North Korea’s Missile Program

David Wright
Senior Scientist and Co-Director of the Union of Concerned Scientists' (UCS)
Global Security Program

This paper was produced as part of the project “Improving Regional Security and Denuclearizing the Korean Peninsula: U.S. Policy Interests and Options.”

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Status as of April 2009

On April 5, North Korea tested the largest launch vehicle it has built, called the Unha-2, in an apparent attempt to launch a small satellite into orbit. The observed details of the launch are consistent with North Korea's claim that it was an attempted satellite launch.

A technical analysis of the launch, using information that has become available since the test, and information from previous tests, suggests both challenges and potential opportunities.[1]

In particular, this analysis shows that the Unha launcher represents a significant advance over North Korea's previous launchers, and would have the capability to reach the continental United States with a payload of one ton or more if North Korea modified it for use as a ballistic missile. This increase in capability is due in large part to technology used in the second stage that is considerably more advanced than that seen in previous North Korean launchers.

On the other hand, the Unha launcher appears to be constructed from components, such as the second stage, that may not have been manufactured in North Korea. It is possible that this critical component was acquired from Russia – although likely without the involvement of the Russian government. If true, this inference could mean that North Korea's indigenous missile capability could be significantly constrained if it can be denied further access to such components. An important factor in understanding the North's program is therefore to clarify this issue.

In the April launch, the first two stages of the launcher appear to have worked essentially as planned. Unlike previous tests, North Korea announced splashdown zones for the first two stages as a warning to ships and aviation (Figure 1). Both stages apparently fell in those zones; the reported splashdown points indicate that the both fell at the ends of the zones closest to the launch site. This is the second time North Korea has demonstrated an ability to successfully use staging in a launch; the first was the TaepoDong-1 (TD-1) launch in 1998, which demonstrated successful staging between the first and second, and the second and third stages.

Several recent reports of the launch say that the third stage separated from the second stage but did not ignite, but there is little hard public information about what happened. Our estimates suggest that had the third stage operated properly it could have placed a small satellite (with a mass of up to a couple hundred kilograms) into orbit at about 500 km altitude.

The launch direction was nearly due east (Figure 1), which is consistent with a satellite launch since it allows the launcher to gain the maximum speed from the rotation of the earth. This direction, however, raised concerns in Japan since it carried the second and third stages of the launcher over the relatively sparsely populated northern end of the main Japanese island of Honshu early in flight. A launch in this direction also carries the upper stage and payload in the general direction of Hawaii (Figure 2).

[1] D. Wright and T. Postol, "A Post-Launch Examination of the Unha-2," *Bulletin of the Atomic Scientists*, 29 June 2009, http://thebulletin.org/web-edition/features/post-launch-examination-of-the-unha-2

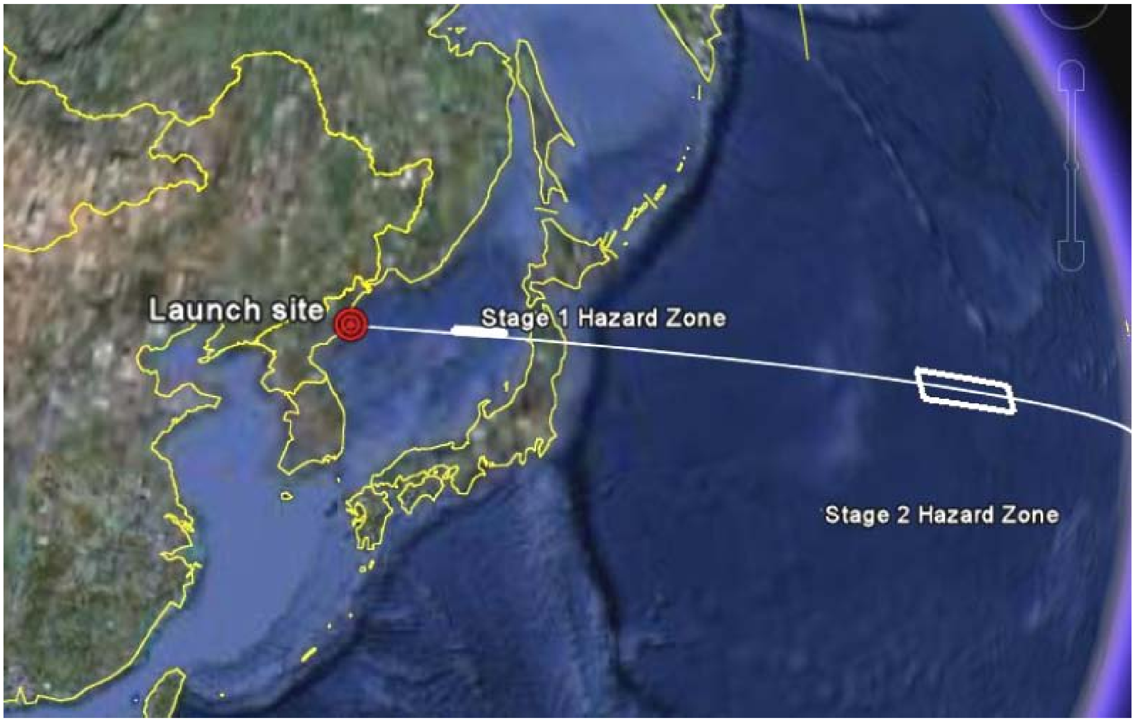

Figure 1. The location of the hazard zones, where the first two stages were expected to return to Earth, shows that the launch direction was essentially due east (figure made in Google Earth).

