework freeze was instituted in 1994. Director Ri told us last year that they are still studying what to do with the reactor.

He said it is most likely less expensive to start over than to continue on the current site. During this visit, he told us that there is nothing new on this reactor. He said: “We will sequence the decision. First, we will do the 50 MWe reactor, then we’ll address the 200 MWe reactor.”

In summary of plutonium production, the status of the 5 MWe reactor operations, DPRK plans to unload the current reactor core of fuel rods and reprocess them, and future plans for reloading are difficult to assess. Some of the key decisions are clearly high-level political decisions. And, although the Yongbyon leadership appears confident, it appears that technical difficulties associated with fuel cladding integrity and refurbishment of the fuel fabrication facility may impact the political decision. For technical reasons, the DPRK will be able to produce at most one bomb’s worth of plutonium per year for the next few years. It also appears that technical difficulties are slowing down the resumption of full-scale construction of the 50 MWe reactor. Although, a political decision on a full restart apparently has not yet been made, these difficulties will put the completion of the reactor and a significant scale-up of plutonium production at least several years into the future. On the other hand, the Yongbyon nuclear center appears to have fully mastered plutonium metal production and casting, including having prepared the plutonium for the DPRK nuclear test.

Uranium enrichment

We held no discussions during this visit related to potential DPRK enrichment efforts. During our previous visits, the DPRK Ministry of Foreign Affairs officials denied having any part of an enrichment program. We concluded, however, that in light of the suspected DPRK procurement activities in the 1990s, confessions of A.Q. Khan and recent statements by Pakistani President Pervez Musharraf, it is very likely that the DPRK has at least a research-scale uranium enrichment effort. We should note that four years after U.S. Assistant Secretary of State James Kelly first accused the DPRK of having a covert enrichment program, we have no additional information about these activities.

Nuclear weapons

We know even less about DPRK’s nuclear weapons than about their nuclear test. DPRK officials told us that they have demonstrated their deterrent. They emphasized, “DPRK needs the deterrent; otherwise it can’t defend its sovereignty.” We probed their view of nuclear weapons as a deterrent and what they considered their new responsibility now that they have demonstrated a nuclear capability. Specifically, we asked what they are doing to ensure nuclear weapons safety and security. We expressed concern that if they have their weapons ready to use in order to deter, they may be particularly vulnerable to safety and security problems. It would be catastrophic for everyone if one of their weapons detonated accidentally on their own soil. They reiterated that, “The DPRK will not use nuclear weapons first, nor give them to terrorists like al Qaeda. We make these expensive weapons to defend our right to survive.” However, in discussions during all three of our visits, we found little appreciation for the serious risks entailed by a weaponized nuclear deterrent and found little thought given to nuclear strategy.

What about denuclearization in light of what they called their successful nuclear test? We were told, "Our commitment to denuclearization and the Sept. 19, 2005 agreement remains unchanged, but we will make tougher demands that the United States remain faithful to its own (Sept. 19, 2005) commitments." The military official agreed, "If the DPRK feels that it could trust the United States, then there is no need even for a single nuclear weapon and we will dismantle them." The Ministry of Foreign Affairs officials also offered some hope by stating, "To achieve the Sept. 19 agreement, we must have both short-term and long-term objectives in the talk. We must suspend our nuclear activities. Without this, the nuclear weapons will increase. What others should do during the period between suspension and dismantlement is to build trust and confidence. The DPRK should stop production, testing, and transferring weapons. This should be done in a verifiable way. The United States should take actions in a verifiable way also."

Yet, my general impression is that the Oct. 9, 2006 nuclear test, which followed DPRK's Feb.10, 2005 announcement of having manufactured nuclear weapons, will make it much more difficult to convince the DPRK to give up its nuclear weapons. The officials with whom we met presented the united front of pride and confidence instilled by what they called a "fully successful" nuclear test. It is also important to note that historically South Africa is the only nation to voluntarily give up nuclear weapons that it produced itself. However, the political and security circumstances were very different. The prevalent view we found in China, with which I concur, is that the United States must demonstrably address DPRK's security before there is any hope of denuclearization.

Summary estimate of DPRK nuclear weapons program:

- *Plutonium inventories*
    - < 1994 (IRT reactor & 5 MWe reactor) ~ 8.4 kg[15,16] (1+ weapons worth)
    - 2003 (5 MWe reactor) ~ 25 kg (4-6 weapons worth)
    - 2005 (5 MWe reactor) ~10-14 kg (~ 2 weapons worth)
    - As of Nov. 2006 ~4-8 kg in reactor now (not separated)

- As of Nov. 2006, DPRK is highly likely to have 40 to 50 kg of separate plutonium (sufficient for six to eight nuclear weapons).
- *Plutonium production capacity*
    - 5 MWe reactor capacity ~ 6 kg/yr (1 weapon worth/yr)
    - Future 50 MWe reactor ~ 60 kg/yr (~ 10 weapons worth/yr)

  (Status: Recovery of components in progress. No visible construction on site. Decision on full restart expected soon from high level. Technical issues slowing progress)
    - Future of 200 MWe reactor ~ 200 kg/yr

  (Status: Decision postponed. Most likely costs more to continue than to start over)
- *Nuclear weapons*
    - We still know very little. After 2004 visit, we concluded that given demonstrated technical capabilities, we must assume DPRK has produced at least a few simple, primitive nuclear devices.
    - No information on whether or not devices are missile capable.

