SCIENCE & GLOBAL SECURITY
2019, VOL. 27, NO. 1, 29–72
https://doi.org/10.1080/08929882.2019.1613805

The Scope of Foreign Assistance to North Korea's Missile Program

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ABSTRACT
There is evidence that North Korea's ballistic missile program benefited from support from the Soviet Union until its collapse and from Russia thereafter. Along with transfers of missile systems and rocket components, it appears that Russian engineers directly supported the program in North Korea. Analysis of missile launches, imagery, design solutions, and technology suggest that Pyongyang's recent missile program may have continued to have external support despite a pause in the 2000s. This assistance may have enabled the progress in North Korea's missile program leading to tests of an intercontinental range ballistic missile in 2017.

ARTICLE HISTORY
Received 6 June 2018
Accepted 27 February 2019

Introduction

Under the rule of Kim Jong Un, the North Korean missile program experienced a major increase in total and annual missile launches (see Figure 1). There were reports of new launches every two weeks, and new missile types were introduced on a regular basis. The missiles ranged from advanced Scud variants and large solid-fueled missiles to Intercontinental Ballistic Missiles (ICBMs) that were capable of reaching the United States and U.S. territories.[1] Combined with static firing tests of several different new engines, these developments underlie the widely held belief that North Korea always had a very capable indigenous missile industry.[2] This image of North Korea as a nation of rocket scientists was fueled by its initial success in "quickly reverse engineering" foreign missiles in the 1980s, followed by rapid and flawless improvement of these missiles into advanced types with improved performance. The exports of these missiles to other countries in the following years only validated North Korea's reputation as a highly capable missile state.[3]

Robert Schmucker argued in 1999 that North Korea's claim that its guided ballistic missile program was an indigenous effort was unfounded and that a more plausible explanation for its missile development progress

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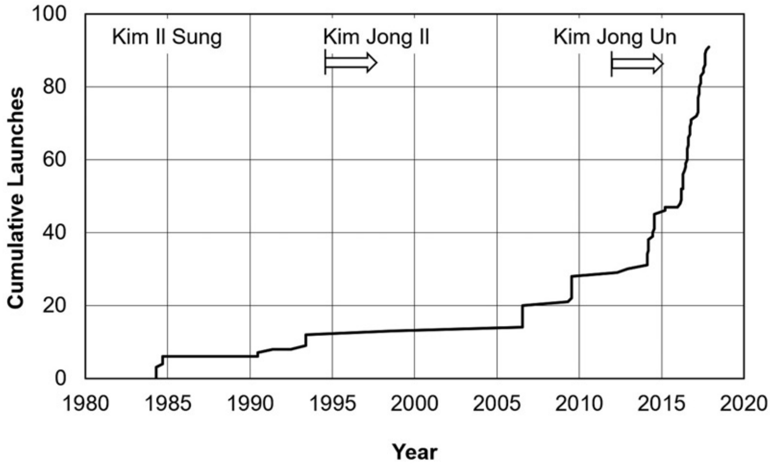


Figure 1. North Korean missile launches 1980–2018. Only space launchers and guided ballistic missiles the size of Scud B and larger are depicted.

was that North Korea received foreign assistance.[4] An important question, with implications for the current negotiations on the denuclearization of the Korean peninsula, is whether North Korea's recent advances are speculative or real. An overview of the North Korean ballistic missile programs is provided in Appendix A.

Ballistic missile systems basics

Missiles are complex systems. The task of a missile is the autonomous and reliable delivery of a payload to a predetermined location. The task's requirements and complexity increase with increases in the range and weight of the payload. While satellite launch vehicles are launched under perfect conditions, with months of preparation, military missiles must be launch ready on a moment's notice under any conditions.

Missiles can be divided into three subsystems: airframe, propulsion unit, and guidance and control (see Figure 2). The warhead and missile are usually designed and built by different institutions. Missiles are designed with either a solid or a liquid propulsion system.

The guidance unit is the "brain" of the missile, the control elements execute the guidance commands that control the missile's trajectory. The airframe is "dead weight" and provides structural integrity for the important subsystems.

While the airframe is difficult to design and build, every industrialized nation is likely capable of building one. The guidance and control system was potentially the most complex subsystem for decades, but with the advances in electronics, sensors, and computers, components of guidance systems are readily available, despite export controls and threats of sanctions to suppliers.[5]

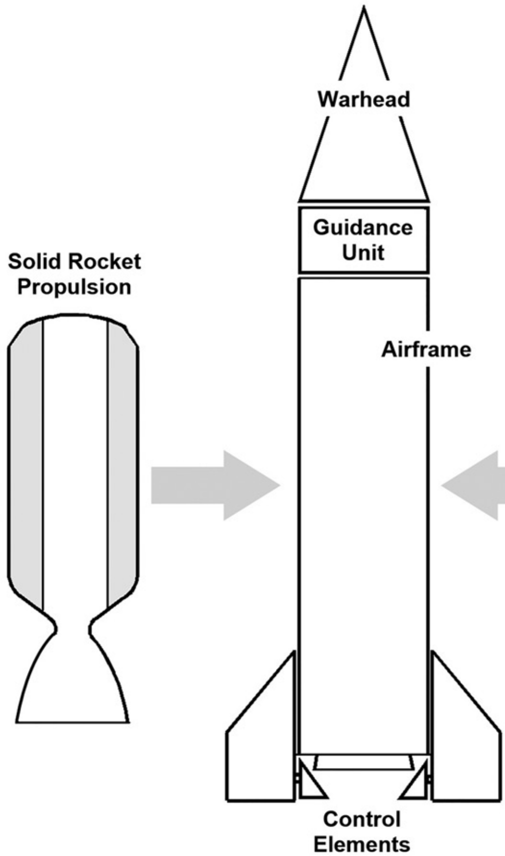


Figure 2. Missile subsystems.

The propulsion unit is the critical path to missile development, and its technical requirements increase with its size and power. Evidence indicates that the development of new rocket engines (liquid or solid) takes several years requiring hundreds of ground tests before first flight.[6] Even modifications to existing engines requires significant effort, and while reverse engineering is often considered a shortcut, there are no examples of rapid reverse engineering successes, even when the original design and production institution plays a supportive role.[7]

The missile system also consists of much more than just the missile. A mobile system requires a specialized launch vehicle, mobile launch support systems for checkouts, initialization, monitoring, fueling trucks to deliver fuel and oxidizer, and specialized vehicles to neutralize the effects of the toxic fumes from the rocket exhaust on the launch vehicle. These vehicles must be designed and built or purchased, and operational procedures must be developed. Getting the missile itself to that stage is a significant effort and usually takes dozens of flight tests, even for experienced institutions.[8]

Getting a complete missile system operational requires even more effort, time, and significant resources.

North Korea and the "testing mystery"

The North Korean missile program has a unique flight test record. Since the 1980s, different guided ballistic missile systems have appeared, all of them capable and reliable, with very few failed launches.[9] This level of success without extensive test campaigns was unprecedented in other countries, including Russia and the United States (see Figure 3, for more data, see Appendix B).

Over time, increased experience, institutional knowledge, and modern development and manufacturing methods reduced the number of required test flights. Today, 10 or more test flights are usually still required by experienced missile developers. North Korea never required even close to 10 tests, even at the beginning, without any previous experience. The chart only shows development tests up to the official declared initial operating capability or deployment. Later tests are not included. The Musudan was declared operational without testing and is therefore not depicted. Neither is the Scud D, which was reportedly transferred from North Korea to Syria without testing. For other missiles, such as the KN-11 or the Scud ER, the data are conflicting. Data for Chinese missiles are for ICBMs only (data for shorter-range missiles are not available publicly).

It is important to understand that testing is not an option during development. Only launch tests can identify problems that cannot be predicted by simulations. Technical problems usually translate to catastrophic failures. Viable programs require dozens of tests for development and qualification

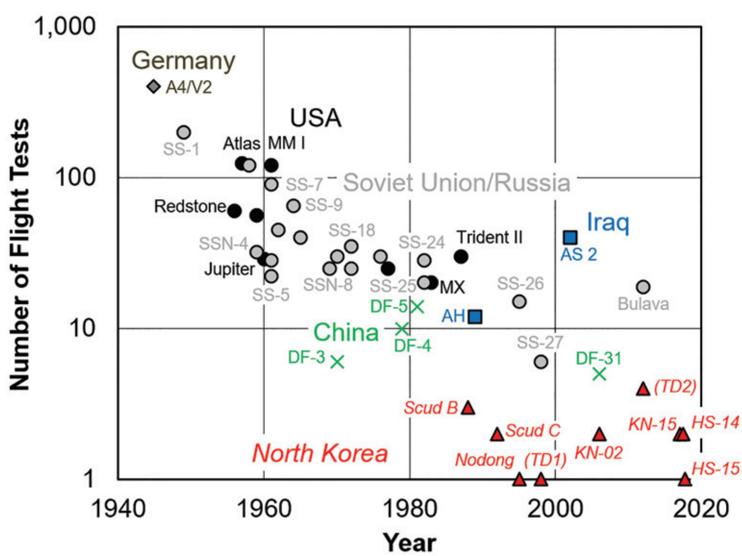


Figure 3. Flight tests for missile development, 1940–2020.

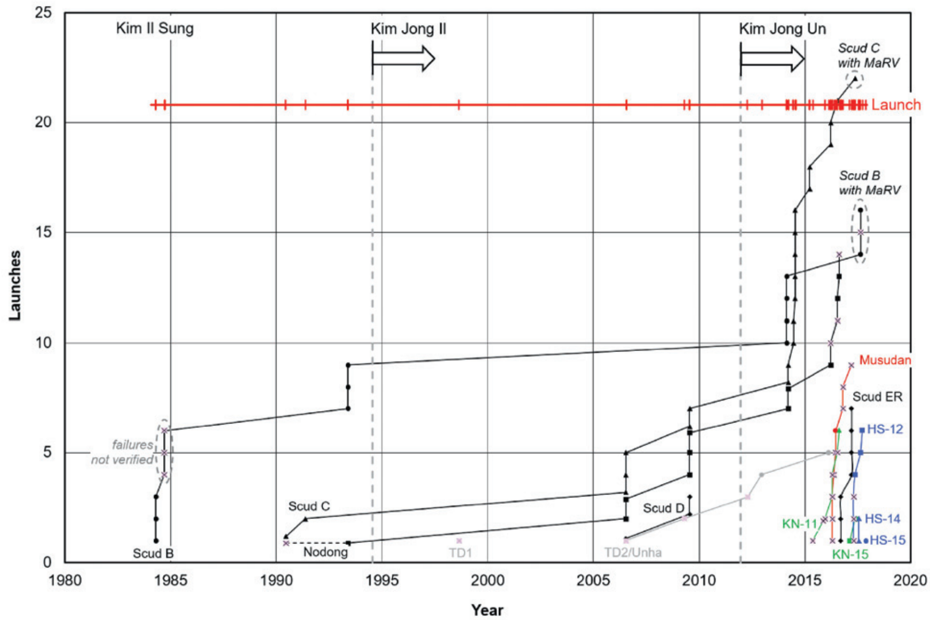


Figure 4. North Korean rocket test flights, 1980–2020 (rockets smaller than Scud Bs are not shown).

and further testing during production to ensure that missiles coming out of the factory are still working.[10]

This is even more true for missiles that are to be used in wartime and by soldiers in the field, under conditions that are far from perfect (weather, time pressure, 24-hour operations, exhaustion, etc.). Once missiles are deployed, ongoing testing is required for launch crew training, readiness, and quality control for older missiles and equipment as well as lot acceptance during production. In other countries, shortcuts were only possible for programs that received different degrees of external help.[11]

The timing and frequency of launches in real development programs are dictated by technical requirements and defined by engineers.[12] Prior to 2014, North Korean tests were rare (see Figure 4), and often happened only on politically relevant dates.