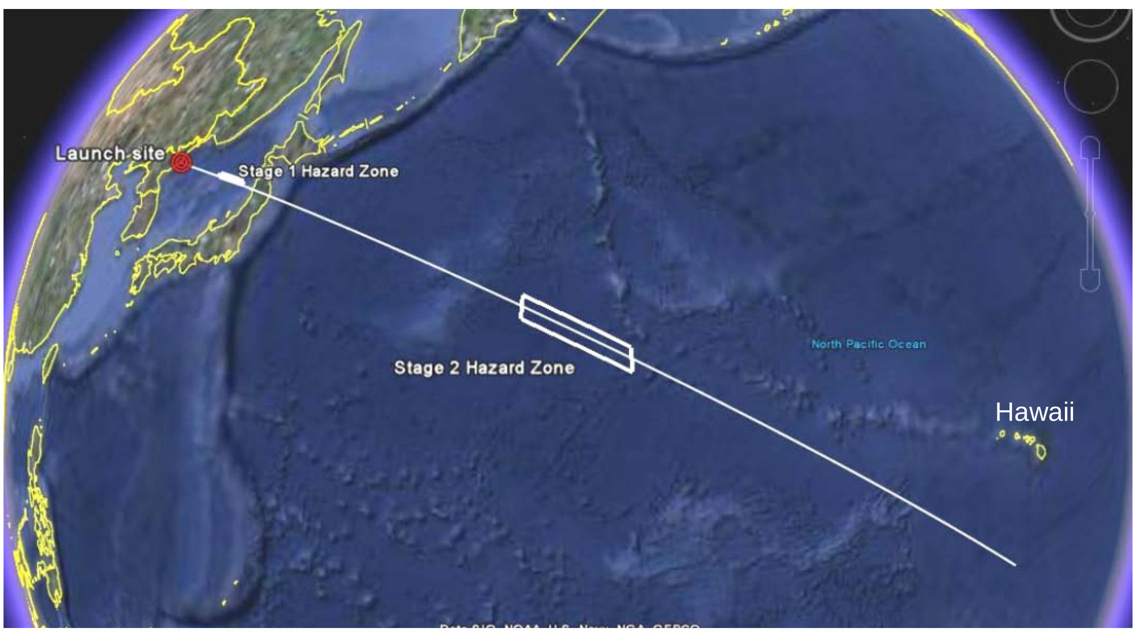

Figure 2. A launch in this direction will carry the rocket stages over Japan and in the general direction of Hawaii (figure made in Google Earth).

Overall, the launcher had a length of roughly 30 m and a mass of roughly 80 metric tons. The first stage appears to use a cluster of four Nodong engines housed in a single missile casing and sharing a common fuel tank. The Nodong engine is essentially a scaled-up version of the engine used in the Soviet Scud-B missile.

The Unha-2 launcher represents a significant increase in capability over the TD-1 used in North Korea's 1998 satellite launch attempt. It is considerably larger than the TD-1, with a first-stage diameter of 2.4 m compared to 1.3 m. The Unha is more than three-times as massive as the TD-1 (roughly 80 vs. 25 metric tons). Since rockets consist mainly of fuel, the amount of payload a rocket can lift is roughly proportional to its overall mass; this difference therefore implies a significant increase in launch capability.

The sizes and shapes of stages two and three are completely consistent with known stages from other rockets. Both stages appear to use technology that is more advanced than North Korea has used in previous launches.

The second stage appears identical to the single-stage Soviet R-27 sea-launched ballistic missile, called the SS-N-6 in the United States, which was first deployed by the Soviet Union in 1968. There have been reports for years that North Korea had acquired some number of SS-N-6 missiles in the 1990s and was modifying them for use as an intermediate range missile.[2] Reports have also stated that in 2005 Iran bought 18 SS-N-6 missiles from North Korea.[3]

The SS-N-6 uses liquid fuels (UDMH and nitrogen tetroxide) that are more advanced than those used in the Scud-B, and it therefore has a high thrust for its size. Since it was designed to be carried on a submarine, the missile has a compact design with a lightweight aluminum casing.[4]

The third stage appears to be very similar if not identical to the upper stage of the Iranian Safir-2 launch vehicle, which placed a small satellite in orbit in February 2009. This appears to be a concrete indication of cooperation between the Iranian and North Korean programs.

Based on an analysis of the Iranian Safir-2 launcher, this stage appears to use the small steering motors from the SS-N-6 for propulsion.[5] This launcher therefore appears to use a third stage with liquid rather than solid fuel (the TD-1 launcher used a solid third stage).

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[2] Andrew Feickert, "North Korean Ballistic Missile Threat to the United States," Congressional Research Service, The Library of Congress, 1 October 2003, http://www.history.navy.mil/library/online/nkoreanmissile.htm#fn22
[3] Alon Ben-David, "Iran acquires ballistic missiles from DPRK," *Jane's Defense Weekly*, 29 December 2005.
[4] For information about the R-27 missile, see Pavel Podvig, ed, *Russian Strategic Nuclear Forces* (Cambridge, MA: MIT Press, 2001), pp.319-322.
[5] Geoff Forden, "Safir—Iran Hops Off the SCUD Bandwagon," 25 August 2008, http://web.mit.edu/stgs/pdfs/Safir--Iran%20Hops%20Off%20the%20SCUD%20Bandwagon1.pdf; Theodore Postol, "A Technical Assessment of Iran's Ballistic Missile Program," 6 May 2009, http://docs.ewi.info/JTA_TA_Program.pdf

Capability as a Ballistic Missile

North Korea has conducted two nuclear tests, but is not thought to have designed a nuclear warhead that could be delivered by a missile. Such a first generation plutonium warhead could have a mass of 1,000 kg or more. North Korea is currently thought to have enough separated plutonium for fewer than 10 nuclear weapons.

Figures 3 and 4 show the ranges from the North Korean launch site to several locations. North Korea already has a missile that can reach Japan with its Nodong missile, which is believed to have a range of 1,000-1,300 km with a 700-1,000 kg payload. The maps show the ranges required to reach other potential targets, starting with Guam (3,400 km), Alaska (5,000-6,000 km), the main islands of Hawaii (7,000 km), and mainland U.S. (8,000 km and longer.

