# Assessing North Korea's progress in developing a nuclear-armed ICBM

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## Defining "success:" North Korean goals and U.S. fears

North Korea openly seeks nuclear-armed ICBMs capable of threatening the United States. Its precise military requirements for such a weapon are, however, unknown. In fact, it is possible that such requirements have not been clearly defined and North Korea is simply doing its best given the available resources.

Assuming that North Korea has defined requirements, potential considerations include: range, reliability, yield, accuracy, and safety. Any criteria are (as with all weapon systems) politically determined; there are no "right answers" from a technical perspective. That said, it seems likely that North Korea wants ICBMs capable of reaching east-coast cities and that it is unlikely to be overly concerned about safety or accuracy. Any goals for yield and, in particular, reliability are much more uncertain (North Korea often mentions reliability in public statements, but it is unclear what this means in practice).

Of course, the magnitude of the threat that North Korea poses to the United States is a function of more than just the design characteristics of individual ICBMs. North Korea may also have requirements related to the survivability of its nuclear forces and the total amount of damage they could inflict, which depend on its nuclear posture as a whole.

There is mixed evidence about whether North Korea believes it has acquired a capability to target the United States *that is deemed credible by Washington*. Its somewhat ambiguous threat, issued in September 2017, to conduct an atmospheric nuclear test over the Pacific suggests that Pyongyang believes its ICBM capability is not yet credible. By contrast, in April 2018, it justified its announced moratorium on nuclear and missile tests by stating it had "realized the technology for mounting nuclear warheads on ballistic rockets."

To complicate matters further, there is no *a priori* reason why the capability level at which North Korea assesses that the United States believes it faces a credible ICBM threat is the same as the level at which the United States actually feels threatened.

Once again, there is mixed evidence about whether Washington believes it currently faces a credible ICBM threat from North Korea. In January 2018, for example, CIA Director Mike Pompeo indicated that it does not (though he made clear that such a threat could emerge rapidly). He stated that the United

[1] This work was supported by the Government of Canada.

States and its partners had developed a "pretty clear understanding" of North Korean capabilities and that "we talk about [Kim] having the ability to deliver a nuclear weapon to the United States in a matter of a handful of months." By contrast, in the same month, Gen. Paul Selva, vice chairman of the Joint Chief of Staff stated that, although North Korea had not yet "demonstrated all of the components of an intercontinental ballistic missile system," the United States "has to place the bet that [Kim] might have them."

Against this background, this paper assesses North Korea's progress towards developing a nuclear-armed ICBM. It focuses exclusively on the two liquid-fueled ICBMs, the HS-14 and HS-15, that North Korea is known to have flight-tested, since these missiles—the HS-15 in particular—appear to represent the ICBMs most likely to be deployed in the near future. However, North Korea may be developing other ICBMs. Indeed, it has exhibited (but is not known to have flight-tested) the liquid-fueled KN-08 ICBM and a possible variant, the KN-14. It is developing solid-fueled missiles that may ultimately include ICBMs. And it has developed space-launch vehicles that could, theoretically, be converted into ICBMs.

## Warhead development

There are at least four characteristics of an ICBM warhead for North Korea to consider: size (because the warhead must be physically small enough to fit inside the re-entry vehicle); mass (which affects the range of a ballistic missile); explosive yield; and reliability (which depends, in part, on the warhead's ability to survive the stresses of flight).

To date, North Korea has conducted six known nuclear tests. Seismic signals (together with open-source satellite imagery and information about test site topology) allow yield to be estimated. North Korea has made statements about—and released photographs intended to suggest—the design of the test devices, but it is impossible to extract design information from seismic signals. It may be possible to infer some design information from any radionuclides that leak following a test. However, except after the first test, no government with the capability to do so has commented publicly on whether it detected radionuclides and, if so, whether it was able to infer design information from them.

Given what is known about the test programs that supported nuclear warhead development in other states, North Korea has likely developed a fission warhead small and light enough to be mounted on a ballistic missile. Moreover, North Korea's sixth and most recent test produced a yield that was probably larger than 100 kT, and perhaps significantly larger. While it is technically possible to produce such a large yield without a thermonuclear device, Occam's Razor would suggest that a thermonuclear device was indeed used (not least because of the large quantity of fissile material that would be needed for a fission weapon with such a high yield). Whether North Korea can mount a thermonuclear warhead on a ballistic missile is more of an open question, though given the size of the HS-15, it may be able to do so.

It is not possible to assess the reliability of North Korea's nuclear warheads given that North Korea's goals for its tests are not known and the possibility that it has conducted additional non-identified tests that failed to produce a significant nuclear yield.[2]

[2] Estimating reliability through a simple "frequentist" approach would be unlikely to be accurate anyway because reliability would be expected to increase over time.

