

The North Korean Plutonium Stock, February 2007

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This report is the latest in a series by ISIS examining North Korea's plutonium production activity and providing our assessment of its current stocks of separated plutonium.¹ This type of plutonium is weapons-usable and provides an indication of the potential size of North Korea's nuclear arsenal. This report also discusses in more detail the number and type of nuclear weapons North Korea could have. The plutonium estimates draw upon information gained on a recent visit by David Albright and Joel Wit to North Korea.

North Korea has been accumulating plutonium since 1986. Between 1994 and 2003, North Korea "froze" its plutonium production program under the "Agreed Framework" with the United States. Under this agreement, North Korea shut down, but maintained, its main source of plutonium, the 5 megawatt-electric (MWe) reactor at the Yongbyon nuclear site, and its nearby plutonium separation plant, the Radiochemical Laboratory (figures 1 and 2). Since the freeze ended, North Korea has been both producing and separating plutonium at Yongbyon.

As of February 2007, North Korea has a total estimated plutonium stock of between 46 and 64 kilograms of plutonium, of which about 28-50 kilograms are estimated to be in separated form and usable in nuclear weapons. The vast majority of North Korea's separated plutonium—at least 80 percent but as much as 99 percent—was produced since the North Korea's freeze on production and reprocessing ended in late 2002. The remainder was separated prior to 1992 (see table 1).

North Korea's estimated stock of separated plutonium is enough for between 5 and 12 nuclear weapons, assuming that each weapon contains about 4-5 kilograms of plutonium, standard unclassified estimates of the amount of plutonium needed in a crude nuclear weapon.²

Little is known about North Korea's ability to make a nuclear weapon, although it is assessed as likely able to build a crude nuclear warhead for its Nodong missile. In order to reduce the size of the nuclear warhead so that it can fit within the reentry vehicle of a Nodong missile, North Korea might use more plutonium in each weapon, at least 6 kilograms per weapon. In this case, the existing estimated stock of separated plutonium is enough for no more than 4-8 nuclear weapons.

North Korea does not appear to be making significant progress in finishing its 50 megawatt-electric reactor at Yongbyon (see figure 3). Ri Hong Sop, the Director of the Yongbyon Nuclear Center, said in interviews with Sigfried Hecker and one of the authors

¹ This report incorporates information learned since the last report, dated June 26, 2006.

² Japanese and South Korean governments use an average of 6 kilograms of plutonium per weapon. Some U.S. analysts use an average value less than 4-5 kilograms per weapon.

of this report, that a schedule for completion of the reactor has not been finalized.³ Ri told Hecker in November 2006 that he had submitted a “schedule to the higher level, but they have not yet received instructions.” In the interview on February 1, 2007 with one of the authors, Ri said that the schedule to finish the reactor was still not finalized. If finished, this reactor could expand North Korea’s plutonium production tenfold.

Plutonium Production Prior to the End of the Freeze

Prior to 2003, North Korea had an estimated total stock of roughly 28 to 39 kilograms of plutonium.⁴ Almost all of this plutonium was produced in the 5 megawatt-electric reactor and discharged from the reactor in 1994 and perhaps in 1989. The reactor typically operates on a core of nuclear fuel for a considerable period of time before the reactor is shut down and the irradiated fuel unloaded. International Atomic Energy Agency (IAEA) inspectors witnessed the core being discharged in 1994. However, the IAEA found evidence that another core could have been discharged and the plutonium separated earlier, when inspectors were not permitted to inspect facilities at Yongbyon. North Korea insists that the 1994 discharge involved the reactor’s first core, and that this core had been in the reactor since it started in 1986. North Korean officials maintain that only some 100 grams of plutonium were separated at the Radiochemical Laboratory from spent fuel rods that had failed and been removed earlier than expected from the reactor. This dispute led to the original crisis between the international community and North Korea in early 1993.⁵

In the early 1990s, the United States intelligence community debated extensively the question of how much plutonium North Korea may have produced and separated and not declared to the IAEA. The vast majority of this plutonium would have been produced in the 5 MWe reactor from 1986, when the reactor started operations, until the spring of 1989, when an undeclared fuel unloading may have taken place. In early 1994, the Joint Atomic Energy Intelligence Committee (JAEIC), the intelligence community’s foremost technical nuclear experts’ group, issued a report that lowered an earlier U.S. estimate from up to 12 kilograms to 8.3-8.5 kilograms of plutonium.⁶ JAEIC called its estimate a worst case scenario, and said that this amount of plutonium was enough to build one nuclear weapon, given expected processing and machining losses of about 20 percent and a reasonable but conservative nuclear weapon design.