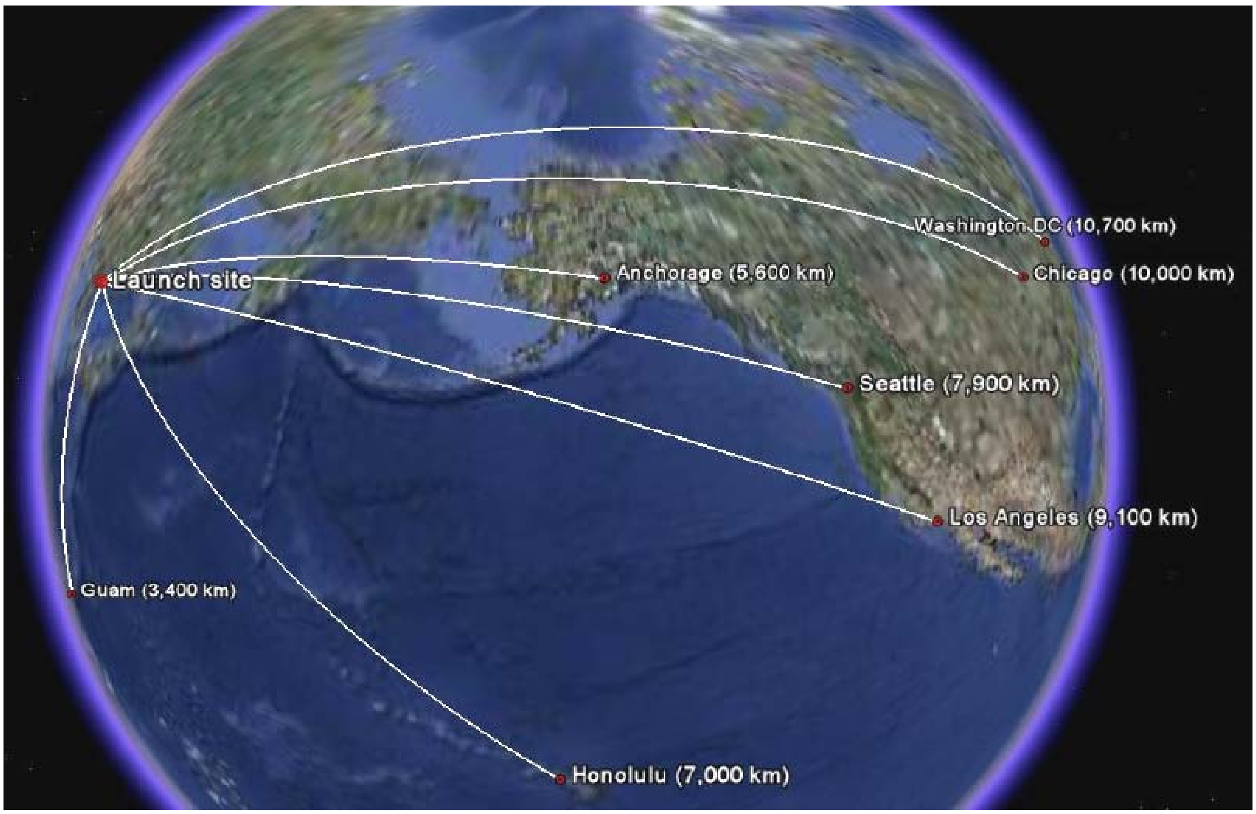

Figure 3: Distances from the North Korean launch site to locations around the world (figure made in Google Earth).

Figure 4: Distances from the North Korean launch site to locations around the world (figure made in Google Earth).

If the Unha-2 was designed to launch a relatively lightweight satellite, its structure may not allow it to carry a warhead as massive as 1,000 kg. If it could, we estimate that it could have a range of 10,000 to 10,500 km with a warhead of this mass. This range would allow it to reach Alaska, Hawaii, and roughly half of the lower 48 states.

If a 1,000-kg payload were instead launched by the first two stages of this missile, it would have a range of 7,000-7,500 km This would allow it to reach Alaska and parts of Hawaii, but not the lower 48 U.S. states.

In order to use this technology for a ballistic missile, North Korea would need a reentry heat shield, which it has not demonstrated for a missile of this range. Reentry heating increases rapidly with the reentry speed of a missile, so a 10,000-km range missile would require a much better heat shield than that developed for the Nodong missile. Heat shield techniques and materials have been developed for more than 40 years, so North Korea should be able to develop a shield adequate to protect the warhead against the heat of reentry, although the heat shield could be a major source of missile inaccuracy. Developing a heat shield that gives relatively high accuracy is a very difficult engineering task.

For example, making the warhead very blunt so that atmospheric drag causes it to lose most of its speed at high altitude would significantly reduce the total heating. However, this results in the warhead descending more slowly through the atmosphere so that it is subjected to high altitude winds for a longer time, which reduces the accuracy. This effect can be reduced by streamlining the warhead so that it passes through the atmosphere quickly. However, the high speed leads to high heating rates, which require more sophisticated heat shielding, such as an ablative coating. The high speed and asymmetric ablation can lead to strong lateral forces on the warhead during reentry, which can lead to large inaccuracies.

The inaccuracy of a missile has two main components, which are guidance and control errors during boost phase and reentry errors during terminal phase. Although nothing is known about the guidance and control system in the Unha-2, it is likely that it is derived from the SS-N-6, which we expect would be used to control the SS-N-6 steering motors on the second and third stages. Using this system on a missile with a range several times longer than the SS-N-6 range would lead to a correspondingly lower accuracy. Moreover, the higher reentry speed of a long-range missile would greatly increase the inaccuracy arising from reentry, as discussed above. As a result, a missile based on the Unha-2 would likely have an inaccuracy of 10 km or more.

Improving the guidance and control system would require North Korea to acquire better accelerometers, and thrusters that could be controlled more precisely. It would also need a series of tests to understand what systematic errors there might be in the guidance system. Significantly reducing the reentry errors, as noted above, would require a significant development and testing program. It is difficult to imagine achieving accuracies below a few kilometers in the foreseeable future. These high inaccuracies could still be sufficient for a terror weapon aimed at a large population center.

Ballistic missiles are complex systems and North Korea has yet to get a three stage missile to function properly. Not only does this undermine its possible military utility, but given North Korea's limited supply of fissile material it may well be reluctant to place a warhead on a missile that is likely to fail. Understanding the launcher reliability would require a series of tests.

The Unha-2 was launched from a known, visible launch site, and requires days to prepare the rocket for launch once it has arrived at the launch site, during which time it is highly vulnerable to attack. Reducing this vulnerability would require launch sites that were concealed from view, which might rely on storing the missiles on transporters in caves, so that the missiles could be rolled out, erected, and fueled on relatively short notice. China is believed to have deployed at least some of its DF-5 ICBMs this way, and North Korea could be developing a similar capability.