## Missile development

In developing a ballistic missile, North Korea must consider its range (which depends on both the design of the missile and the mass of any payload), accuracy, and reliability.

In 2017, North Korea conducted identified ICBM flight tests for the first time. The liquid-fueled HS-14 was tested twice, and the larger liquid-fueled HS-15 once. All three tests were conducted on lofted trajectories that fell west of Japan—the equivalent of a lob shot in tennis. The results of calculations conducted by David Wright of the Union of Concerned Scientists about how far each missile would have travelled had it been "served" at full range—on a so-called Minimum-Energy Trajectory (MET)—are shown below.

| Test | Missile | Observed maximum altitude (km) | Calculated MET range (km) | Coverage of North America on an MET |
|---|---|---|---|---|
| July 4, 2017 | HS-14 | 2,802 | 6,700 | All of Alaska and Western Hawaii |
| July 28, 2017 | HS-14 | 3,725 | 10,400 | All of Hawaii, Alaska, and the contiguous United States except the south east |
| November 28, 2017 | HS-15 | 4,475 | 13,000 | All of Hawaii, Alaska, and the contiguous United States |

"Calculated MET range" does not take into account Earth's rotation (which increases the range of a missile fired at North America from North Korea, although the magnitude of this effect depends on the missile's precise heading). The qualitative descriptions of coverage do, however, factor in this effect.

One complication in assessing these tests is that it is not known whether the DPRK loaded these missiles with mock warheads of the same mass as the real thing. If these missiles did not contain mock warheads, then their true ranges (when loaded with actual warheads) would be shorter than shown in the table, as discussed further below.

North Korean ICBMs are likely to be at least as accurate as early U.S. ICBMs, which reportedly had accuracies of a few miles (although it is impossible to make a quantitative assessment of their accuracy).[3] Some U.S. and South Korean officials have stated that North Korea has yet to complete development of a terminal guidance system (which would enable re-entry vehicles to steer towards their target, thus increasing their accuracies). However, considering that U.S. ICBMs are not equipped with this technology, terminal guidance is certainly not necessary and, in fact, there is little reason to suppose that North Korea is even developing it for missiles of this range.

If the three reported ICBM tests in 2017 really were the only tests of the HS-14 and HS-15 missiles, North Korea's achievement in conducting three successful launches involving two new missile types

[3] Technically, accuracy is defined as circular error probable, that is, the radius of the circle in which a missile has a 50% chance of landing.

would be significant. It is, however, possible that unreported failures also occurred. In any case, the number of tests is too small to make a quantitative estimate of reliability.[4]

### Safing, arming, firing, fusing

Any ICBM must be equipped with a safing, arming, firing, fusing (SAFF) system to support "surety" (ensuring that the warhead always detonates when ordered), and safety (that it never detonates at other times). In reality, there is always some trade-off between these goals (the so-called always-never dilemma). The SAFF system can also be used to tailor the precise altitude at which a detonation occurs to maximize the weapon's military effectiveness (though it is unknown whether North Korea seeks such a capability).

There is not enough publicly available evidence to assess North Korea's progress in developing a SAFF system (though the challenges it faces are relatively modest). That said, if history is any guide, North Korea is likely to prioritize surety above safety.

### Re-entry vehicle development

A re-entry vehicle (RV) must be able to withstand the heat and force experienced on re-entry to protect the warhead inside. Moreover, for an ICBM equipped with a sufficiently sophisticated guidance system, the design of an RV can be the limiting factor in determining a weapon's accuracy. That said, it seems unlikely that North Korea's missile guidance systems are sufficiently advanced for RV design to matter all that much for accuracy.

North Korea's development of a viable RV is widely seen (correctly or otherwise) as the last significant hurdle it must cross to develop an ICBM. Even if this claim is correct, however, the challenges to developing a viable RV are much smaller than those that North Korea has already surmounted in its nuclear and missile development efforts.

Moreover, media reporting based on unnamed U.S. intelligence officials suggests that North Korea may have made significant progress in developing an RV for its ICBMs, especially the HS-14. In July 2017, the *Diplomat* reported that the United States believes that the RV used in the July 4 HS-14 test survived to altitude of about 1 km, potentially adequate for an air-burst. The following month, it reported that, although the RV used in the July 28 HS-14 test broke up higher in the atmosphere, the CIA concluded that the design would likely be viable for an ICBM launched on an MET.

By contrast, CNN reported in December 2017 that U.S. officials believe that "the North Koreans had problems with re-entry" in the November HS-15 flight, suggesting that North Korea has not yet completed the development of an RV from that missile. However, it may be straightforward for North Korea to solve any problems by using a heavier heat shield and accepting a reduction in the missiles' range.