Failed North Korean launches were also rare prior to early 2014. In Figure 4, launch failures are depicted with an "x". Launches of satellite launch vehicles are gray. Three Scud B failures in 1984 and the 1990 Nodong on-pad failure are not confirmed. Unconfirmed information such as a 1986 rocket launch or a 1992 Nodong failure are not included. A larger version of this chart is in Appendix G.

Before 2014, North Korea had very reliable missiles, but few observed activities and tests that were consistent with an active indigenous research and development (R&D) program.[13] North Korea was (and continues to be) a country with low industrial and financial capabilities, with no experience in missile development before the Scuds appeared in the 1980s. So why were its missiles so reliable? Carefully piecing together publicly available information sheds light on this mystery.

Soviet origins of Scud technology

The Scud B

The story begins with the R-17 missile, better known as the Scud B. This Soviet missile was developed in the late 1950s by the Makeyev design bureau (SKB-385) and outfitted with an engine developed by the Isaev design bureau (OKB-2). Both design bureaus were renowned institutions of the large Soviet missile development complex. An overview of relevant Soviet design bureaus and production sites can be found in Table C1.

The Scud B is about 11 m long, weighs almost 6 tons, and can deliver a 1-ton payload to 300 km. The Scud B was produced from the 1960s until perhaps 1987, in two Soviet factories, Votkinsk (Machine Plant No. 235) and Zlatoust. Votkinsk could produce 300 Scuds per year, and Zlatoust's production capacity was 1,000 Scuds per year in wartime.[14] Many thousands of missiles were produced. About 2,000 Scud Bs were used in Afghanistan, almost 1,000 were shipped to Iraq, and another 1,000 to other countries, but these numbers vary between sources. The Scud B was to be phased out in the 1980s and replaced by its successor, the SS-23/Oka. In the Soviet Union, outdated and decommissioned weapons were usually not destroyed but stored, and thus, huge stockpiles of the Scud B likely existed in the late 1980s.

Beginning in the 1960s, the Soviet Union transferred Scud B missile systems to numerous states, including Egypt. Estimates are that Egypt received roughly 100 missiles. Some have claimed that Egypt transferred several to North Korea in the late 1970s or early 1980s.[15]

In April 1984, North Korea successfully fired three Scud B missiles for the first time. There is also speculation that three failed launches occurred in September 1984, but it is unknown to the author why they failed. According to common belief, North Korea had used the Egyptian Scud Bs as blueprints for reverse engineering.[16] Within a few years, North Korea had allegedly copied and improved the complete missile system and began selling their version of the Scud B to other countries.[17]

It is further assumed that the Scud B reverse engineering efforts allowed North Korea to gain enough experience to successfully develop and produce other more advanced missiles. Had this occurred, North Korea appears to have avoided many of the problems experienced by all the other major nations with early missile programs, including the Soviet Union and the United States.[18]

At about the same time that North Korea had access to Scud B systems, the war between Iran and Iraq entered a critical phase. The Soviet Union had supplied Scuds to Iraq but denied shipments to Iran, thus providing an opportunity for North Korea. From 1987 forward, 90 to 100 North Korean Scud B missiles (allegedly quickly reverse engineered from the Egyptian Scuds) were delivered to Iran, where at least 77 of them were successfully launched against Iraq.[19]

Widespread suggestions of North Korean reverse-engineering of Scud missile systems all appear to stem from the claim that North Korea initiated such a reverse-engineering effort with the Egyptian Scud B missiles it had received in 1976 and possibly gave the effort more priority in the mid-1980s with a view to selling such missiles to Iran. It also was claimed that North Korea "imports components" and "fabricates [Scud B] missiles," with China as a possible source for the missile components, although it was not possible to rule out a Soviet source.[20] An alternative notion was that North Korean Scuds originated in the Soviet Union, with reports that North Korea received about 240 Scud B missiles from the Soviet Union, of which about 100 of them were re-sold to Iran.[21]

This time frame is in line with the phase-out of the Scud B in the Soviet Army. The Soviets were sitting on a large inventory of obsolete missiles, had lots of potential customers, and needed money. It cannot be ruled out that selling these Scud Bs to North Korea (and on to Iran) served Soviet strategic interests. It should also be noted that the Soviets did not pursue patent infringement or make accusations of counterfeiting when North Korea started exporting Soviet missile designs to other countries.

A Soviet missile transfer might explain the high success rate of the North Korean Scuds in Iran, especially given the minimal testing by the North Koreans to start their so-called "indigenous Scud B production." Without any previous experience, North Korea allegedly produced hundreds of reliable guided ballistic missiles.

Another interesting issue is the "weapon system mystery." Every ballistic missile system consists of much more than just the rockets. The truck that carries and launches the missile, the transporter-erector-launcher (TEL), is just one part. A typical Warsaw Pact Scud B brigade with only 6 TELs required more than 300 support vehicles, some with very special equipment, in addition to the TELs themselves, which are trucks outfitted with complex launch systems.[22] The brigade included survey vehicles with special tool sets, communication vehicles with coded radio systems, fueling vehicles for oxidizer and fuel, checkout vehicles for the guidance and self-destruct systems, and checkout vehicles for other onboard systems. Did North Korea quickly reverse engineer all these vehicles and support systems, too? To the authors' knowledge, no one ever asked this question (Appendix E).[23]

There is more evidence that speaks against the Scud B reverse engineering hypothesis. As early as 1999, a Scud drawing was found on the North Korean freighter Kuwolsan during a search in the Indian harbor of Kandla (see Appendix F for an image of the drawing). The nominal Soviet engine thrust level was noted on the drawing. In addition, the technical data published by Iranian authorities on the North Korean Scuds were identical to the Soviet nominal data. The missiles' performance, as a video analysis of an Iranian Scud B launch in 2006 proved, was identical to the Soviet Scud B.[24] The similarities of North Korean missile specifications with their Soviet counterparts can only mean that these missiles used nominal Soviet propulsion systems and not some system derived from the original Scud B engine.

North Korea's ability to accurately clone Scuds became clear in 2002, when the North Korean freighter So San was boarded by the Spanish Navy in international waters on its way to Yemen. Several Scuds were found on board the ship, ostensibly produced by North Korea. The imagery shows that the Soviet and these North Korean Scuds were identical, including Cyrillic markings and jet vane serial numbers that, as in the Soviet Union, were adopted from the Scud B's predecessor, the R-11/Scud A (see Appendix E). [25]

The difficulty of reverse engineering is illustrated by failed Iraqi efforts to reverse engineer the Scud in the 1980s. Iraq was unable to produce many of the parts indigenously. Among others, companies in Germany were tasked with that, and the results looked quite different than the original (see Appendix E). Details like color, exact shape, or materials used were different on parts that served no critical role. The resulting missiles would not have been identical clones, and there is no reason that North Korea's missiles should look exactly like Soviet ones up to the smallest details.

Based on this evidence, the author concludes that there is only one explanation. North Korea never reverse engineered the Scud B because it had received large numbers from the Soviets. This conclusion has major implications for North Korea's other programs. If the North Koreans never gained experience by reverse engineering the Scud B, how could they possibly have built the Scud C or the Nodong?

The Scud C

In 1990, after six years without launching a single missile, North Korea successfully tested one Scud missile, this time over roughly 500 km. This missile was named the Scud C by Western experts. Not much was publicly known about the Scud C at the time, except that it looked like the Scud B and had a range of up to 500 km. It was quickly assumed that North Korea had again pulled off a remarkable feat, advancing the Scud B to a much better version without any development flight tests.

It later turned out that the Scud C featured several clever modifications, including thinner tank walls, a common bulkhead for the tanks, and a torus pressure tank at the front. The warhead mass had also been reduced to around 750 kg.

After one more launch in 1991, the North Koreans were apparently happy enough with their product to approve serial production, and within one year, the Scud C was exported in large numbers to Syria and Iran, where it was also successfully launched.

The Scud C design was not new.

Just after Scud B deployments by the Soviet Army began, the Votkinsk machine plant had started a program to improve the Scud B. This program, extending the range up to 500 km, was approved by the government and officially launched under the lead of the Makeyev design bureau in 1963. Flight tests took place at Kapustin Yar between 1964 and 1967, but there were problems with the structural integrity, the reentry behavior, and the accuracy of the missile. The structural problems could be solved, but the missile still suffered from poor accuracy, and the program was reportedly terminated in favor of the Temp-S missile.[26]

The United States was aware of these efforts by the Soviets to develop an improved Scud B, using the designation Scud C more than a decade before North Korea "developed" its own Scud C missile. The North Korean Scud C showed all the characteristics of the original Soviet Scud C. Barton Wright's "World Weapon Database: Volume 1–Soviet Missiles" of 1986 describes a Scud C missile with a range of either 450 km or 450 miles. It is further stated that:

> "The existence of a longer range Scud C was confirmed in a U.S. Armed Services Committee reference in hearings of April 1978 to the KY-03 Scud, when it was stated that this version was first deployed in 1965."[27]

There also are reports that Scud C missiles were among the ~2,000 Soviet Scud missiles transferred to Afghanistan and launched during and after the Soviet intervention. According to these reports, Scud missiles were fired from Kabul to Kandahar in 1989, covering more than 450 km.[28]

It is not clear whether the Scud C ever was deployed in the Soviet Union, but if it was, it is likely that it was also phased out at the same time as the Scud B.

The North Korean Scud C appears to have followed the same development path as the Scud B. A Soviet missile developed by the Makeyev design bureau and produced in Votkinsk was used in Afghanistan and then suddenly appeared in North Korea and was demonstrated and then exported to other countries without a test program. Despite this evidence, it appears that the expert community was convinced that North Korea had independently developed and produced this missile and its associated support equipment.

The Makeyev experts

Just after the Scud C had surfaced in North Korea, a small group of Russian missile experts from the Makeyev design bureau traveled to North Korea, and more were blocked from doing so by Russian authorities.