Once North Korea developed a long-range missile, a deliverable nuclear warhead, and a heat shield, it could in principle pose a threat to the United States and other countries, which could be launched as an act of desperation. However, without an understanding of the reliability and accuracy of the launcher, and a basing mode that did not rely on visible launch sites with long preparation time, this ability would not be very credible.

Possible Future Missile Developments

To develop a launcher with greater satellite launch capability or a missile with longer range, there are several steps North Korea might take if it had the technical capability. For example, it could replace the third stage of the Unha-2 by a stage having higher thrust and a short burntime. It might also improve the thrust of the first stage by using more advanced propellants, and decreasing its structural weight by making the body out of light-weight materials, such as aluminum alloys.

Gaining substantially more capability would require North Korea to build a significantly larger missile. For example, China launched its first satellite on the Long March 1 launcher, which was similar in size and capability to the Unha-2 but had a more advanced first stage. However, for its first intercontinental ballistic missile (the Dong Feng-5), China developed a much larger missile, with a first-stage diameter of 3.35 m (compared to 2.4 m for the Unha-2) and an overall mass of 183 metric tons—twice the mass of the Unha-2. This missile was able to carry three tons to a range of 12,000 km. It was also modified to become the Long March 2 space launch vehicle, which was able to place more than a ton into low Earth orbit—a much greater capability than the Unha-2.

However, North Korea's ability to make changes of this kind is unknown.

The general assumption for many years has been that in the early 1990s North Korea successfully reverse-engineered the Soviet Scud missile and began producing its own version. Following that, it was thought to have scaled up the Scud engine to produce a larger missile called the Nodong. However, there is evidence that North Korea received very significant technical assistance from Soviet/Russian missile designers—although not necessarily with the involvement of the Soviet/Russian government—and that its missile program may rely heavily on the acquisition of Russian production equipment and possibly key rocket components.

This evidence includes:

- Press accounts in the early 1990s of Russian missile experts attempting to travel to North Korea at a time when Russia was facing severe economic distress and North Korea was reportedly offering high salaries and money for missiles and technology. These experts were said to come from the Makeyev missile design bureau in Russia, which produced the Scud B and extended-range Scud C missiles, the R-27 (SS-N-6), and a number of other liquid-fueled missiles.

- An apparent lack of missile testing at a level that is typically seen for reverse engineering or developing a successful indigenous production capability, either for its Scuds or

Nodongs. In addition to conducting relatively few tests, the success rate of those tests was very high.[6]

- Recent analysis that shows that the velocity curves for Soviet Scuds and Iranian Scuds, which were likely purchased from North Korea, are essentially identical.[7] This would not be expected if the Scuds had been reverse engineered, and strongly suggests that these missiles were either Soviet-made or were manufactured with Russian help and equipment and to Russian specifications.

- Analysis suggesting that both the TD-1 and Unha-2 launchers may have been designed and built around components of Soviet missiles.[8] The apparent lack of testing of these components by North Korea suggests that they were not indigenously produced systems.

On this final point, we note that while it is possible that North Korea has acquired production equipment to build an SS-N-6, it has apparently never flight tested one. It seems unlikely that North Korea would use a stage on a very high profile satellite launch if it had built that stage indigenously but had never flight tested it. On the other hand, even if the SS-N-6 stage flown on the Unha-2 was purchased from a Russian source, North Korea may also have acquired the production equipment to produce this stage in the future.

If North Korea is not able to build indigenously some key rocket components, then its missile program may rely on combining existing components in clever ways. That could significantly limit what of the steps listed above North Korea might be able to take in the near term, unless it could adapt existing components. For example, North Korea is not known to have a large rocket engine that can use more advanced propellants. Similarly, it might not currently possess or be able to build a third stage of the right mass and thrust to significantly improve the range/payload of the Unha-2.

On the other hand, North Korea has shown the ability to use what technology it has to build increasingly capable launchers and one must assume that process would continue unless steps are taken to stop it.

None of this evidence is conclusive. Understanding this issue is important since it has implications for the future of North Korea's program and for understanding what measures might be effective in limiting it. It should therefore be a high priority for the United States to assess the

[6] See for example Robert Schmucker, "3rd World Missile Development—A New Assessment Based on UNSCOM Field Experience and Data Evaluation," 12th Multinational Conference on Theater Missile Defense: Responding to an Escalating Threat, Edinburgh, Scotland, 1-4 June 1999.

[7] Robert Schmucker and Markus Schiller, "Die nuklear bewaffneten Fernraketen des Iran," presentation at Symposium Missile Defense/Theatre Missile Defense, Bonn, Germany, 22 October 2008.

[8] The TD-1 appears to have used a modified Nodong missile for the first stage, a modified engine from a Soviet surface-to-air missile (SA-5) for the second stage, and the engine from a solid-fueled Soviet SS-21 tactical missile for the third stage. Schmucker, "3rd World Missile Development," and Theodore Postol, "Technical Addendum to the Joint Threat Assessment on the Iran's Nuclear and Missile Potential," East West Institute, May 2009, pp. 25-32, http://docs.ewi.info/JTA_TA_Program.pdf .

evidence and work with Russia to determine what technical assistance and components North Korea may have received.

North Korea and Diplomacy

Stopping North Korea's nuclear and missile programs will require diplomatic efforts. Military attacks on North Korean installations are likely to cause severe responses and cannot be assumed to be successful since the locations of key sites are unknown. Similarly, missile defenses cannot be assumed to be effective since countries able to develop or acquire long-range missiles with nuclear warheads would be able to develop or acquire decoys and other countermeasures that could defeat missile defenses, as the 1999 National Intelligence Estimate and other studies have pointed out.[9]

It is difficult to know at this point what North Korea wants, what it is willing to give up, and how much transparency it is willing to allow. In 1999, there were indications that, despite some of its actions at the time, it was exhibiting restraint in some areas, such as not reprocessing its spent fuel rods between 1991 and 1994 when the Agreed Framework was signed, and agreeing to a unilateral missile flight moratorium from 1998 to 2006. During this time it allowed international inspectors to verify that its spent fuel rods were locked up, allowed a visit to the underground site at Kumchang-ni, and discussed the possibility of transparency related to a missile freeze. It appeared to be interested in developing economic relations with the rest of the world, and appeared to understand that its nuclear and missile programs were barriers to engagement, and that those programs represented things of value that it could offer as part of negotiations.