³ Siegfried Hecker, “Report on North Korean Nuclear Program,” Center for International Security and Cooperation, Stanford University, November 15, 2006; and interview by Albright with Director Ri, February 1, 2007.

⁴ For background information on North Korean nuclear facilities and plutonium production, see David Albright and Kevin O’Neill (eds), *Solving the North Korean Nuclear Puzzle* (Washington, DC: ISIS, 2000).

⁵ For a discussion of the development and causes of this crisis, see, *Solving the North Korean Nuclear Puzzle*, Section 2 and appendix 4.

⁶ For a discussion of some of the factors leading to this reduction, see *Solving the North Korean Nuclear Puzzle*, chapter 4, in particular pp. 93-96. Based on reactor operating data from North Korea that was judged as reliable, the U.S. intelligence community lowered its estimate of the energy output of the 5 MWe reactor during the period up to early 1989 by almost 30 percent. In addition, the North Korean reactor operators calibrated the reactor power instrumentation incorrectly; as a result, the actual values were 10 percent less than the values recorded by the operators.

JAEIC's conclusion was soon afterwards adopted as the basis for the intelligence community's view, where the amount was given as 8-9 kilograms of plutonium. In interviews in 1994 with one of the authors, CIA officials involved in these assessments stated that there was a better than even chance that North Korea separated this plutonium, although the basis for this specific judgment can be debated.⁷ After taking account of estimated losses, the CIA concluded that this was enough separated plutonium for one or perhaps two nuclear weapons. However, assuming losses of 20 percent, as JAEIC did, the 8-9 kilograms of plutonium would likely not be enough plutonium for the second nuclear weapon, (again assuming that 4-5 kilograms of plutonium were needed for each weapon).⁸

The Department of Energy assessed that North Korea also separated and did not declare up to another 1 to 2 kilograms of plutonium produced in the Russian-supplied IRT research reactor at the Yongbyon site and separated in a nearby facility. JAEIC assessed that the amount produced in the IRT was at most a few hundred grams. The IAEA also independently arrived at this smaller estimate, after initially estimating a value similar to the Energy Department's one.

Adding the two worst case scenarios, a reasonable conclusion is that no more than 10 kilograms of plutonium were separated prior to 1994, when the Agreed Framework froze all plutonium activities at the Yongbyon site. It must be emphasized that these estimates represent worst-case scenarios and thus require continuing scrutiny. Under any disarmament agreement with North Korea, the IAEA could be expected to focus extensively on resolving this issue.

Until 2003, the bulk of the plutonium produced by North Korea remained in almost 8,000 irradiated fuel rods, stored in a pond near the 5 megawatt-electric reactor and subject to monitoring by the IAEA. These rods contained an estimated 27-29 kilograms of plutonium.

Post-Freeze Period

Spent Fuel Discharged in 1994

Since restarting the Radiochemical Laboratory in 2003, North Korea is believed to have reprocessed most of the 8,000 irradiated fuel rods discharged from the reactor in 1994. This conclusion is based on North Korean statements, independent experts, commercial satellite images, and on information from government officials and experts in the United States, Japan, and South Korea.

⁷ See for example, *Solving the North Korean Nuclear Puzzle*, op. cit.

⁸ Two weapons would only be possible in the extreme case, namely a stock of 9 kilograms of plutonium, 4 kilograms per weapon, and 100 percent recycling of scrap from the first weapon. If ten percent losses are assumed, two weapons could be achieved with difficulty, but this case would require a stock of at least 8.5 kilograms of plutonium, assuming again 100 percent recovery of the scrap produced during the production of the first weapon.

North Korean officials have stated that the Radiochemical Laboratory operated during the first six months of 2003, and in that period processed all 8,000 rods. However, there is little confirmatory evidence to substantiate this claim. Commercial satellite imagery revealed no significant activity at the plant during this period. In addition, the nearby coal-fired plant, which produces process steam for the Radiochemical Laboratory, did not appear to be operating except in late January 2003. The reprocessing of spent fuel leads to the release of krypton 85, which can be detected at a considerable distance from the plant, but little was detected by U.S. intelligence agencies. The United States is reported publicly to have detected krypton 85 from North Korea only once, and at the end of this 6-month period.