There are several reports available of these incidents, some of them conflicting regarding the number of people involved and the exact dates. To cite just a few:

> 15 October 1992–"A group of 32 Russian engineers planning to fly to North Korea to assist in the modernization of ballistic missiles is intercepted by Russian police at Moscow International Sheremetyevo-2 Airport. Most of the engineers were from the Makeyev Design Bureau in Miass, which is responsible for submarine-launched ballistic missiles (SLBMs) and Scud tactical ballistic missiles. The recruiting agent was Anatoliy Rubtsov, a Russian posing as a government official, who was actually employed by North Korea."[29]

> "Although the contribution of ex-Soviet missile engineers cannot be positively determined, it is known that 60 engineers from the Makeyev OKB were prevented from flying to North Korea in October 1992."[30]

> "In one extraordinary case, North Korea attempted to recruit an entire missile design bureau: [I]n 1993, the specialists at the V. P. Makeyev Design Bureau in the city of Miass, near Chalyabinsk, were invited to travel to Pyongyang. […] About twenty of the designers and their families were preparing to fly out of Moscow's international airport in December when they were stopped by the Russian authorities and sent home."[31]

> "I encountered one crucial tentacle of Kim's program some 14 years ago, in late October of 1992. A group of 64 Russian rocket scientists, accompanied by their wives and children, were stopped just as they were about to board a flight to North Korea. The scientists were employees of a super-secret facility in the Urals, the V.P. Makeyev Design Bureau, responsible for the development of the Soviet Union's [SLBMs]. […] In the spring, a group of 10 scientists had gone for an initial foray. […] But the project was not officially sanctioned, and the KGB held them outside of Moscow for two months while the broker tried to renegotiate their departure."[32]

Judging by the available sources, it appears that a group of 10 Russian experts from the design bureau that developed the Scud B, its successors, and the SS-N-6 missile, were in North Korea in 1992, and about 60 more attempted to travel to North Korea in October 1992 but were detained until December. It unknown whether they traveled to North Korea at other times, and it is possible that earlier or later transfers went unnoticed.

The Nodong

About the same time that the Scud C appeared in North Korea, there were rumors of an even more powerful North Korean missile. In May 1993, four missiles were launched. The exact types are still not known, but one is believed to be the debut of a rocket that played a central role in global proliferation. Designated as the Nodong (or Rodong) by the West, the missile looks like an enlarged version of the Scud B. The main diameter is 1.25 m compared to the Scud's 0.88 m, and length is more than 15 m, with a weight of more than 15 tons.

The only test of 1993, and one that achieved a range of 500 km, was enough to place the Nodong in high demand for export. Initially, it was widely assumed that a cluster of four Scud engines powered a 1.3 m diameter airframe, which should have allowed the Nodong to launch a 1-ton payload to a range of up to 1,300 km.[33] This turned out to be wrong. Without further testing, the missile appeared in Iran and in Pakistan in 1998. Video imagery showed a very different missile than previously assumed. The Nodong appeared to be a large clone of the Scud B, with a single engine that had to have a lower thrust than the Scud engine cluster. However, this different configuration had no effect on the established performance data estimate. In many reports, the Nodong is still stated today as delivering a 1-ton warhead to 1,300 km, even though this range has never been observed in any flight tests in North Korea, Iran, or Pakistan.[34]

Both Iran and Pakistan claim that the Shahab 3 and Ghauri missiles are indigenously developed missiles based on the Nodong. However, there is evidence that the Ghauri, the Shahab 3, and the Nodong are the same missile.[35] Moreover, the Nodong first presented in Iran in 1998 was covered with Cyrillic lettering.[36]

As with the Scud C, development testing for the Nodong has never been observed. In addition, the missile showed characteristics typical for early Soviet designs:

- Designed for heavy nuclear payloads (accuracy too low for conventional)
- Large instrument section
- Medium combustion chamber pressure
- Typical early Soviet configuration
- Aerodynamically stable
- Fueled only in vertical position

There also were some inconsistencies that spoke against a North Korean development:

- New engine instead of clustered Scud engines
- Geometrical shape derived from the nuclear Scud B version
- No use of the more advanced Scud C design features
- No transportation in fueled condition
- No development program observed

An important clue about the engine was discovered in a Russian textbook that was published in the context of a training course for rocket production in Iran during the 1990s. The course was held by Russian rocket experts, and the book contains the drawing of a manufacturing device for rocket engines. The decisive figures of the engine, the nozzle, and throat diameter perfectly match the Nodong engine.[37]

The assumption that the engine was a Soviet development was fortified when Iran published photos of the engine in the 2000s that looked even older by design than the Scud.

Another mystery is why North Korea chose to enlarge the nuclear version of the Scud B. It is not generally known that the Scud B missiles designed to be equipped with nuclear warheads slightly differed from the ones to be used with conventional warheads (which were intended for export). There is a minor design difference in the missile body, but more important, the nuclear warhead is slightly longer, featuring an additional cylindrical section on the warhead that increases the total missile length from 10.944 m to 11.164 m. The Nodong's shape is clearly derived from the longer nuclear Scud B, but the known North Korean Scuds have the shorter dimensions like the conventional Scud B. Why would the Nodong be a larger version of the nuclear Scud when North Korea only had the conventional version?

In addition, if North Korea had successfully developed the Scud C just before the Nodong, why were the performance gains of the Scud C not incorporated into the Nodong?[38] The Nodong shows none of the technical improvements seen in the Scud C.

Details seem to suggest that the Nodong may predate the Scud B. From exercises in Iran and the location of the fill and drain valves, it can be determined that the Nodong must be filled vertically just before launch, which takes about an hour. During fueling, the missile is visible and vulnerable to an airstrike. New road-mobile ballistic missiles were eventually developed to be fueled horizontally before being launched, eliminating the tactical weakness of lengthy on-pad tanking operations.[39]

While the Nodong's origin remains a mystery, there are strong indications that the missile was developed in the Soviet Union during the 1950s or 1960s. During this period, Soviet missile design bureaus developed many missiles in parallel, hoping to gain the favor of the Politburo, which adopted only a few of these designs and dismissed a lot of their competing proposals. One of these designs could have found its way to North Korea, perhaps along with unknown amounts of old hardware. It is impossible to know definitively whether North Korea received old missiles, and at some point, produced their own airframes, while still relying on older engines and guidance systems.

There are other plausible hypotheses. North Korea could have received new missiles from an old Soviet (later Russian) production line. Or North Korea received old engines and guidance systems from Soviet stocks, and new airframes from Russia which were later assembled in North Korea. Or North Korea received engines from older inventory, or newly produced Russian Nodong engines and assembled them with airframes produced in North Korea.

The Taepodong I

In 1998, North Korea conducted its first satellite launch attempt. The rocket used for this mission, the so-called Taepodong I (or Paektusan-1), was launched only once at this very occasion and never again. According to available imagery, the first stage was a standard Nodong, and the dimensions of the second stage seemed like a Scud. But physics demands that this second stage had to be equipped with an engine with varying thrust levels, a feature that no Scud engine is capable of. On top of this stack, a small third stage was mounted, probably powered by a small solid rocket motor, possibly from the Soviet SS-21/Tochka.[40]

Most of the flight went according to plan, including stage separation events—a procedure that is quite demanding. (SpaceX, for example, failed twice before they managed their first clean stage separation in 2008.) Just before reaching orbit, the third stage experienced an anomaly and the satellite was lost.

But instead of a second launch attempt using an improved third stage the program was canceled, and the Taepodong I was never seen again.

Again, a sophisticated rocket appears out of nowhere, works well during its North Korean maiden flight (only failing late during third-stage operations), and again, Soviet/Russian components and design approaches seemed to have played a role.

The Unha

In early 1994, four years before the flight of the Taepodong I, U.S. satellites reportedly detected an even larger rocket in North Korea. There were no further sightings reported until the rocket, designated the Taepodong II, was launched in 2006. The first stage suffered an anomaly roughly 40 seconds into flight, however, and the rocket fell about 10 km downrange from the launch pad. No photos or videos of the Taepodong II were ever released to the public.

Three years later, in April 2009, North Korea attempted a second official satellite launch. Video footage of the launch indicated that this new rocket's design, the Unha-2, had nothing in common with previous North Korean designs, especially with the Taepodong I from 1998.

Another failed satellite launch occurred in April 2012 with a rocket named Unha-3. The next Unha-3 launch, eight months later, successfully put North Korea's first satellite into orbit.

The Unha, at 30 m long and 80 tons, can certainly be considered the flagship of North Korean rockets. Strange enough, photos from the April 2012 launch revealed poor rivet joints on the rocket. Shortly after the December 2012 launch, the rocket's first stage was recovered from the ocean by South Korea,[41] and it turned out that several parts inside this rocket stage were from the United Kingdom, Switzerland, the United States, China, and the former Soviet Union (including cannibalized Scud parts).[42] The design and the incorporated technical solutions were clever; it seemed, however, that the indigenous manufacturing capabilities were extremely limited.

While North Korean engineers were believed to have quickly reverse engineered Scuds from head to toe and indigenously manufactured Nodongs within a few years, it took them around 15 years to build and launch a rocket using foreign parts and 20 years and three launch failures before they achieved a successful flight with the Unha.

The Scud D and the Scud ER

Another advanced North Korean Scud, the Scud D, had appeared in Syria in 2000 but no North Korean launches were reported before 2006. Open source information about the Scud D is very limited, and no photos are available. The few available public sources claim that the Scud D has a theoretical range of more than 700 km, but was only launched (perhaps) three times in North Korea, barely exceeding a range of 400 km.

In early September 2016, North Korea unveiled another even more advanced Scud. Named the Scud ER, for "extended range," it features a larger diameter of 1 m (the Scud standard is 0.88 m), a total length of more than 12 m, a launch mass of roughly 9.3 tons, and a reported range of 1,000 km.[43]

But the Scud ER was not new. Around 2000, there were rumors that North Korea offered missiles for export beyond the Scud B, the Scud C, and the Nodong. One was a stripped-down and [highly] optimized Scud version, with specifications that matched the Scud ER. It also had a large diameter of 1.025 m, a total length of more than 12 m, and a 9.3-ton launch mass. The range was given as 1,000 km with a 500 kg warhead. The data indicated a very ambitious design beyond North Korea's proven capabilities, the missile was never seen, and no development work was known, so the whole issue was dismissed as a North Korean disinformation campaign.

Besides that, another look at the Kuwolsan drawings of 1999 (Appendix E) shows parallels to the Scud ER. The dimensions that are written along the side of the missile sketch are a perfect match for the "new" missile. Only one short segment with around 450 mm length seems to be missing, if compared to the now available photos of the Scud ER.

There are also Soviet links to this missile and Votkinsk had started a performance improvement program for the Scud B in 1963. At the same time, there was a request from the Army for a missile capable of firing a 500 kg warhead roughly 1,000 km. This request was later met by the OTR-22/Temp-S/S-22, or Scaleboard, deployed from 1967 onward.[44]

A 1974 declassified Defense Intelligence Agency (DIA) report mentions Scuds developed for "ranges considerably above the ranges presently assessed and the longer ranges reported are inconsistent with one another."[45] One of these "advanced" Scuds was the Scud C. The "new" North Korean Scud ER may have been an advanced version that was developed as a rival system for the 1,000 km requirement, combining the improved Scud C design with the newly mastered aluminum airframe technology. Except for the fins, the Scud ER's dimensions are almost the same as the OTR-22's. The Scud ER missile would probably fit into the oddly shaped transport container of the old Soviet Temp-S system, and the Temp-S warhead has about the same diameter as the Scud ER's missile body.