Today, North Korea appears to be taking a different approach. In recent years it thrown out nuclear inspectors and reprocessed the spent fuel rods that were previously locked up, conducted two nuclear tests (Oct. 2006 and May 2009), and resumed missile testing, including two tests of launchers larger than the TD-1 (July 2006 and April 2009). In addition, it has pulled out of the six-party talks and said that it is no longer bound by the armistice to the Korean War.

This could be due in part to internal political changes that may have taken place in North Korea. It may also in part be a negotiating tactic. But North Korea has likely also been influenced by external factors. It may have decided, based on experiences with the Clinton administration, which attempted engagement but was limited by domestic debates over the approach, and the Bush administration, which seemed to largely reject an engagement strategy, that diplomacy with the United States is not likely to produce the results it wanted.

Other external events may have also affected its view and added to its recalcitrance. It saw the United States send forces into Afghanistan and Iraq. It has seen Iran's domestic nuclear program continue to progress, including the development of uranium enrichment facilities that could be

[9] National Intelligence Council, "Foreign Missile Developments and the Ballistic Missile Threat to the United States Through 2015," September 1999, http://www.nti.org/e_research/official_docs/cia/9-99CIA.pdf ; A. Sessler, et al., *Countermeasures*, April 2000, http://www.ucsusa.org/nuclear_weapons_and_global_security/missile_defense/technical_issues/countermeasures-a-technical.html

used to produce weapon-usable uranium. It has seen Pakistan conduct several nuclear explosions without severe long-term reactions from the rest of the world. It has seen Iran continue its missile development program (apparently with North Korean aid) and successfully launch a small satellite into orbit (February 2009). And it has watched South Korea build up its domestic launch capabilities and attempt a satellite launch.

As a result, North Korea may have decided that it faces a real security threat, that it does not want to appear technologically inferior to these other countries, and that the long-term political costs of continuing with its military programs are less than it previously imagined.

While the story of past negotiations and actions is complicated and a continuing subject of disagreement, North Korea's view of these may well have led it to a position in which it will be much more difficult to engage.

What North Korea appeared to want in the past was progress toward fundamental changes in its relationship with the United States, with the goal of improving its economic situation. This included a "peace agreement" (not necessarily a formal peace treaty ending the Korean War), consisting of a pledge that neither country would have hostile intent toward the other, and a resulting growth of economic ties. However, North Korea may now see the United States as interested only in capping its nuclear weapons and missile programs while lacking the political will to significantly change the relationship. North Korea did not get the larger benefits it expected as part of the Agreed Framework, and may therefore be cynical about the prospect of rejoining talks without some reason to believe it will gain from them.

Satellites and Space Launch Vehicles

The overall goal of missile negotiations would be to get North Korean agreement to stop the further development of launchers, to roll back its existing deployments of missiles, and to eliminate its missile stocks. Because the technology for space launchers can also be used to make long-range ballistic missiles, this would require North Korea to give up its development of space launchers, and therefore its future capability to launch satellites. Two key questions are: what interest is North Korea likely to have in satellites, and what incentives could be put on the table to persuade it to give up the option of launching its own?

Pyongyang's Interests

Prior to its April 2009 launch attempt, North Korea announced that it had developed a State Space Development Prospect Plan that called for it within the next few years to launch "satellites for communications, resources exploration, weather forecasts, and the like, which are essential for the country's economic development and will normalize their operation."[10]

Satellite remote sensing can be useful for humanitarian purposes such as environmental management; disaster monitoring, relief, and management; etc. In recent years, North Korea has

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[10] "DPRK 'Space Technology Committee' Issues Statement on Plan to Launch Satellite," KPP20090224106003, Pyongyang, *KCNA Online* in Korean, 24 February 2009.

suffered famines due to natural disasters combined with environmental degradation and mismanagement, and satellite imagery could in principle be used to help deal with these issues.

North Korea also has mineral deposits and in the past has expressed interest in help in exploiting these resources and developing its mining operations, and remote sensing satellites might be able to play a role in this as well.

Other uses for remote sensing satellites with several-meter resolution (similar to that expected for satellites being built for Nigeria and Vietnam) include urban mapping, land use change, irrigation and water use, crop production and forest monitoring, mapping and terrain analysis, road/railway development and maintenance, and detection of fires and illegal mining.[11]

Satellite communications could be useful to North Korea both for humanitarian and development purposes, especially since it has little communication infrastructure.

However, North Korea could have access to all of these satellite services without building and owning its own satellites or without developing its own launch capability.

It could acquire data from satellites owned by other countries and develop domestic expertise in using that data. For example, North Korea has had access to low-resolution Landsat imagery and has a Landsat interpretation center funded and equipped by the UNDP and China, but its expertise in this area, its access to satellite data, and its ability to use satellite information could be expanded considerably. [12] In addition, given the cost of owning and operating a geostationary communications satellite, it would make economic sense for North Korea to buy service on existing satellites.

Even if North Korea decided it wanted to own satellites so it did not rely on others for these services, Russia or China could supply launch services so it would not need its own launcher.

Moreover, given the current available launch capacity and satellite capacity, it is difficult to imagine that it would make sense for North Korea to develop these capabilities in order to provide these services to other countries as a money-making venture.

Aside from these incentives, Pyongyang may have an interest in demonstrating a domestic launch capability so it is seen as keeping up with its neighbors, especially South Korea. Similarly, a number of developing countries have recently acquired their own satellites and North Korea may see this as having a symbolic value that it is unwilling to give up. For example, in the past decade Algeria, Argentina, Egypt, Indonesia, Kazakhstan, Nigeria, Pakistan, the Philippines, South Korea, Venezuela, Vietnam and others have acquired their own satellites, which were built and launched by foreign companies.[13]

[11] NigeriaSat-2, http://www.globalsecurity.org/space/world/nigeria/nigeriasat-2.htm
[12] Peter Hayes, personal communication.
[13] UCS Satellite Database, updated 1 April 2009, http://www.ucsusa.org/satellites

Possible Incentives for Foregoing a Domestic Launch Program
Given this set of interests, there are various approaches the United States could take as part of negotiations.