Director Ri explained to ISIS officials in Pyongyang on February 1, 2007 that North Korea “does not like to let others know when we are reprocessing.” He said that the Radiochemical Laboratory can process over 100 tonnes of uranium fuel per year; therefore, a core from the 5 MWe reactor, which involves about 50 tonnes of uranium, can easily be processed in six months. He added that it was not surprising that the coal plant would not have been observed to be operating, because little steam is needed in the processes to extract plutonium. He said, however, that a large amount of steam is needed when the plant processes liquid radioactive wastes, but that this processing has been done after the plutonium was separated.

Ri stated that the Radiochemical Plant did not have equipment to recover krypton 85, but regardless, that this spent fuel did not contain very much krypton 85. The krypton was produced many years earlier in the reactor, and krypton 85 has a half-life of 11 years.⁹ The lack of krypton detection could also be explained by considering the wide variation in the burn-up, or irradiation exposure, of the spent fuel discharged in 1994.¹⁰ If the lower burn-up spent fuel were reprocessed first, the chance of detecting krypton 85 off-site would have been very low. The higher burn-up fuel could have been processed last, and krypton 85 from this fuel could have been the material detected off-site by the United States. Such a strategy would have also permitted the North Korean to extract the highest quality plutonium first, which is in the lower burn-up spent fuel.

According to Ri, the coal plant should have been operating when the Radiochemical Laboratory was processing radioactive waste. Press reports state that smoke and steam plumes were visible at the coal plant in December 2003.¹¹ Hecker reported that Ri told him that the radioactive waste processing for fuel discharged in 2005 was being done during their visit in the fall of 2006. We are still trying to confirm the coal plant’s operation with commercial satellite imagery.

⁹ This spent fuel was estimated to contain in total about 5,000 curies of krypton 85 in early 2003, see Albright, “Plutonium Separation in the Radiochemical Laboratory: Always Detectable?,” July 2003, presented at a workshop at the Japanese Foreign Ministry (unpublished).

¹⁰ The median burn-up was about 610 MWth-d/t and the range was 64 to 1,370 MWth-d/t.

¹¹ “U.S. Reports North Nuclear Plant Activity,” *Jong Ang Daily*, December 11, 2003.

Based on Ri's explanation, a reasonable conclusion is that North Korea did separate a significant amount of plutonium from these rods. Without further confirmation, the amount of plutonium separated is estimated to be between 20 and 28 kilograms. The lower bound reflects confidence that most of the rods have been reprocessed and the amount separated is highly unlikely to be lower than this value. The upper bound is the amount that would result if all the rods have been reprocessed with only small losses of plutonium during the entire process.

First New Core, Post-2002

The 5 MWe reactor was restarted in early 2003 and subsequently operated consistently, based on analysis of commercial satellite imagery. Ri stated that the power of the reactor has been 25 megawatts-thermal (MWth). During the February interview, he declined to provide the average or nominal burn-up of the spent fuel, but he said that since restarting the reactor in 2003, the average innage factor--the percent of time the reactor operates at full power--has been greater than 80 percent.

Unclassified reports, confirmed by commercial satellite imagery, indicate that the reactor was shut down in April 2005, likely to unload the fuel (see figure 4). Ri added further confirmation to this, stating that the reactor was shut down for unloading in March 2005. After several weeks of cooling, the spent fuel was sent to the Radiochemical Laboratory. Reprocessing started in June 2005, he said.

The amount of plutonium in this core can be estimated, where the total plutonium is the product of the thermal power, the innage factor, the amount of time the reactor operated, and a conversion factor based on the average burn-up of the discharged fuel. Using an innage factor of 80 percent, the estimated average burn-up is about 330 megawatt-thermal-days per tonne of uranium fuel. Using data about an idealized gas-graphite reactor, the conversion factor at this burn-up would be about 0.93 grams of plutonium per MWth-d/tonne.¹² Varying the innage factor between 70 and 90 percent and adjusting the conversion factor accordingly, then the amount of plutonium in the discharged core would be about 13.5 to 17.1 kilograms.¹³

Some uncertainty surrounds these estimates, because the 5 MWe reactor is not operated in the same manner as assumed in the reactor used as a model for estimating the

¹² Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996* (Oxford: Oxford University Press and SIPRI, 1997), appendix A.