The evolution of the Scud C to the Scud D and then to the Scud ER appears to take a logical, stepwise approach, one that the same design team adopted to increase the range of the Scud B. As the range was incrementally increased, the weight of the warhead decreased. The team maintained the successful designs, and new design solutions were applied as needed. This development approach appears similar to what is known about many of the older Soviet rocket lines, including the R-1, R-2, and R-5 line (SS-1, SS-2, SS-3); the R-12, R-14, and R-16 line (SS-4, SS-5, SS-7); or the famous R-7/Soyuz line (SS-6, Vostok, Molniya, Voskhod, Soyuz). This hypothesis that the Scud ER is of Soviet origin is consistent with the Soviet origin hypothesis of all other North Korean missile types of the 1990s.

Links to Soviet SS-N-6 technology

The Musudan

In the early 2000s, there were rumors that North Korea had developed another new missile based on the Soviet R-27/SS-N-6 submarine missile developed in the 1960s by the Makeyev design bureau. No North Korean name was known for the rumored missile, and it was named the "Musudan" by Western experts. This would have meant the use of very different technology than the Scud technology, offering more performance due to more powerful propellants, advanced and highly complex engine design, and a sophisticated lightweight airframe. However, the R-27 had been developed for submarine deployment, and road-mobile deployment would have been a poor choice for that technology due to several constraints, including the fragile airframe and the use of hypergolic propellants that would explode instantly when they came into contact. One of the two propellants (the oxidizer NTO) froze at $-11\,^{\circ}$C ($+12\,^{\circ}$F) and boiled at $+21\,^{\circ}$C ($+70\,^{\circ}$F), which did not increase operational flexibility, either.[46,47]

In 2010, North Korean military paraded facsimiles of the Musudan through the streets of Pyongyang, but the mockups were of surprisingly poor quality, implying that the missile could be a phantom.[48] North Korea confirmed a successful Musudan launch in June 2016 after five failed attempts (according to unofficial reports). There are rumors of at least three more failed launch attempts, but the June launch remains the only known successful Musudan flight to date.

Considering all rumored and acknowledged failures, the success rate of the Musudan of one in nine attempts is surprisingly low compared to the rest of the North Korean missile program. However, this success rate is exactly what should be expected for a first prototype production lot. Perhaps this was the one indigenous North Korean program.

The KN-08 and KN-14 ICBMs

Starting in mid-2011, U.S. officials had indicated on several occasions that North Korea was working on a road-mobile ICBM.[49] If true, this would have meant a massive leap forward, far beyond the technology of the Unha satellite launcher.

In April 2012, the KN-08 (Hwasong-13 in North Korea) was paraded through the streets of Pyongyang. This new missile system (shown in Appendix F) looked like a road-mobile ICBM, seemingly confirming the earlier rumors. But at a closer look, it turned out that the paraded missiles mockups of poor design and quality; they did not even seem to represent a real missile design at all.[50]

In October 2015, a new ICBM design emerged, commonly referred to as the KN-14. The KN-14 has no resemblance to the older KN-08 and looked much more like a viable missile.[51] However, no studies questioned why North Korea would switch ICBM designs so quickly. A possibility is that North Korean engineers had little to no clue about how a functional ICBM would or should look like and only realized their mistakes when critical voices started to point to poor design choices. It could also be that the North Korean engineers wanted to demonstrate their efforts to their leaders, just like the Iraqis designed many modifications of the Scud. Surprisingly, the KN-14 was only seen once more at a publicity event held in March 2016. When President Kim Jong Un presented a nuclear warhead design for the already outdated KN-08, the KN-14 was shown only briefly in the background, signaling its minor role in the ICBM program. At this event, Kim also inspected the base of the KN-08 (see Appendix F), which appeared to be two Musudan propulsion units powering the KN-08 first stage. This seemed to be a poor design option because this engine never flew before in North Korea (the first known Musudan launch was still one month away!). Another reason was—just like for the Musudan—that the propellants were not suited for road-mobile launch use.[52]

As of 2019, neither the KN-08 nor the KN-14 ICBMs have been launched, and the source of the design, and whether it will ever be tested, is unknown. One possible explanation is that the failed Musudan tests led to the cancelation of this ICBM program. Reports in late 2017 seem to confirm this.[53] An alternative explanation is that these ICBM designs were never meant to fly and were only placeholders for later designs.

Large solid rocket motors

The KN-11

In 2015, a completely new line of missile technology seemed to appear in North Korea. In May, North Korea started tests of a submarine missile, the KN-11 SLBM, which the North Koreans called the Pukguksong-1.

Some analysts claimed that the KN-11 was initially developed as a liquid-fueled missile, relying on the R-27/SS-N-6 technology, the same technology believed to have powered the Musudan and the KN-08, but was switched to solid-fueled propulsion within a few months.[54] Converting from a liquid- to a solid-fueled rocket is impossible and only North Korea has ever claimed to do so.[55]

Photos and videos from later launches and military parades (see, for example, Figure 5) made clear that the KN-11 missile was a two-stage solid-fueled rocket with a diameter of approximately 1.4 m (like the Chinese DF-21/JL-1 line, or the Pakistani Shaheen 2 that is closely related to the Chinese

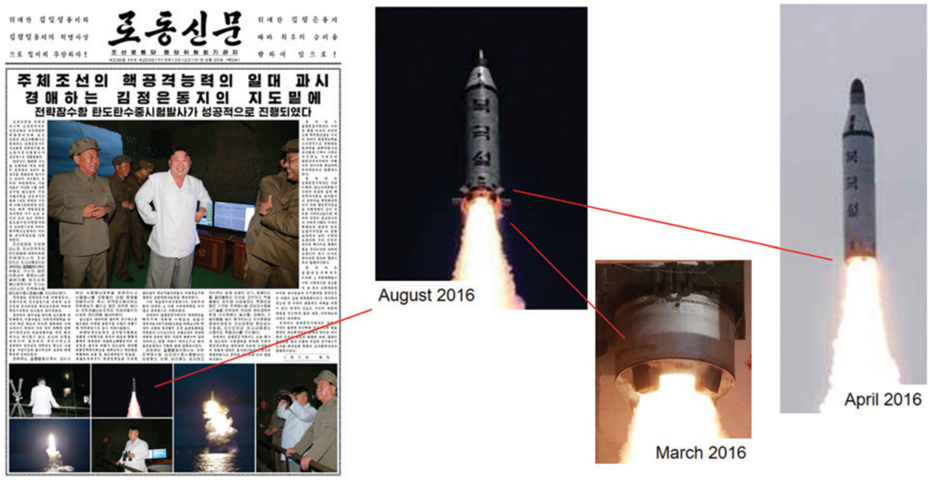


Figure 5. KN-11 Rocket motor design (*Rodong Sinmun, 25 August 2016*).

missile line),[56] which would mean that North Korea mastered yet again a new technology without a broad and visible R&D program. Manufacturing a solid rocket motor with a diameter of this size usually requires many years of research and experiments, including pre-programs with smaller motors. Only much smaller motors with a maximum diameter of up to 0.65 m were known to be available in North Korea, and this technology was different from the larger KN-11 motors.[57]

The KN-11 program went public with a claimed successful underwater test launch that was observed by Kim himself in May 2015. It later turned out that the launch images and video were altered,[58] that the launch was from a barge and not a submarine, and that it was merely a test of an underwater ejection system.[59]

Several other failed tests were reported over the following year, but it seems likely that at least some of these were just further ejection tests that were never intended to fly a complete mission trajectory. Again, the test sequence gives reason to doubt North Korea's declarations about independent indigenous rocket development activities.

North Korea eventually announced a successful test in August 2016, when a KN-11 missile was fired to an altitude of 500 km. As of December 2018, no further KN-11 tests have been conducted.

A photo from the front page of the North Korean newspaper *Rodong Sinmun* suggests that the KN-11 uses the same single-nozzle motor tested in March 2016. But a photo from the failed April 2016 test suggests a four-nozzle design due to the wide exhaust plume. This would make sense for a submarine missile with length restrictions, because a four-nozzle design is shorter than a single nozzle.

The KN-11 may be the result of a disinformation campaign, considering the following:

- The KN-11 uses a completely different technology than the KN-02/Toksa, the only other solid fueled missile previously available in North Korea.
- KN-11 development is limited to a few underwater launches, no land launches.
- Only one known static rocket motor "development" test (March 2016).
- There is no known upper stage motor test.
- The North Koreans implied that the first stage had a single nozzle, while available photos as well as SLBM design rationales suggest a four-nozzle design.

The real reason for North Korea's KN-11 disinformation campaign remains a mystery; however, a possible explanation could be that it is an attempt to hide its true origin. Some indications point to a Chinese origin, perhaps from Pakistan. But a link to a Soviet design bureau cannot be ruled out. Regardless, there must have been some assistance due to the sheer size of the solid rocket motors and North Korea's lack of experience with this technology.

The KN-15

In February 2017, North Korea displayed a new missile design, the Pukguksong-2, by launching it from a canister mounted on top of a tracked vehicle. It seems that this rocket, also known as the KN-15, is a land-based version of the KN-11. Converting a submarine launched missile to ground based launch is not unheard of, the Chinese DF-21/CSS-5 family also started with the submarine-launched JL-1 missile development. What is unusual, though, is the very short development window. The first launch of the ground-based version occurred six months after the first successful flight of the submarine-launched version, as well as an amazing track record of two successes for the two known launches so far (which is by far not enough to declare the system operational and iron out potentially catastrophic unknown failure sources).

Back to Soviet technology

The RD-250 technology

In September 2016, North Korea claimed the successful test of a new "single engine whose thrust is 80 tf", meaning 80 tons of force (or

784.5 kN). It was heralded as an "engine of a carrier rocket for the geo-stationary satellite."[60]

This was a surprise in several dimensions. First, the announced thrust of 80 tons would have been almost three times that of the Nodong engine, which was the most powerful engine known in North Korea at that time. More surprising, the design showed no parallels to the engines that were available in North Korea. This was not an engine derived from Scud technology and clearly not an engine that made use of the SS-N-6's technology.[61] Also, the announced thrust seemed too high for the small size of the engine. The position of the gas generator was also unusual. It was not mounted on top of the engine, but on the side, a configuration rarely seen in engines anywhere else in the world.