(1) One approach would be to develop a plan to give North Korea access to various kinds of satellite services and developing the expertise needed to use it, without owning and operating its own satellites. While this is a reasonable place to start negotiations, it does not satisfy the last set of interests noted above and is unlikely to be enough.

(2) A second approach would be to set up a consortium that would work with North Korea to help it develop technical satellite expertise and design and build a satellite. A key element of this proposal would be free or highly subsidized launch services to compensate for its lack of domestic launch capability. Either Russia or China could do the launches, which would be paid for by a fund set up by the partners in the six-party talks.

One possibility would be to have Surrey Satellite Technology Ltd. (SSTL) work with North Korea to design, build, and launch a small remote sensing satellite, as well as help it set up the ground stations required to operate such a satellite. SSTL had such collaborations with Algeria, Nigeria, and Portugal to produce their first satellites. These satellites were small—50 to 100 kg in mass—and were designed using commercial parts to keep the cost down.

NigeriaSat-1, launched by Russia in 2003, had a mass of 100 kg and was reported to have cost $13 million.[14] The market cost of launching a satellite of this mass into low Earth orbit would be about $2million,[15] but small satellites are often piggybacked with other payloads, which can keep the launch costs down. NigeriaSat-1 had a 32-meter resolution imager in 3 spectral bands.[16] SSTL is now building NigeriaSat-2, which reportedly will have "2.5-meter ground resolution in black-and-white mode and a 5-meter resolution in four-color mode and a swath width of 20 kilometers," as well as a wide-area sensor with "32-meter ground resolution and a swath width of 300 kilometers."[17] This satellite is expected to have a mass of 300 kg. Based on other satellites in this class, this satellite would probably cost $50-100 million.[18] The launch cost at market rate would be about $6 million.

If North Korea developed a satellite with SSTL, it could also join the Disaster Monitoring Constellation (DMC) that SSTL has organized, which currently includes organizations from Algeria, China, Nigeria, Thailand, Turkey, the United Kingdom, and Vietnam.[19]

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[14] http://www.globalsecurity.org/space/world/nigeria/nigeriasat-1.htm
[15] A ballpark figure for launch costs to low Earth orbit is about $20,000/kg.
[16] By comparison, LandSat 7, launched in 1999, reportedly has a panchromatic band with 15 m spatial resolution and a thermal infrared channel with 60 m spatial resolution.
[17] Peter de Selding, "Surrey Signs Deal to Build Nigeriasat-2," 14 Nov. 2006, http://www.space.com/spacenews/archive06/sstlnigeria_1113.html
[18] For example, the 150 kg VNREDSat-1 remote sensing satellite that France is building for Vietnam is reported to cost $100m ("France to finance Vietnam's second satellite project," Jan. 2009, http://www.eomag.eu/articles/797/france-to-finance-vietnams-second-satellite-project)
[19] http://space.skyrocket.de/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/nigeriasat-1.htm

(3) A third possibility is that the United States could organize a group of countries to buy or heavily subsidize a small geosynchronous communication satellite for North Korea. A growing number of developing countries in the past decade have acquired such satellites, most of which have been built by U.S., French, Chinese, or Russian companies.

The capability of a geo-communication satellite scales roughly with its mass. Recent satellites include the 1,400 kg KazSat-1 that Russia built for Kazakhstan in 2006 for $100 million, the 2,600 kg VinaSat-1 that Lockheed Martin built for Vietnam in 2008 for $200 million, and the 3,500 kg KoreaSat-3 that Lockheed Martin built for South Korea in 1998 for $200 million. Satellites of this kind can carry broadcasts as well as handle tens of thousands of simultaneous telephone calls.

The cost of launching a satellite into geosynchronous orbit would be roughly $50 million for a 1,400 kg satellite and $125 million for a 3,500 kg satellite.[20] The total cost of a satellite of this class would therefore be $150 million to $325 million. In addition, there would be costs for developing a ground station to operate the satellite.

While these costs may seem high, it is worth comparing it to costs of the U.S. Ground-based Missile Defense system, which is motivated in large part by a concern about future North Korean missiles. For example, each flight test of the system reportedly costs roughly $100 million.

(4) Another incentive could be to help integrate North Korea into the international space community by including it in regional forums related to space. Possibilities include:

Asia-Pacific Satellite Communications Council (APSCC): APSSC is a nonprofit international association that includes satellite and space-related industries, including private and public companies, government ministries and agencies, academic and research entities. The goal is "to promote communication and broadcasting via satellite as well as outer space activities in the Asia-Pacific for the socioeconomic and cultural welfare of the region. It "works to develop, expedite and broaden the distribution of new services via satellite in the region" and "assists in the formulation of recommendations on policies, regulations and technical standards within the region and the world."[21]

Asia-Pacific Space Cooperation Organization (APSCO): Headquartered in Beijing, APSCO was created in 2005 by China, Bangladesh, Indonesia, Iran, Mongolia, Pakistan, Peru, Thailand, and Turkey. The objectives of APSCO are "to focus on space science/technology and its applications,

[20] A rough cost figure for launching into GEO is $36,000/kg (D.E. Koelle, "Specific transportation costs to GEO—past, present and future," in "The New Face of Space: Selected Proceedings of the 53rd International Astronautical Federation Congress, *Acta Astronautica*, Vol. 53, Issues 4-10, August-November 2003, pp. 797-803, http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V1N-4B1RG8C-1Y&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=949775613&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=75a7b6a198e4baa1585c10d3221b53d6)

[21] http://www.apscc.or.kr/

education/training and cooperative research to promote peaceful uses of outer space in the region." In addition, "the organization aims to promote multilateral cooperation in space science and technology. Its members will work together in development and research, space technology application and training of space experts."[22]

ASEAN Subcommittee on Space Technology and Applications: Working under the ASEAN Committee on Science and Technology, this group works to enhance collaboration in space technology and its applications in the ASEAN region. The Subcommittee also designs and coordinates collaborative programs for remote sensing, communications, environmental and natural resource management, and development planning. It also proposes ways to involve government agencies, industries and academia in promoting and sustaining regional cooperation in space technology and its applications[23]

Asia-Pacific Regional Space Agency Forum (APRSF): The goals include fostering interaction between representatives from space agencies and international organizations in the Asia-Pacific region; seeking measures to contribute to socio-economic development to the Asia-Pacific region and the preservation of the global environment, through space technology and its applications; discussing possibilities of future cooperation among space technology developers and space technology users to bring mutual benefits of the countries in the Asia-Pacific region; and identifying areas of common interest. The National Space Development Agency of Japan plays a central role in planning and organizing the annual meeting of the Forum.[24] Projects being organized through the Forum include "Sentinel Asia: Disaster Management Support System" and "Space Application For Environment" (SAFE).