        - U.S. report on Oct. 9, 2006 test: It was a nuclear test. DPRK confirmed it was a plutonium device. The explosion yield was estimated at ~ 4kt, but resulted in a yield < 1 kiloton.
        - DPRK Nov. 2006 statement: It was fully successful. No more tests needed.
        - China analysis: DPRK predicted 4 kt, achieved 1kt: "Successful, but not perfect."
        - Even with test, still a long way to go to get missile-capable device.
- *Uranium enrichment*
    - We know even less. Continued denial by Ministry of Foreign Affairs against evidence that they have had some level of effort in this area.

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[1] R.L. Garwin and F.N. von Hippel, Arms Control Today, Vol. 36, No. 9. November 2006.
[2] Jungmin Kang and Peter Hayes, "Technical Analysis of the DPRK Nuclear Test," Nautilus Institute Policy Forum Online 06-89A: Oct. 20th, 2006. http://www.nautilus.org/fora/security/0689HayesKang.html
[3] Thom Shanker and David Sanger, "North Korean Fuel Identified as Plutonium," *The New York Times*, October 17, 2006.
[4] Siegfried S. Hecker, Senate Committee on Foreign Relations Hearing on, "Visit to the Yongbyon Nuclear Scientific Research Center in North Korea," Jan. 21, 2004.
[5] Siegfried S. Hecker, "The Nuclear Crisis in North Korea," *The Bridge*, National Academy of Engineering, 17-23, Summer 2004.
[6] During the Jan. 2004 visit, Yongbyon nuclear center officials showed me a thin-walled conical shaped piece of plutonium that they said was a scrap piece cut off from one of their castings. They told me that the piece weighed 200 grams, had a density between 15 and 16 grams per cubic centimeter, and was alloyed. Alloying plutonium with a few atomic percent gallium or aluminum is a metallurgical technique used to make it easier to produce sound plutonium castings because in the unalloyed state plutonium is notoriously difficult to manufacture. This technique was used in the United States during the Manhattan Project to manufacture the plutonium components for the Trinity test and the Nagasaki bomb.
[7] Containing a 20-kiloton explosion in a horizontal tunnel with sufficient depth and overburden is technically quite feasible. Although there is ample information in the open literature on how to accomplish this, it is not clear how confident the DPRK technical specialists were given the disastrous political consequences of a significant radiation leakage. It is also known that sealing an underground explosion cavity completely is actually easier to do with a 20-kiloton explosion than an explosion of one to four kilotons. However, the DPRK technical specialists may have been mostly concerned with a major breach of the tunnel and, therefore, opted to be conservative.
[8] The 5 MWe reactor is an indigenously built graphite-moderated, gas-cooled reactor that was shut down during the Agreed Framework freeze (with only routine maintenance allowed) and restarted in February 2003 (see Note 3 for more detail). Its plutonium production capacity is approximately 6 kg (or roughly one weapon worth) per year.
[9] The uranium-aluminum alloy fuel is clad with a magnesium alloy that can degrade at elevated temperature. This reactor experienced considerable fuel cladding problems during the early operating experience before the 1994 shutdown.
[10] We refer to three reactor campaigns. The first resulted in the 8000 spent fuel rods that were stored in the spent fuel pool during the Agreed Framework freeze from 1994 to 2003. The second campaign refers to the fuel rods loaded in 2003 when the reactor was restarted, and according to the director's claims in August

2005, were reprocessed in 2005. The third campaign refers to the fuel rods loaded in June 2005. These fuel rods are still in the reactor as of Nov. 3, 2006.

[11] In August 2005, Director Ri told us that parts of the fuel fabrication facility had corroded so badly that they collapsed during the Agreed Framework freeze. However, they were in the process of refurbishing the facility and expected to fabricate new fuel rods in 2006.

[12] In August 2005, Director Ri told us that they were close to finishing the reprocessing of all the fuel rods from the second campaign, which was in the reactor from Feb. 2003 through March 2005. He also indicated that they had made some equipment improvements that allowed them to increase the throughput by 30 percent.

[13] One of the greatest difficulties is having to work inside a heavily shielded, highly radioactive environment in which normal operations are done remotely with manipulators.

[14] These reactors are described in References 3 and 4. In brief, the 50 MWe reactor was claimed to be within a year of completion and the 200 MWe reactor within a few years of completion when the Agreed Framework was adopted in 1994. The plutonium production potential of the 50 MWe reactor is roughly 60 kg of plutonium per year (roughly ten times that of the 5 MWe reactor). The production potential of the 200 MWe reactor is roughly forty times that of the 5 MWe reactor.

[15] David Albright, Kevin O'Neill, editors. *"Solving the North Korean Nuclear Puzzle,"* ISIS Reports, The Institute for Science and International Security, Washington, D.C., 2000.

[16] A recent report by the Institute for Science and International Security reports somewhat larger ranges of potential plutonium inventories. David Albright and Paul Brennan, "The North Korean Plutonium Stock Mid-2006," http://www.isis-online.org/publications/dprk/dprkplutonium.pdf