A German analyst named Norbert Brügge might have been the first person to point out that the unusual configuration looked like a single-chamber version of the old Soviet RD-250 engine.[62] This was a big surprise because both the Scud engine technology as well as the SS-N-6 engine technology available in North Korea at that point had been developed by A. Isayev's OKB-2 design bureau (now KBKhM). The RD-250 engine was a two-chamber engine with a single turbo pump. Three of these units were used to propel the first stage of Yangel's R-36/SS-9 ICBM.[63] The RD-250 engine was part of a whole different family of engines dating back to the late 1950s and 1960s that were developed by V. Glushko's design bureau OKB-456 (now Energomash) and used by rockets from M. Yangel's design bureau OKB-586 (now Yuzhnoye), among them the R-14/SS-5 and the R-16/SS-7.

The suspicion that RD-250 technology might be involved in the "new" engine was substantiated six months later when North Korea conducted and publicly revealed a static engine test in March 2017. Again, an engine with the same turbo pump configuration and the same nozzle silhouette was tested, but this time with four small vernier engines added around the big main engine. The available photos allowed a better view on the turbo pump, which looked indeed very much like the one that powered the RD-250, including the characteristically shaped gas generator exhaust pipe (Figure 6).[64]

Amazingly, it would take just a few more weeks until this propulsion unit successfully lifted a large missile off the launch pad. Once again, North Korea presumably succeeded in mastering an old Soviet technology. Furthermore, and consistent with all other North Korean missile developments, North Korea conducted a very low number of tests (relative to the experience of other countries). During the 1960s in the Soviet Union, the RD-250 engine logged 1,860 static tests over six years.[65] In North Korea, only two static tests are known: September 2016 and March 2017 (although none of them in the Hwasong-15

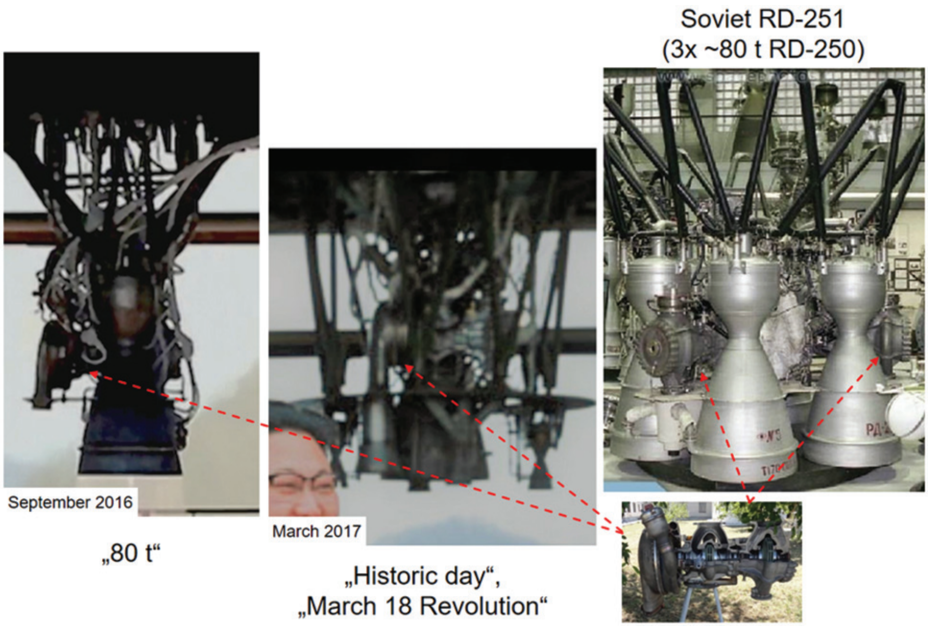


Figure 6. New liquid rocket engines and the Soviet RD-250 family.

double chamber flight configuration). Other ongoing international rocket development efforts continue to rely heavily on static tests. In early 2018, the United States and New Zealand company "Rocket Lab" announced its 500th static engine test. Ten days later this engine powered the first successful Electron rocket flight.[66] In 2013, SpaceX fired its upgraded Merlin1D engine 28 times just for qualification (not counting development tests).[67]

Unlike missile flight tests, static engine tests are usually not widely publicly reported. However, it seems plausible that a sequence of tests of an engine that size should have been newsworthy in 2016 and 2017 when all eyes were on North Korean missile developments. While more than the two known tests may have taken place in secret, it seems unlikely that North Korea pulled off a test program of several hundred secret firings. In times of constant satellite monitoring, preparation and burn marks would have hardly gone unnoticed. Therefore, North Korea must have received engines that were developed and produced elsewhere.

The HS-12

Just a few weeks after the static test of the "RD-250-like" engine, this new propulsion unit was identified in the first successful flight test of a new North Korean rocket. The flight, on May 14, 2017, reportedly covered less than 800 km, but the rocket reached an altitude of more than 2,000 km, far beyond anything that North Korea reached before.[68]

The rocket was reportedly named the Hwasong-12 or KN-17 and was presented at a parade one month earlier. According to the authors' analyses, the airframe was made of aluminum, and the tanks featured a common bulkhead design. The back end had a slightly conical shape, meaning that the diameter slightly increased over the part where the engine was located, so the back end of the missile had a slightly bigger diameter than the main part of the missile. Of interest, this is a common feature of some old Soviet missiles, for example Yangel's R-12 and R-14 designs.

The missile was fired from a launch table, meaning that a truck carried the missile and table to a concrete pad and left them there for launch. Some analysts suggested that the trucks were too precious for North Korea to risk a failing missile destroying them at launch.[69] This launch mode was common back in the early days of the Soviet missile program. For example, Yangel's early missile designs had to be launched the same way.

There are unconfirmed reports that this was not the first attempt to launch a Hwasong-12.[70] There may have been up to three failed attempts already in April 2017,[71] which would add credibility to the claim that the missile was newly developed, but which would also reduce the time between the propulsion unit's successful static test and first flight from two months to less than three weeks.

The HS-14

On 4 July 2017, five weeks after the HS-12 test, North Korea successfully launched an even bigger missile, later named the Hwasong-14 or KN-20. The reported flight trajectory exceeded the trajectory of the HS-12. The missile was launched almost straight up, reaching a higher altitude than on a standard ballistic trajectory, but also reducing its range this way, like a stone that is thrown upward instead of being thrown for maximum range. Indeed, if launched on a normal trajectory, the missile could have reached more than 5,500 km, which is the range that typically classifies a rocket as an ICBM. However, while there are still debates about the true range of the HS-14, it seems that it would have difficulty reaching the U.S. mainland with a noteworthy payload.

While there were some technological parallels between the HS-14 and the HS-12, including the apparent use of the same propulsion unit situated in a conical back skirt, there were also some strange differences. The propellant tanks lacked a common bulkhead, and the rocket's main diameter was bigger than the HS-12, which would require completely new manufacturing tooling sets. It would have made a lot more sense to design both rockets with a common diameter to save the extra efforts. One possible explanation is that the HS-12 and HS-14 were fully developed once they were transferred to North Korea and that the HS-12 is the more advanced missile, having been developed after the HS-14. Additional evidence would be required to confirm this.

Judging by its shape, the Hwasong-14 looked like the KN-08. The dimensions were virtually the same, but while the KN-08 was an unconventional three-stage design, the HS-14 had a two-stage design with sensible staging ratios.[72] The launch thrust level of the HS-14 also was like the displayed KN-08 first stage configuration using the two Musudan propulsion packs. Another HS-14 was successfully launched the same month. Both missiles were launched from a launch table, just like the HS-12.

The HS-15

Analysts were still debating whether the relatively small HS-14 could be an ICBM when North Korea showed off its masterpiece only four months after the two HS-14 launches. On 29 November 2017, the Hwasong-15 (or KN-22) was launched to an altitude of almost 4,500 km, about 10 times higher than the International Space Station. Available photos and videos showed a large missile that clearly should have the capability to carry a noteworthy payload across most of the U.S. mainland, with a range in the order of 10,000 km or more.

The HS-15 looked different than the HS-12 and HS-14. The common bulkhead for the first stage seemed to be back, but there was no conical skirt shape at the back of the rocket. Some parameters also did not match, including diameter, tank lengths, propellant weight, launch thrust, and launch acceleration. It almost seems as if the rocket presented on the photographs did not quite match the configuration that was launched. More important, the propulsion unit was different from the HS-12 and the HS-14. It seemed that the same turbo pump and main engine were used, but the vernier engines were gone (see Figure 7). Instead, the single turbo pump now powered a two-chamber design, just like the original RD-250. The resulting thrust of this combination would be 80 tons, as officially stated after the first test of this engine in March 2016.

The same characteristic oval-shaped gas generator exhaust as the one from the turbo pump used for the Soviet RD-250 family of engines is visible at the back of the Hwasong-15. The piping at the Hwasong-15 engines is different though, probably because the chambers must move to steer the rocket.

The guidance concept was also different, with two exhaust chambers controlling the missile instead of four small engines. The two chambers are swiveled to change the direction of thrust, thus steering the missile. The HS-12 and HS-14 had four small extra engines for this task. This would

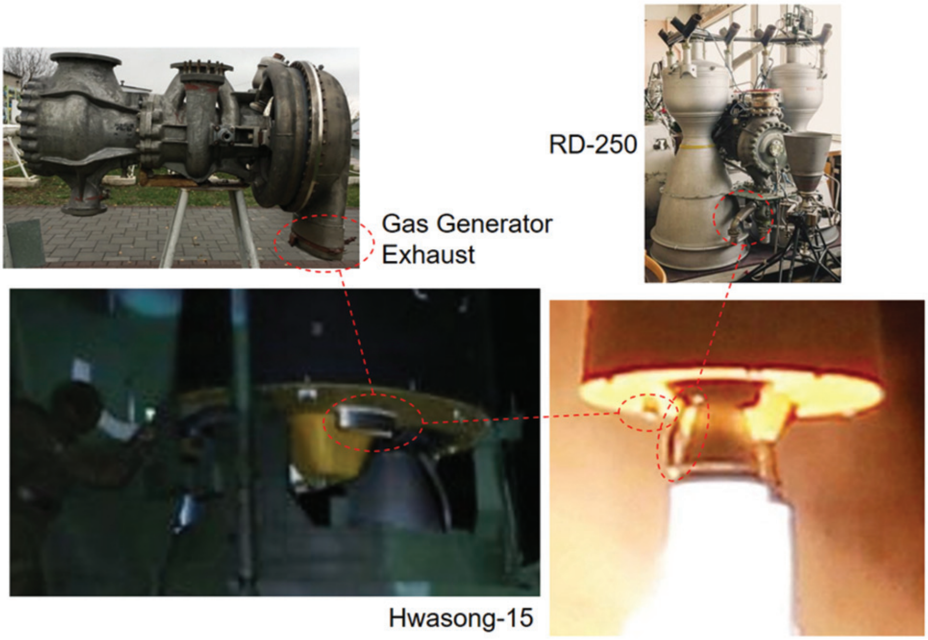


Figure 7. The Hwasong-15 engine.[76]

not have been possible with the original RD-250 design because the thrust chambers and nozzles of the original RD-250 type engines were fixed together, including the pipes that fed propellants into the chamber and into the nozzle for cooling. However, changing the piping to make this possible was possible.