¹³ Applying this set of conversion factors to other cases results in good agreement, although the estimate is slightly larger in each case. The fuel discharged in 1994 had a burn-up of about 635 MWth-d/t, and the conversion factor results in an estimate of 28 kilograms of plutonium in this fuel. North Korea provided detailed burn-up information for 86 failed fuel rods taken from the 5 MWe reactor in about 1989 and subsequently reprocessed. The average burn-up of the rods was 185 MWth-d/t [see Nuclear Research Center, Ministry of Atomic Energy, DPRK "Explanation of the 'Inconsistency' Problems Proposed by the IAEA," February 1993]. Using the appropriate conversion factor, the resulting plutonium value is about 3-4 percent higher than the value given in this report. Although the total plutonium quantities appear accurate using this method, the isotopic composition of the plutonium can be significantly misstated with this method in the case of the 5 MWe reactor.

conversion estimates. Ri told Hecker that the outlet temperature had been reduced to 300 centigrade from 350 centigrade, which reduced the efficiency of the electrical power output, but produced higher quality weapons-usable plutonium.¹⁴ Ri added in February 2007 that although the temperature was reduced, the burn-up of the fuel was maintained at the same level. He also said in February that control rods are inserted into the reactor to maintain uniformity of the burn-up of each fuel rod.

Ri stated that the reprocessing of this core was completed in 2005. As discussed above, waste processing reportedly occurred in the fall of 2006. Although confirmation is still lacking, it is judged that the spent fuel from this core has likely been reprocessed, resulting in the separation of about 13-17 kilograms of plutonium, where in this case almost all of the plutonium in the spent fuel was recovered.

New Core Loaded in 2005

Ri said that the reactor restarted in June 2005. Japanese media reported in the summer of 2005 that U.S. satellites had detected a steam plume at the 5 MWe reactor, indicating that operations had indeed resumed. A September 2005 commercial satellite image shows a steam plume, confirming that the reactor was operating again. Subsequent satellite images confirm continued, although not continuous, operation of the reactor.

From June 2005 to the end of February 2007, the reactor could have produced another 10-13 kilograms of plutonium, using the same methods and assumptions as above. This plutonium remains in the reactor. Ri said on February 1 that barring political developments, the reactor was expected to discharge this core in late 2007 or early 2008.

Ri said that the next load would require the production of additional fresh fuel. In anticipation of this requirement, North Korea has been refurbishing the fuel fabrication complex at Yongbyon, which was not maintained during the period of the Agreed Framework. Ri said on February 1 that if there is “no additional hindrance,” fresh fuel production would start soon.¹⁵ The recent deal negotiated at the Six Party Talks should also include this plant, although the future status of this plant has not yet been addressed in official announcements about the deal.

Construction of the 50 Megawatt-Electric Reactor

North Korean officials stated in the first half of 2005 that construction of the 50 MWe reactor had resumed. As of early June 2005, commercial satellite imagery did not show significant construction activity; in August 2005 media reports state that a mobile crane was moved to the site.¹⁶ Additional reports stated that new gravel was seen along the

¹⁴ Hecker, “Report on North Korean Nuclear Program,” op. cit.

¹⁵ Ri said in February 2007 that the main problem was corrosion in the fluoride processes at the fuel fabrication plant. Unable to fix the process, the North Korean engineers switched from a wet to dry process. He said that the vacuum induction furnaces were in good order.

¹⁶ Nobuyoshi Sakajire, “North Korea Brings in Crane Vehicle in Nuclear Construction Site Probably Six Party Talks in Mind,” Asahi Shimbun, July 19, 2005, morning edition. Translation by FBIS.

road at the same site. Commercial satellite images from September 2005 confirmed these activities. A satellite image from May 2006 does not appear to show any substantial construction activity. In addition, the mobile crane, first identified in the September 2005 image, remains in the same location in the May 2006 image (see figure 5).

Sig Hecker reported that because of the long period of inactivity at this reactor site, and the effect of the weather on the unfinished reactor, several reactor components must be renovated.¹⁷ As discussed above, the North Koreans had not settled on a construction schedule as of early February 2007.