Satellite Technology for the Asia-Pacific Region Program (STAR): The Japan Aerospace Exploration Agency (JAXA) is inviting members from space agencies Malaysia, Thailand, India, Japan, South Korea, and Vietnam to participate in the STAR program, to begin in 2009. The participants will begin a three-year study of the EO-STAR satellite (300 to 500kg) to monitor land and/or ocean areas and will develop Micro-STAR (50 to 100kg). The goal is to increase opportunities to develop human resources in the field of satellite development for personnel from the space agencies and add to the number of Earth-observation satellites in the Asia-Pacific region through this activity. In so doing, it seeks to meet the future needs for Earth observation in this area. The major activities will be to hold satellite technology seminars for researchers and engineers who participate in the STAR Program and research the Earth-observation needs in the Asia-Pacific region, primarily the needs of agencies utilizing the data from Earth-observation satellites.[25]

[22] http://www.suparco.gov.pk/pages/apsco.asp; http://english.peopledaily.com.cn/90001/90776/90883/6554845.html; APSCO Convention is at http://tradeinservices.mofcom.gov.cn/en/b/2005-10-28/18583.shtml
[23] http://www.unescap.org/pdd/publications/regcoop/regcoop_full.pdf
[24] http://www.aprsaf.org/
[25] "Starting the Satellite Technology for the Asia-Pacific Region (STAR) Program," 2 June 2009, http://rescommunis.wordpress.com/2009/06/02/asia-pacific-satellite-technology-cooperation/

Japan's Regional Broadband Program: Japan launched this Program in March 2003 to promote the application of broadband communication and data transfer in the region. It will assist in connecting countries of the region to a regional broadband network. Implementation of the Program requires wide regional cooperation to create a policy framework, ensure security, and promote standardization.[26]

Asia-Pacific Satellite Communications Council: The Council is a non-profit regional organization that aims to promote satellite communications and broadcasting in the Asia-Pacific region through regional cooperation among its members to enhance the social, cultural and economic prosperity of the region. It also seeks (a) to exchange views and ideas on policies, technologies, systems and services which have potential benefits for the region, (b) to accelerate the introduction of services via satellite and (c) to develop and broaden the national and regional satellite communication and broadcasting services of Asia-Pacific countries. The Council promotes cooperation among member countries to minimize technical or regulatory barriers and works towards expanding the impact of information technology on development and promoting digital opportunities through the greater use of space technologies. The secretariat of the Council is hosted by the Republic of Korea.[27]

In addition to these multinational organizations, bilateral arrangements are possible. For example, China has developed a number of bilateral arrangements with other countries. In particular, China has signed cooperative agreements on the peaceful uses of outer space with Argentina, Brazil, Canada, France, Malaysia, Pakistan, Russia, Ukraine, ESA, and the European Commission, and has established cooperation mechanisms with Brazil, France, Russia, and Ukraine. China has also signed cooperative memorandums with the space organizations of India and the United Kingdom; and has conducted exchanges with space-related bodies in Algeria, Chile, Germany, Italy, Japan, Peru, and the United States.[28]

Possible Elements of a Diplomatic Approach

Negotiations between the United States and North Korea would need to focus on the big picture and on changing the fundamental relationship between the two countries, as well as making progress on military issues. As part of a diplomatic effort, there should be a step-by-step process to limit North Korea's missile program. Conceptually, this effort was consist of three steps, which are discussed in more detail below:

(1) Stop new missile developments in North Korea, as well as the export of missile technology and expertise.
(2) Stop the further deployment and production of missiles.
(3) Reduce numbers of deployed missiles and dismantle missiles taken off deployment.

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[26] http://www.unescap.org/pdd/publications/regcoop/annex3.pdf
[27] http://www.unescap.org/pdd/publications/regcoop/annex3.pdf
[28] John Logsdon and Clay Moltz, "Collective Security in Space: Asian Perspectives," January 2008, p. 30, http://www.gwu.edu/~spi/Collective%20Security%20in%20Space%20-%20Asian%20Perspectives%20-%20January%202008.pdf

In each step, transparency and verification measures should be developed to provide confidence.

Since North Korea sees its missile program as part of its defense against foreign aggression, making progress on these issues would almost certainly require the United States to offer a non-aggression agreement and a timeline for beginning to normalize relations between the two countries and remove sanctions that restrict economic engagement.

Details of Step 1: Stop missile development, sales, and technical assistance

An important first step for stopping future development would be re-establishing a ban on missile flight testing. Such a ban would be effective in stopping the development of new missiles and is readily verifiable by U.S. early warning satellites. There would also need to be a strict ban on assistance from other countries to North Korea, including technical expertise, technology, or the results of flight tests done in other countries. This could be difficult to verify, and so a flight test ban should be combined with other measures, such as shutting down missile research and development facilities and banning ground tests needed to develop and test engines and related systems.

As noted above, the United States should work with Russia to understand what assistance and technology North Korea received from Russian sources. This would allow a better assessment of the current state of North Korea's missile development program, and what technical limitations it may face.

The United States should seek a complete ban on the sale or transfer of all ballistic missiles, missile components, and related technologies, as well as a ban on technical assistance for such systems. Missile transfers can be difficult to detect, although they can often be inferred after the fact. Verifying an end to technical assistance is more difficult, but it is important to build into any agreement clear prohibitions on these activities.

North Korea has said in the past that its missile exports are aimed at obtaining foreign currency, and wanted compensation for its foregone sales; in the late 1990s, North Korea reportedly sought $1 billion a year for three years. A better approach might be for the United States and other countries to agree to give aid to help North Korea develop other ways of earning foreign currency as trade restrictions are eased. During negotiations in 2000, the United States was reportedly willing to offer to arrange for $200-300 million per year in investment and aid, and agreed to launch two or three North Korean satellites a year.[29]

Israel has in the past shown an interest in providing hard currency to North Korea as well as assisting in lining up trade and foreign investment as a way of stopping North Korean missile sales to the Middle East. Israel also discussed providing mining assistance to North Korea in the early 1990s, and this might be an area to explore again. The United States could urge Israel to provide such assistance as part of a U.S. package for North Korea.