The HS-15 showed some parallels to the old Soviet UR-100/SS-11 design. There was an early competitor to the UR-100 called the R-37, developed by the Yangel design bureau (OKB-586), which must have looked very similar and could have used a propulsion unit based on the RD-250.[73]

The new design with the new engine configuration and the new guidance scheme performed flawlessly, and at its first launch in November 2017, the HS-15 was fired in the middle of the night, under field-like conditions. Just after the launch, North Korean state media quoted Kim Jong Un. "Now we have finally realized the great historic cause of completing the state nuclear force, the cause of building a rocket power."[74] With that, Kim seemed to have achieved his goal, demonstrating the successful launch of a missile that could hit the United States. As of December 2018, North Korea has not launched or tested another missile.

Observed technology lines

Many technologies were used for the various North Korean missiles. At first glance, it appears that North Korea has successfully made one step

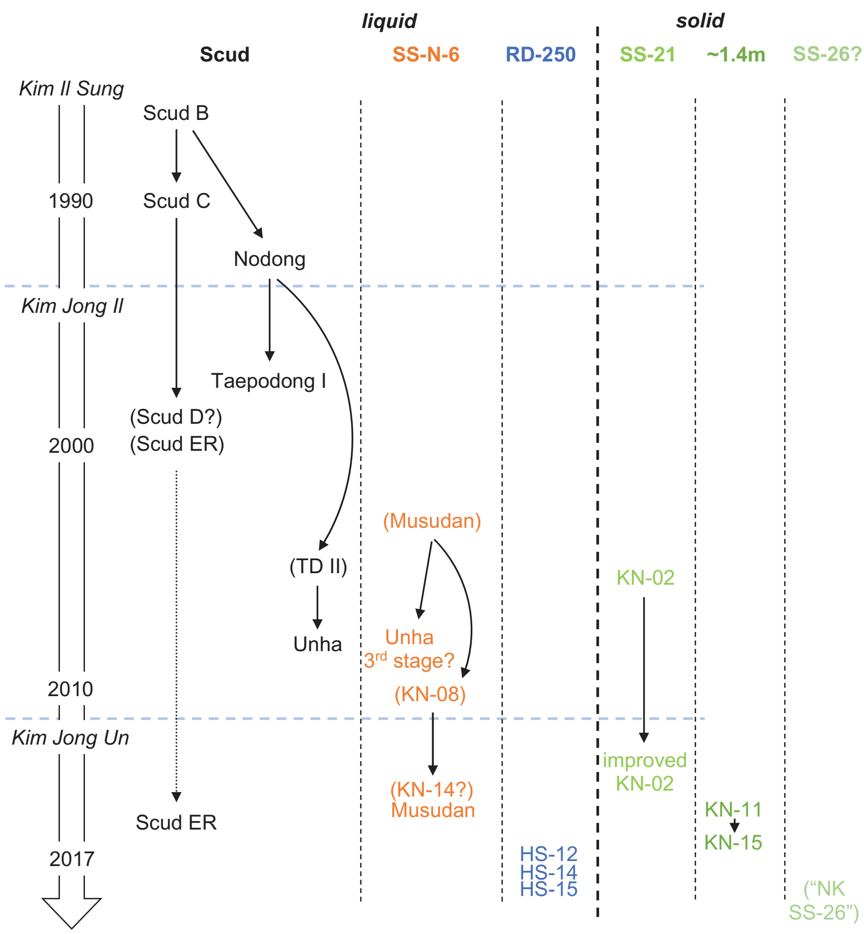


Figure 8. Identified technology lines in North Korea.

after another, moving from Soviet Scud technology of the 1950s to bigger rockets with more powerful engines and propellants, and finally arriving at the Hwasong-15 ICBM. Along the way, solid propellant rockets were added to the inventory as a backup plan.

However, tracing back and analyzing the technical details, the applied design solutions, and comparing technology paths, such as liquid engine propellant feed cycles, or approaches to guidance and control system, a very different picture emerges. It seems that North Korea was jumping from one technology line to another and back. Some clever design solutions were dismissed at later stages, some potentially promising developments were not pursued at all, and completely different technologies appeared out of nowhere. Figure 8 shows the multiple technology lines.

A close look reveals that these technologies are not related to one another and seem to be linked to different periods. Because the Scud ER seems to have existed in North Korea around 2000, and the KN-08 project was likely initiated under Kim Jong Il, there are no signs of Scud- or SS-N-6-related developments under Kim Jong Un's regime. He just used existing equipment and focused on completely different technologies from different sources.

The different patterns of three leaders from three eras

Once joined, the pieces of the puzzle form an interesting picture. There is a good chance that the three North Korean leaders Kim Il Sung, Kim Jong Il, and Kim Jong Un had different objectives in mind and used different approaches to pursue the North Korean missile program.

Kim Il Sung initiated the North Korean missile program but may have taken a different approach than usually assumed. Under his rule, North Korea acquired several old (but functional) missile types from the Soviet Union and Russia, even in the chaotic years after the Soviet collapse in the early 1990s. His motivation may have been to ensure access to reliable missiles and gain a source of income by transferring missiles to Iran, Libya, and other countries. The Scud B, the Scud C, and the Nodong clearly are part of these transfers and all from Russia's Makeyev design bureau, as were the experts who wanted to travel to North Korea in 1992. There is a good chance that this group was also heavily involved in the Taepodong I, which shows some typical Soviet design solutions. This can be true as well for the Unha program, which probably also started in the early 1990s and might have been the first indigenous North Korean missile program that was supported by Soviet/Russian experts, with heavy use of foreign hardware components.

The heavy reliance on Soviet/Russian support in the 1980s and early 1990s is apparent in the visible efforts taken by North Korea at that time. The only launch site in the country was at Musudan-ri on the east coast, with dirt roads leading to the only pad. Launches were rare, but not required anyway, because the missiles were simply bought from abroad.

Kim Il Sung died in July 1994, and his son Kim Jong Il took over. During his regime, the rare launches nearly ceased completely. Over the course of 17 years, there were only four launch events, all of them with political messages (see Figure 9). The mysterious Scud D appeared in the late 1990s, but this missile did not seem to play an important role for Kim Jong Il. He pursued the Unha satellite launcher program and built a new launch site on the west coast now known as the Sohae launch center. Sohae was much bigger and far more sophisticated than the old Musudan-ri site.

Kim Jong Il took over in July 1994 and died in December 2011. During his regime and until February 2014, Scud size and larger launches only occurred on politically relevant dates. The satellite launch attempt in April

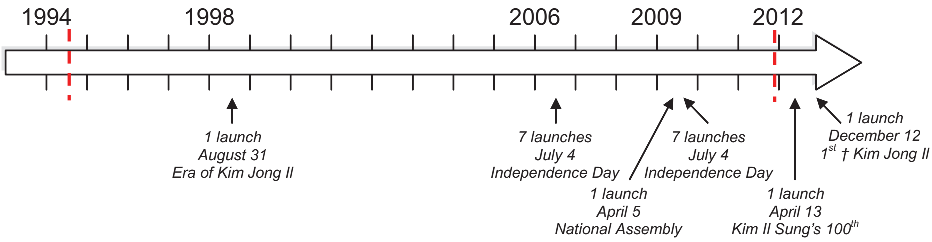


Figure 9. Rocket launches during Kim Jong Il's regime (including 2012).

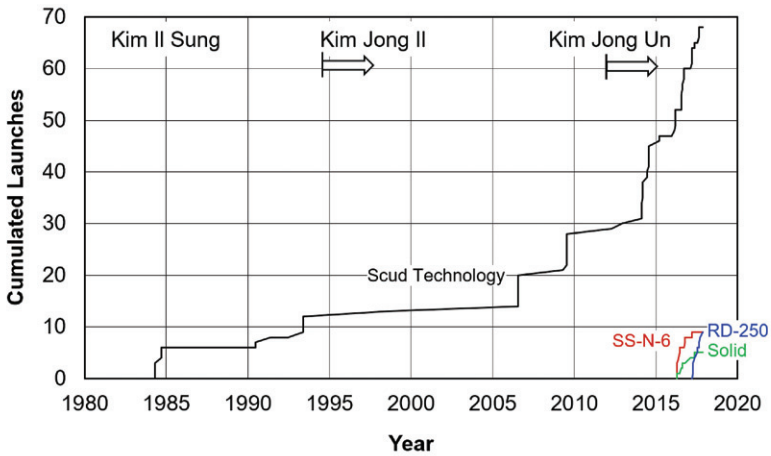


Figure 10. North Korean launches sorted by technology lines (Scud missiles and larger rockets.).

2012 was probably scheduled before his demise. His son, Kim Jong Un, may have opted for the second launch in 2012, taking place at the first anniversary of his father's death.

Kim Jong Il also initiated the Musudan program, and probably the North Korean ICBM effort, with what is known now as the KN-08. An undated video released in 2015 briefly shows Kim Jong Il walking along the side of a large missile, perhaps a Musudan, perhaps a KN-08, with another missile in the background that looks very much like a KN-08 (judging by the visible engine configuration, see Appendix F).

Kim Jong Il died in December 2011, and the North Korean approach to missiles changed completely after Kim Jong Un came into power. There were only two launch events in 2012, again at politically relevant dates, and none in 2013.[75]

But from February 2014 onward, North Korea's launch policy drastically changed. Within less than 30 months, the country launched more large rockets than in the previous 30 years, and in just four years, more than twice as many rockets have been launched than in all previous decades

Table 1. Launches in North Korea (includes Scud B and larger rockets).

	April 1984–January 2014 (30 years)	February 2014–2018 (4 years)
Missiles launched	30	64
Days with launches	10	41

Note. The 1990 "burn marks on pad" event is not counted.
Source: ST Analytics launch database.

(Table 1). For the first time in history, North Korean missile launches became a frequent occurrence.

During 2014 through 2018, North Korea regularly launched Scuds and Nodongs, introduced new types of missiles every few months, and for the first time, the first few launch attempts of new types—including the Musudan, KN-11, and HS-12—failed. However, there were fewer new missiles than generally assumed. Many of the launches still relied on familiar missiles based on old Scud technology (see Figure 10).

Most North Korean missile launches used Scud technology, even under Kim Jong Un. While the satellite launchers Taepodong I and Unha might have used different technologies in their upper stages, missiles that solely relied on other technology lines than the Scud only were launched since 2016. Launches of the KN-11 solid-fueled SLBM were communicated as early as mid-2015, but these seemed to have been ejection tests only, with real hot-fire launches only starting in 2016. Missiles using RD-250 technology were only launched in 2017.

It is as if someone told Kim Jong Un that his missile program would not be taken seriously without frequent launches and occasional failures. It also seems that a clear goal was to demonstrate that North Korea can develop and launch a real ICBM.