In any case, the reactor would likely take several years to complete. If the recent Six Party agreement succeeds, this reactor will be eventually dismantled. However, if the agreement fails and the reactor is finished, the 50 MWe reactor could produce enough plutonium annually for roughly ten nuclear weapons.

Summary

By the end of February 2007, North Korea is estimated to have produced in total about 51-69 kilograms of plutonium. About 33-55 kilograms have been separated.

Roughly 5 kilograms of plutonium would have been used in the October 2006 nuclear test. Reducing the above estimates accordingly, the total estimated plutonium stock in February 2007 is about 46-64 kilograms of plutonium, of which about 28-50 kilograms are separated and available for use in weapons.

Nuclear Weapons

Little is known about the amount of plutonium used in a North Korean nuclear weapon. Standard estimates are that each weapon would require about 4-5 kilograms of weapon-grade plutonium. In this case, its existing stock of separated plutonium is enough for about 5-12 weapons. It is judged unlikely that North Korea could build more than a dozen nuclear weapons.

Given that North Korea has been working on developing a warhead for the Nodong ballistic missile since at least 1994 and is strongly suspected of having obtained nuclear weapon designs to fit on missiles from the Pakistani Abdul Qadeer Khan, North Korea is judged capable of putting a crude warhead on a Nodong missile. Nonetheless, the warhead may not be reliable, and it may have a relatively low yield. To miniaturize the warhead, North Korea may have opted to use a relatively large amount of plutonium, taken as at least 6 kilograms of weapon-grade plutonium. In this case, North Korea would have enough plutonium for no more than about 4-8 nuclear weapons.

¹⁷ Hecker, "Report on North Korean Nuclear Program," op. cit.

North Korean officials have not discussed with foreigners the composition or plans for a North Korean nuclear arsenal or strategy. Based on the experience of the Iraqi and South African nuclear weapons programs, their lack of candor is not unexpected.

For the purposes of discussion, a hypothetical nuclear arsenal can be derived given the constraints imposed by the total estimated stock of separated plutonium. In this exercise, the nuclear weapons are taken as containing in total about 40 kilograms of weapon-grade plutonium. The hypothetical arsenal is composed of the following:

- 1 test device, with 5 kilograms of plutonium;
- 3 warheads for Nodong missiles, each with 6-7 kilograms of plutonium;
- 3 larger, heavier nuclear weapons, not deliverable by missiles, each with 5 kilograms of plutonium

With such an arsenal, North Korea's nuclear strategy would be based on deterrence. Its potential existence has already reduced the chance that North Korea would be attacked in a crisis. The warheads, mounted on ballistic missiles, serve to threaten U.S. military assets in Japan and elsewhere, causing further deterrence. In addition, this type of arsenal allows North Korea to threaten credibly a nuclear attack during a crisis as a way to end the crisis on terms favorable to itself. Because of the asymmetry in military forces in the region, North Korea would be unlikely to commit to a no-first use pledge.

The possible nuclear strategy we have outlined can be expected to focus on ways to prevent an attack on North Korea. In such a case, the detonation of nuclear weapons as "warning shots" in a crisis might result. Early in a crisis, a nuclear test could be conducted to prevent further escalation. If that failed to stop the crisis, it may detonate a warhead over the sea as a further demonstration. It could do so in many ways, including launching a ballistic missile and detonating a warhead over the ocean or sailing a ship or barge off the coast of South Korea and detonating a nuclear weapon.