[29] Leon Sigal, "Verifying a Missile Accord with North Korea," *Verification Yearbook 2002,* pp. 111-128.

North Korea has also argued that it wants to develop a satellite launch capability for civil purposes, and is likely to reiterate that desire, pointing to its recent joining of the Outer Space Treaty. In the late 1990s, in return for freezing its development program, North Korea demanded several satellite launches each year and a monetary payment for the revenue it would forego by not selling launch services in the future. As noted above, the United States, Russia, China, and Japan could instead offer satellite services from their satellites in the near term (especially communications and weather/environmental monitoring), and offer assistance in developing satellites that would be useful for its economic development and social infrastructure, and offer launch services for those satellites.

The continuing development of missile technology and space-launch vehicles by other countries, especially Iran and South Korea, is likely to make it more difficult to get North Korea to agree to stop its own development of these systems.

South Korea conducted an unsuccessful attempt to launch a satellite launch attempt in August 2009. Interestingly, the first stage of its KSLV-I launch vehicle is reportedly based on the first stage of the Russian Angara launcher, which is under development. This stage uses cryogenic fuels (liquid oxygen and kerosene) which cannot be stored for long periods of time and are more suited to space launchers than ballistic missiles. The second stage reportedly uses solid fuel and was developed indigenously. The launcher is said to be able to place a payload of 100 kg into a low orbit and therefore has a similar capability to the Unha-2.[30]

North Korea is likely to want to maintain at least the perception of parity in space issues with South Korea. Getting it agree to give up a domestic launch program may become more difficult if South Korea successfully launches its first satellite in the near future. However, the fact that North Korea has claimed success in launching satellites in 1998 and 2009 may make it easier to adopt this position domestically, especially if it can announce collaborative programs to develop and operate satellites for remote sensing and communication.

It would be useful to develop a set of strict transparency measures that would apply to launches from anywhere on the Korean Peninsula, and that would be administered by the other partners of the Six Party talks, all of whom are space-faring countries. The goal of these measures would be to give public reassurance that the programs are peaceful; it may also have the effect of reducing North Korea's interest in having a program that would be subject to intrusive transparency measures.

Details of Step 2: Stop the further deployment and production of missiles

A deployment freeze should be accompanied by a declaration of types and numbers of deployed missiles, and what military base each is associated with. Scuds and Nodongs are mobile and therefore do not have fixed locations, but are expected to be associated with a missile base that is responsible for maintaining them and fueling them in a time a crisis. There have been unverified

[30] The KSLV-1 launcher has two stages and is reportedly somewhat larger than the Unha-2, with a diameter of 2.9 m and a launch mass of 140 metric tons (http://www.astronautix.com/lvs/kslvi.htm).

reports since 2003 that North Korea has also deployed small numbers of a 2,500 km range missile based on the Soviet SS-N-6 (R-27) missile; North Korea must clarify whether it has deployed these missiles, and how many.

Verifying a freeze on deployment is likely to be difficult, but this could be aided by a ban on production. Verifying a production ban would first require a declaration of production facilities and some provision of challenge inspections for other suspect sites. The U.S.-Soviet Intermediate Nuclear Forces (INF) Treaty, which bans those countries from having missiles with ranges between 500 and 5,500 km, lays out procedures for portal monitoring of production facilities, which could be used to verify that a facility is not operating, or that it is only producing allowed missiles. In return for North Korea's acceptance of on-site monitoring of these facilities, the United States could provide or arrange for assistance to convert the production facilities to other uses.

Reaching agreement on these steps would likely require applying restrictions only to missiles with range greater than a given threshold, at least initially, which could be 300 km/500 kg as laid out in the Missile Technology Control Regime (MTCR) (which would ban North Korean Scuds), or could be 500km/500 kg, as was discussed with North Korea in the late 1990s. North Korea seems unlikely to agree to a 300 km limit since it considers its Scuds as part of its conventional forces and banning them would likely require discussions of the conventional forces of other countries, including South Korea.

Setting the threshold at 500 km would allow North Korea to retain some short-range missiles while banning the Nodong missile (which can reach Japan) and stopping the development of longer range missiles. While a 500 km range missile would allow the North to target all of South Korea, a 300-km range missile could still reach most of the South's large cities. Since the technology used in short-range missiles differs from that needed for long-range missiles, such a threshold would not undercut the goal of the ban. However, allowing some kinds of missile-related activities to continue would likely make verification more difficult, because it would have to determine the nature of a detected activity, not just that an activity was occurring.

Details of Step 3: Reduce numbers of deployed missiles and dismantle missiles taken off deployment

The final step would be to reduce the number of deployed missiles with range greater than the agreed threshold, with a timeline for elimination. Getting North Korea to agree to get rid of its Nodong missiles, which can reach Japan, is likely to require some level of normalization of relations with Japan.

The INF Treaty has detailed protocols for dismantling missiles, which could be adapted to this situation.

It may be difficult to verify with high confidence that North Korea's declaration of numbers of deployed or produced missiles is accurate, and that it does not have some number of missiles stored clandestinely. A right to challenge inspections should be included in the negotiations.

However, it is important to note that if production is stopped, then destroying missiles represents a real reduction in its arsenal. Further, the military utility of any residual missiles could be reduced by verifying that there are no missiles at North Korean military bases and that crews are not training with them. This would be reinforced by a missile flight ban.

Conclusion

There are a range of specific steps the United States can take as part of a diplomatic effort to place meaningful limits on North Korea's ballistic missile program. These could help roll back the threat posed by these weapons, and could help integrate North Korea into the international community.

Ultimately, of course, the United States might conclude that North Korea is not interested in negotiations and that a strategy of containment and isolation is the best it can do. But it makes no sense to start with such a strategy. A serious, pragmatic approach to national security demands that the United States seriously pursue a policy of engagement with North Korea to find out if it will work.