Conclusion

An analysis of a range of available information suggests the diversity, relative speed and apparent success of the North Korean missile program since the first ballistic missile tests, involving three Soviet-origin Scud B missiles in April 1984, may be due to extensive and enduring reliance on Soviet missile technology and expertise. While reverse engineering and access to Russian designers and engineers from the Makeyev Design Bureau may have allowed North Korea to gain some experience in developing and producing more advanced missiles, acquisition through clandestine procurement networks of missile parts or functional missiles from the Soviet Union may plausibly explain in particular how North Korea was able to develop the KN-11 SLBM and the Hwasong-12, Hwasong-14, and Hwasong-15 long-range missiles. Their similarity to Soviet missile technologies raises questions about the limits of indigenous design, development and manufacturing capabilities in the current North Korean missile program.

The evidence suggests the three North Korean leaders Kim Il Sung (who ruled from 1954 to1994), Kim Jong Il (1994-2011), and Kim Jong Un (since 2011) may have had different goals and pursued different approaches to advancing the missile program. Under Kim Jong Un, starting in 2014 and contrary to previous North Korean missile launch campaigns, there has been an aggressive push forward with more regular tests and training launches with older missiles, as well as development test and displays of new missiles. During the four-year period from 2014 to 2018, failures have been more often observed in missile tests, which may indicate a greater degree of local missile technology development and component manufacture than was common before. These failures are still limited to a few missile types, however. Some missiles seem to work on their initial flight and in subsequent tests. If North Korea is moving to increase reliance on indigenous capability, by adapting the Soviet designs for its early missiles, more failures may be likely in the missile development and testing program as North Korea seeks to achieve and demonstrate that it has a reliable intercontinental ballistic missile capability.

Notes and References

1. See, for example, David C. Wright, "North Korea's Longest Missile Test Yet," All Things Nuclear Blog, Union of Concerned Scientists, 28 November 2017, available at https://allthingsnuclear.org/dwright/nk-longest-missile-test-yet.
2. Exact numbers may vary due to sources and interpretation, but North Korea is attributed with having more than a dozen unique guided ballistic missiles deployed and/or in production. This contrasts with China (12), Russia (~10), India (~9), the United States (3), and France (2). If true, North Korea's missile program is as large as China's, Russia's, and India's.
3. Narrative provided by Wikipedia at "North Korea and Weapons of Mass Destruction, Delivery Systems," October 2018, available at https://en.wikipedia.org/wiki/North_Korea_and_weapons_of_mass_destruction#Delivery_systems.
4. Robert H. 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, available at http://www.st-analytics.de/app/download/5802794709/Schmucker_3rd_World_Missile.pdf.
5. Robert H. Schmucker and Markus Schiller, *Raketenbedrohung 2.0* (Hamburg/Bonn: Mittler Verlag, 2015), ch. 3.4.
6. Ten days after the first successful launch, Rocket Lab logged its 500th static rocket engine test. See Rocket Lab Website, News update, 31 January 2018, available at http://rocketlabusa.com/news/updates/rocket-lab-reaches-500-rutherford-engine-test-fires/.

7. The United States did not produce the RD-180 engine despite years of support from the Russian producer/designer. India might have succeeded in designing and building a modified version of the S-75 Volga engine for the Prithvi after years of failed efforts at reverse engineering. Pakistan never produced Ghauri/Nodong engines. Although there is no consensus among experts, Iran may have successfully produced Scud and Nodong engines with foreign support.
8. The Russian RSM-56 Bulava SLBM logged 19 flight tests before it was commissioned in 2013, https://en.wikipedia.org/wiki/RSM-56_Bulava#2010_tests.
9. In 2011, the known North Korean–guided ballistic missiles were the Scud B, the Scud C, the Scud D, the Nodong, the Musudan, and the KN-02/Toksa. Of these six programs, there were only three failed Scud launches in 1984 and maybe one failed Nodong launch attempt in 1990, an unusually low number of failures for a missile program. The Taepodong I satellite launch in 1998 almost succeeded. Only the Unha satellite launcher program experienced significant failures.
10. For details on rocket development programs, see Robert H. Schmucker and Markus Schiller, *Raketenbedrohung 2.0*, ch. 6.5.
11. Robert H. Schmucker and Markus Schiller, *Raketenbedrohung 2.0*, ch. 7.
12. The author has access to reliable data on various programs. Among them are A1, A2, A3, A5, A4 (Germany), R-1, R-1, R-5M, R-7, R-11, R-11M, R-12, R-17, R-27K, Temp-2S, Topol, Iskander, Bulava (Soviet Union/Russia), Atlas, Titan, Titan II, Trident C4, Trident 2 D5 (USA), M112, M45, M51 (France), Al-Hussein, Al-Samoud 2 (Iraq), DF-2, DF-3, and DF-4 (China). Data were collected over the past 50 years by Robert Schmucker and independently over the past 15 years by the author, with sources including original documents, personal communications, books, countless papers, and publicly available launch databases.
13. Between 1984 and 2014, the Scud B, Scud C, and the Nodong were launched at an average rate of roughly one every three years.
14. Robert H. Schmucker and Markus Schiller, *Raketenbedrohung 2.0*.
15. Joseph S. Bermudez Jr., "A History of Ballistic Missile Development in the DPRK," Occasional Paper No. 2, Center for Nonproliferation Studies, Monterey, November 1999, 9.
16. Wikipedia, North Korea and Weapons of Mass Destruction, Delivery systems, available at https://en.wikipedia.org/wiki/North_Korea_and_weapons_of_mass_destruction#Delivery_systems; Joseph S. Bermudez Jr., "A History of Ballistic Missile Development in the DPRK," 9.
17. Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," Technical Report TR-1268, RAND Corporation, Santa Monica, September 2012, 101f, available at http://www.rand.org/pubs/technical_reports/TR1268.html.
18. There are a few other countries where operational ballistic missiles also appeared without encountering any problems, for example, Pakistan. However, it can be shown that all these countries received massive support for their programs including transfers of complete missile systems.
19. Joseph S. Bermudez Jr., "A History of Ballistic Missile Development in the DPRK," 12.
20. IBID
21. Joseph S. Bermudez Jr. and W. Seth Carus, "The North Korean 'Scud-B' Programme," *Jane's Soviet Intelligence Review,* 1 (1989): 177–181.
22. Personal communication with former East German Scud brigade officers, January 2014–April 2016.

23. United Nations, "Report of the Panel of Experts Established Pursuant to Resolution 1874 (2009)," S/2013/337, 11 June 2013, 26–27, available at http://www.un.org/ga/search/view_doc.asp?symbol=S/2013/337.
24. Analysis conducted at Schmucker Technologie, Munich; results can be found in *Raketenbedrohung 2.0*.
25. Imagery can be found at the Wikimedia Commons site, available at https://commons.wikimedia.org/wiki/File:US_Navy_021209-O-0000X-011_Scud_missile_parts_and_equipment_found_in_the_cargo_hold_aboard_the_North_Korean_vessel,_So_San,_discovered_after_being_boarded_by_Spanish_Special_Forces.jpg.
26. Karpenko, A.V., «СКАД»: от вертолетов до «Рекорда» и «Аэрофона», http://bastion-karpenko.narod.ru/R-17_2.pdf.
27. Barton Wright, *World Weapon Database, Volume I–Soviet Missiles* (Brookline, MA: Institute for Defense and Disarmament Studies, 1986), 381.
28. Guy Perrimond (ed.), "The Threat of Theatre Ballistic Missiles 1944–2001," *TTU Special Issue* (2002): 8.
29. Nuclear Threat Initiative, "North Korean Missile Chronology," 2012 update, 252, available at https://www.nti.org/media/pdfs/north_korea_missile_2.pdf?_=1327534760?_=1327534760.
30. Christoph Bluth, *Korea* (Cambridge: Polity Press, 2008), 161.
31. David E. Hoffman, *The Dead Hand: The Untold Story of the Cold War Arms Race and Its Dangerous Legacy* (New York: Doubleday, 2009), 407.
32. "Missiles Are Pivotal to North Korea's Military Strategy Says Shorenstein APARC's Daniel Sneider," *San Jose Mercury News*, 25 July 2006, available at https://aparc.fsi.stanford.edu/news/missiles_are_pivotal_to_north_koreas_military_strategy_says_shorenstein_aparcs_daniel_sneider_20060725.
33. See, for example, David C. Wright and Timur Kadyshev, "An Analysis of the North Korean Nodong Missile" *Science & Global Security* 4 (1994): 129–160.
34. Iran soon started working on an advanced version that is often referred to as the Ghadr-1. This missile has a proven range greater than 1,300 km with a smaller warhead.
35. Robert H. Schmucker and Markus Schiller, *Raketenbedrohung 2.0*.
36. Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," 29.
37. Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," 28.
38. Robert H. Schmucker and Markus Schiller, *Raketenbedrohung 2.0*, ch. 7.2.1–7.2.2.
39. Iran later addressed this flaw. Later versions of a modified Shahab 3, known as the Ghadr, are clearly capable of horizontal tanking.
40. Robert H. Schmucker, "3rd World Missile Development.
41. South Korean Ministry of Defense, "North Korean Long-Range Missile Debris Survey." 18 January 2013. English translation by David C. Wright, Union of Concerned Scientists, available at http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nwgs/SK-report-on-NK-rocket-debris-analysis-translation-1-18-13.pdf.
42. United Nations, "Report of the Panel of Experts Established Pursuant to Resolution 1874 (2009)."
43. See Markus Schiller and Robert H. Schmucker, "Flashback to the Past: North Korea's "New" Extended-Range Scud." 38 North, 8 November 2016, available at http://38north.org/wp-content/uploads/2016/11/Scud-ER-110816_Schiller_Schmucker.pdf.
44. At that time, this missile was also referred to as the SS-12, but later, the designation shifted to SS-22. The Soviet system name was *Temp-S*.
45. Defense Intelligence Agency, SCUD B Study, August 1974, The National Security Archive, available at http://nsarchive.gwu.edu/NSAEBB/NSAEBB39/document1.pdf.