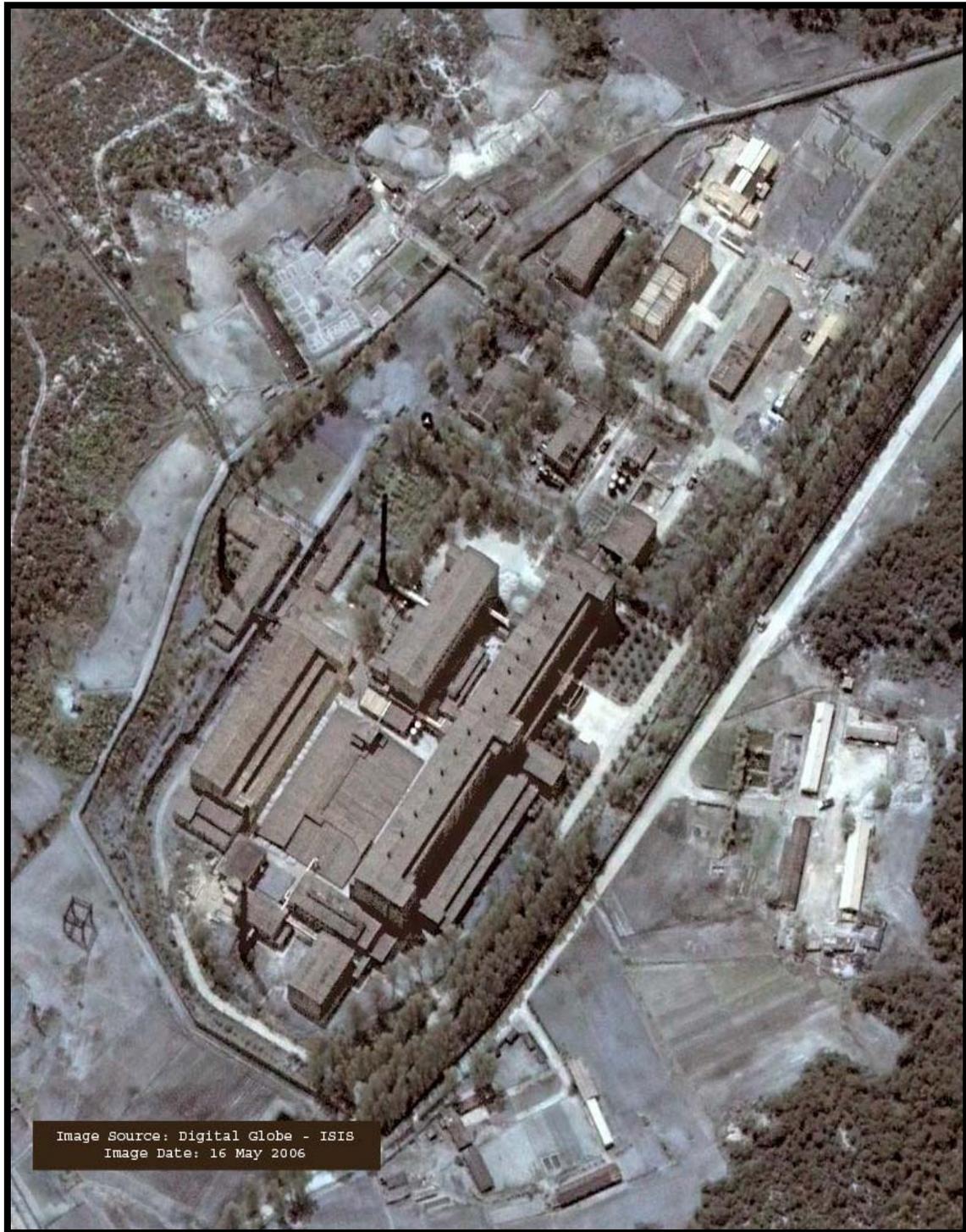
In the event of a war, North Korea would be expected to use its nuclear weapons against military targets and population centers in South Korea or Japan. The larger weapons could be delivered by truck or ship or simply placed at a strategic location inside North Korea awaiting the arrival of enemy forces.

Figure 1



5 MWe reactor at Yongbyon.

Figure 2



Radiochemical Laboratory at Yongbyon. Note the demolished corner near the bottom of the image in a facility whose purpose is unknown. The “canyon” where reprocessing occurs is a long, multistory building on the right.