In any case, there are at least two complications in using North Korea's 2017 ICBM tests to infer how nuclear-armed North Korean RVs would fare if launched toward North America.

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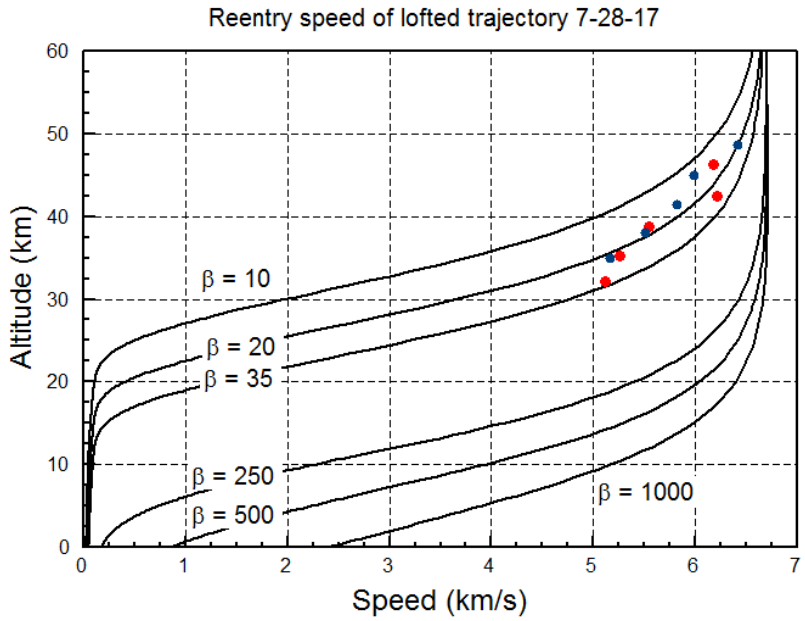
[4] See note 1.

First, as the *Diplomat*'s description suggests, the conditions experienced by an RV on a lofted trajectory and an MET are not the same. Specifically, on a lofted trajectory, the maximum heating *rate* of the RV is generally higher. On an MET, the *total amount* of heat transferred to the RV is generally higher. In consequence, surviving re-entry on an MET is neither a necessary nor a sufficient condition for surviving re-entry on a lofted trajectory.

Second, one of more of North Korea's 2017 ICBM tests may not have included a mock warhead. The mass of a warhead (mock or real) helps to ensure that an RV is oriented nose-first during re-entry and does not tumble (increasing the chance of its failing). Without the mass provided by a warhead, even an otherwise viable RV might fail.

There is some evidence that the July 28 ICBM test did not contain a mock warhead. The RV was caught on tape by two TV cameras in Japan. By analyzing footage from these cameras (some of which has not been made public), David Wright, Jeffrey Lewis from the Center for Nonproliferation Studies, and I obtained the following graph showing how the speed of the RV varied with altitude during re-entry. (The different colored data points were extracted from different videos.)




Based on this data, the RV appears to have decelerated more rapidly and higher in the atmosphere than is usual (that is, its ballistic coefficient, β, is much lower than would be expected for a missile re-entry vehicle). In fact, we believe that the data can best be explained if the RV did not carry a mock warhead, tumbled, and was perhaps still attached to the second stage (though these conclusions are tentative).

Given the absence of a mock warhead (and the possible absence of a mechanism to separate the second stage and RV), it is possible that the July 28 test was not, in fact, intended to gauge the performance of the RV. Instead, by reducing the mass of the RV, North Korea may have been aiming to maximize the altitude attained by the missile and hence give a somewhat misleading impression of the missile's maximum potential range.

It is unclear whether the July 4 HS-14 test carried a mock warhead—though it is possible it did, given the lower maximum altitude reached in this test. If so, the HS-14 range with a payload may be too short to reach the contiguous United States.

There is no publicly available evidence about whether the HS-15 missile launched in November carried a mock warhead. If it did not, its range with a payload would be less than 13,000 km. However, there seems little doubt that it could nonetheless reach much—if not all—of the contiguous United States when loaded with a real warhead.

## Conclusion

Confident statements that North Korea does not yet have the capability to threaten the United States with a nuclear-armed ICBM are overly optimistic. However, there is room for reasonable doubt about whether it has yet acquired this capability. If it has not, it is likely to be able to surmount any remaining barriers relatively quickly—most likely in months—following the political decision to do so.

After completing development efforts (if they are not already complete) then, in the event that on-going diplomatic efforts collapse, North Korea may feel the need to demonstrate categorically that it can threaten North America with a nuclear-armed ICBM by conducting a missile-launched nuclear test over the Pacific Ocean.