Figure 3



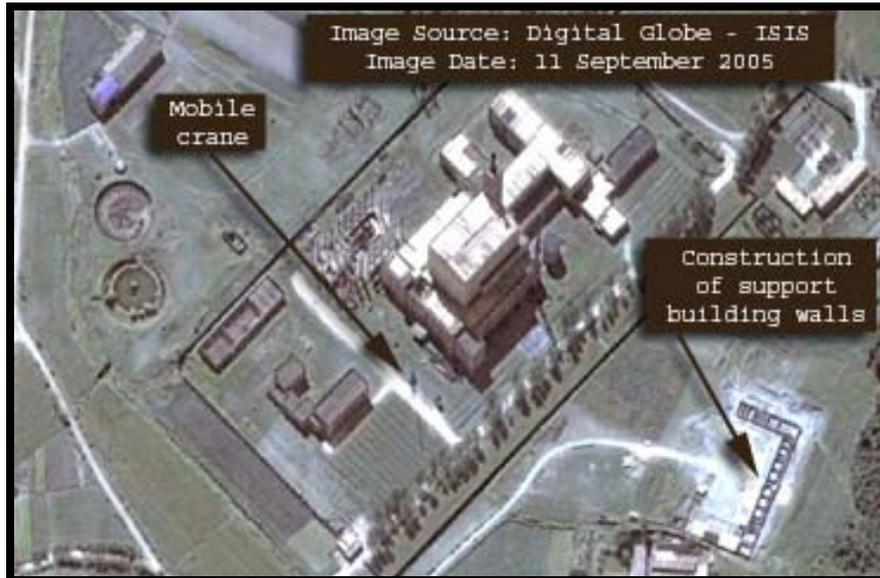
50 MWe reactor at Yongbyon.

Figure 4

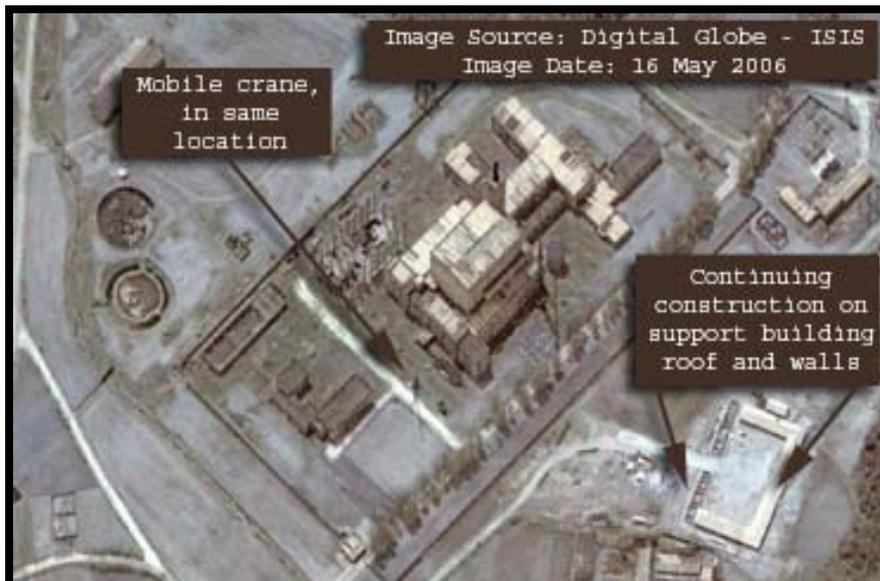


A composite series of images showing the cooling tower at the 5 MWe reactor. A plume is visible in January 2005 and is not visible in the images from April and June 2005. A plume is visible in September 2005 and January 2006. In the most recent image, from May 16, 2006, a plume is not visible above the cooling tower.

Figure 5



September 11, 2005



May 16, 2006

A comparison of September 2005 and May 2006 images of the 50 MWe reactor at Yongbyon. Continuing construction is evident at a support building adjacent to the 50 MWe reactor facility. Within the compound housing the industrial buildings, however, there does not appear to be any substantial construction activity. A mobile crane, first identified in the September 2005 image, remains in the same location in May 2006.

Table 1 North Korean Plutonium Production and Separation, as of end February 2007

Plutonium Discharged From 5 MWe Reactor		Plutonium Separation		Weapon Equivalents*
Date	Amount (kg)	Date	Amount (kg)	(number)
Before 1990	1-10**	1989-1992	0-10	0-2
1994	27-29	2003-2004	20-28	4-7
Spring 2005	13.5-17	2005-2006	13-17	2-4
In core of 5 MWe reactor	10-13	--	--	--
Subtotal	51.5-69		33-55	6-13***
Total reflecting test	46-64		28-50	5-12

Comments

- * It is assumed that each nuclear weapon would require 4-5 kilograms of separated plutonium.
- ** This quantity includes up to 1-2 kilograms of plutonium produced in the IRT reactor prior to 1994, see text. Since then, this reactor has barely operated.
- *** The upper bound of the number of weapons can be higher than the sum of the individual upper bounds, because particular periods list more plutonium than needed to give the upper bound for that period.