46. Missile Threat and Proliferation, Musudan, Missile Defense Advocacy Alliance, 20 December 2018, http://missiledefenseadvocacy.org/missile-threat-and-proliferation/todays-missile-threat/north-korea/musudan/; Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," 88.
47. Some analysts proposed that a slightly different mixed oxides of nitrogen would solve this problem, but that would only have moved the small window of liquidity down to lower temperatures.
48. Markus Schiller and Robert H. Schmucker, "Explaining the Musudan," May 2012, available at http://lewis.armscontrolwonk.com/files/2012/05/Explaining_the_Musudan_Schiller_Schmucker_v1.2.pdf
49. See, for example, David C. Wright, "A North Korean Mobile ICBM?" 38 North, 12 February 2012, available at http://www.38north.org/2012/02/dwright021212/.
50. See Markus Schiller and Robert H. Schmucker, "A Dog and Pony Show," April 2012, available at http://lewis.armscontrolwonk.com/files/2012/04/KN-08_Analysis_Schiller_Schmucker.pdf.
51. See Markus Schiller and Robert H. Schmucker, "Getting Better," ST Analytics, October 2015, available at http://www.st-analytics.de/app/download/5799168213/Getting_Better_Schiller_Schmucker.pdf.
52. The SS-N-6 engine uses unsymmetrical dimethylhydrazine and nitrogen tetroxide (N2O4 or NTO) as propellants. NTO freezes at approximately −15 °C and boils at just over 20 °C. It is therefore unsuitable to be deployed in the winter or the summer without thermal protection. Thermal protection is not provided to road-mobile missiles on a TEL that hides until the launch command is issued. In addition, the propellants are hypergolic. A breach in a pipe, valve, or propellant tank poses a threat of immediate explosion. Therefore, no country ever fielded a road-mobile missile with this propellant combination.
53. Yonhap News Agency, "日언론 "北, 화성-13형 개발 중단… 연료 주입시간·출력 문제", 2 December 2017 (Daily Press, North, Hwasong-type 13 development stopped … fuel injection time, output problem). Available at http://www.yonhapnews.co.kr/bulletin/2017/12/02/0200000000AKR20171202040300073.HTML?input=1195m.
54. Stated, for example, at KN-11 (Pukkuksong-1), Missile Threat–CSIS Missile Defense Project, available at https://missilethreat.csis.org/missile/kn-11/.
55. Rockets are designed as solid- or liquid-fueled. Each has unique airframes, stage size ratios, length to diameter ratios, tanks, and engines. Switching from liquid fuel to solid, or vice versa, is not possible.
56. Robert H. Schmucker and Markus Schiller, *Raketenbedrohung 2.0*.
57. North Korea is believed to have copied the Soviet SS-21 Tochka solid-fueled missile in the 2000s. The result, the North Korean KN-02 missile, looks like an exact replica of the Soviet original, which was readily available in several countries besides Russia, among them Syria, Belarus, Ukraine, and Yemen. The Tochka has a 0.65 m diameter solid rocket motor with a cartridged grain. The propellant is cast into a container inserted into the airframe. The added weight limits missile performance and reduces range. Modern high-performance rockets use case-bonded propellant grains, where the propellant adheres to the missile's airframe skin and serves as the combustion chamber wall. This reduces weight, but the casting and production process is more complicated.
58. According to analyses at the Middlebury Institute of International Studies at Monterey. Jeffrey Lewis, personal communication, February 2017.

59. Markus Schiller and Robert H. Schmucker, "Not Much Below the Surface?" Federation of American Scientists, Public Interest Report Summer/Fall 2015, available at https://fas.org/wp-content/uploads/2015/10/SchillerSchmuckerKim_Notmuchbelowthesurface.pdf.
60. See KCNAwatch.org for the original Rodong Sinmun newspaper from 20 September 2016, or the English website of Rodong Sinmun for the official English translation, available at https://kcnawatch.org/periodical/rodong-sinmun-257/ and http://www.rodong.rep.kp/en/index.php?strPageID=SF01_02_01&newsID=2016-09-20-0002.
61. The SS-N-6 main engine uses a staged combustion cycle, which yields more performance but is harder to develop. The new engine used a gas generator cycle, like the Scud engine, but with more advanced technologies and higher pressure.
62. Norbert Brügge's website on rockets and space launchers can be found at http://www.b14643.de/Spacerockets_1/index.htm.
63. See Pavel Podvig, *Russian Strategic Nuclear Forces* (Cambridge, MA: MIT Press, 2004).
64. KCNA and KCTV; Space Launch Vehicles, N. Brügge; M. Schiller.
65. Between 1962 and 1964, early development at OKB-456 (Moscow) required 145 static tests. In parallel, production at OKB-586 (Dnepropetrovsk) logged 174 static tests. Eighteen test launches of the R-36 added 72 engine firings at flight for a total of 391 firings. Vibration problems discovered in 1964 required redesigns and upgrades. Certification and additional modifications required more tests. In 1967, the RD-250 logged 392 tests, including 33 firings in 11 flights. In March 1968, after Phase 2 certification, the RD-250 series accumulated 1,860 static test firings and 310 flight firings at nearly 80 test flights. See Anatoly Zak, "The RD-250 Engine at the Center of an International Storm," RussianSpaceWeb, 10 September 2017, available at http://www.russianspaceweb.com/rd250.html.
66. Rocket Lab, "Rocket Lab Reaches 500 Rutherford Engine Test Fires," 1 January 2018, available at http://rocketlabusa.com/news/updates/rocket-lab-reaches-500-rutherford-engine-test-fires/.
67. See, for example, "Testing Times for SpaceX's New Falcon 9 v.1.1" at NasaSpaceflight.com, available at https://www.nasaspaceflight.com/2013/06/testing-times-spacexs-new-falcon-9-v-1-1/.
68. The satellites reached orbit at roughly 500 km. The only successful Musudan launch in June 2016 reportedly reached around 1,000 km peak altitude.
69. See, for example, Scott LaFoy, "TELS AND MELS AND TES! OH MY!," *ArmsControlWonk*, 1 June 2017, available at https://www.armscontrolwonk.com/archive/1203304/tels-and-mels-and-tes-oh-my/.
70. NTI, "The CNS North Korea Missile Test Database," 4 May 2018. See the Excel database for details and further references, available at https://www.nti.org/documents/2137/north_korea_missile_test_database.xlsx.
71. Ankit Panda, "Exclusive: North Korea Tested Its New Intermediate-Range Ballistic Missile 3 Times in April 2017," *The Diplomat*, 3 June 2017, available at https://thediplomat.com/2017/06/exclusive-north-korea-tested-its-new-intermediate-range-ballistic-missile-3-times-in-april-2017/.
72. Markus Schiller and Robert H. Schmucker, "A Dog and Pony Show."
73. See Markus Schiller and Nick Hansen, "Retro Rocket–North Korean ICBM Shows External Influence." *Jane's Intelligence Review* 30, March 2018, available at http://www.janes.com/images/assets/014/78014/2_North_Korean_ICBM_design_shows_external_influence.pdf.

74. KCNA, 29 November 2017. See https://kcnawatch.co/newstream/1511929851-215959348/dprk-govt-st/.
75. On both occasions, only the Unha satellite launcher was launched. The first launch, at Kim Il Sung's 100th birthday, likely was already scheduled by Kim Jong Il. The second launch was likely in honor of Kim Jong Il, taking place about one year after his death.
76. Photos: KCNA/KCTV; Space Launch Vehicles, N. Brügge; M. Schiller.
77. Robert H. Schmucker and Markus Schiller, *Raketenbedrohung* 2.0.
78. Launch vehicle flight test history and plans for U.S manned spaceflight programs, Declassified Briefing Slide From 1965, Wikimedia Commons, available at https://commons.wikimedia.org/wiki/File:USAF_ICBM_and_NASA_Launch_Vehicle_Flight_Test_Successes_and_Failures_(highlighted).png.
79. Launch vehicle flight test history, Wikimedia Commons.
80. Peter Hall, "Boden-Boden-Raketen–Militärische, historische und technische Aspekte,"2007, available at http://www.peterhall.de/srbm/nva/5rbr/5rbr48.html.
81. Photo RAND TR1268-5.2, Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," 25.
82. Photo RAND TR1268-5.10, Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," 30.
83. Photo RAND TR1268-5.1, Markus Schiller, "Characterizing the North Korean Nuclear Missile Threat," 24.
84. Courtesy of German Customs Investigation (Zollfahndung).
85. Markus Schiller and Robert H. Schmucker, "Getting Better – The New KN-08 Design", Report, ST Analytics GmbH, Munich, 28 October 2015, available at http://www.st-analytics.de/app/download/5799168213/Getting_Better_Schiller_Schmucker.pdf.
86. KCNA and KCTV.
87. KCNA and KCTV.

Acknowledgements

This article owes a great debt to Robert H. Schmucker, who first proposed the idea of foreign assistance to North Korea's ballistic missile program. He also suggested major parts of the analysis presented here. The author is grateful for his encouragement to work in the field of rocket and missile program analysis and for his ideas and suggestions.

Appendix A: Overview of North Korean missiles and space launchers as of December 2018

This overview includes guided ballistic missiles and space launchers only. Anti-ship missiles, air defense missiles, cruise missiles, and unguided missiles (artillery rockets) are not included.

Italic text with first flight dates in brackets: No first flight yet, missile was only presented at parades or publicity events. The date is the date of the first public appearance (Tables A1 and B1).

Table A1. Overview of North Korean rocket programs.

Name	Alternate Name	Range (Payload)	Stages	Propellant	First Flight	Technology	Type	Source of Foreign Assistance	Scope of Foreign Assistance
Scud B	R-17, Hwasong-5	300 km (1 t)	1	Liquid	1984	Scud	Missile	Soviet (Makeyev design)	Missile system
Scud C	Hwasong-6	500 km (0.75 t)	1	Liquid	1990	Scud	Missile	Soviet (Makeyev design)	Missile system
Nodong	Hwasong-7	940 km (1 t)	1	Liquid	1993	Scud	Missile	Soviet (Makeyev design)	Missile
Taepodong 1	Paektusan-1	Orbital (few kg)	3	Liquid/ liquid/solid	1998	Scud/SS21	Space launcher	Soviet (Makeyev design)	Engines, guidance, design
Scud D		700+ km (0.5 t)	1	Liquid	2000	Scud	Missile?	Soviet (Makeyev design)	Engine? Missile?
Unha	Taepodong 2	Orbital (~100 kg)	3	Liquid/ liquid/liquid	2006	Scud	Space launcher	Soviet/North Korean?	Engines, guidance, components
KN-02	Toksa, OTR-21	70 km (0.48 t)	1	Solid	2007	SS-21	Missile	Soviet (Kolomna design)	Missile system
Impr. KN-02	KN-10?	"200 km" (0.48 t)	1	Solid	2014	SS-21	Unrealistic performance	Soviet (Kolomna design)	Missile?
KN-11	Pukguksong-1	~1,200 km (0.5 t)	2	Solid/solid	2015*	PRC/PAK?	SLBM	Chinese/ Pakistani? Soviet?	Solid motors, missile?
Musudan	Hwasong-10	~2,500 km (0.6 t)	1	Liquid	2016	SS-N-6	Missile	Soviet (Makeyev design)	Engine, design, missile?
Scud ER	Hwasong-9	1,000 km (0.5 t)	1	Liquid	2016	Scud	Missile	Soviet (Makeyev design)	Missile
KN-15	Pukguksong-2	~1,200 km (0.5 t)	2	Solid/solid	2017	PRC/PAK?	Canister, missile	Chinese/ Pakistani? Soviet?	Solid motors, missile?

(*continued*)

Table A1. Continued.

Name	Alternate Name	Range (Payload)	Stages	Propellant	First Flight	Technology	Type	Source of Foreign Assistance	Scope of Foreign Assistance
Hwasong-12	KN-17	3,500+ km (0.5 t)	1	Liquid	2017	RD-250	Missile	Soviet (Yangel/ Glushko design?)	Engine, design, missile?
KN-18	Precision Scud	450 km (0.9 t)	1	Liquid	2017	Scud	Scud C with separable MaRV?	Soviet (see Scud C)	Missile
Hwasong-14	KN-20	6,500+ km (0.5 t)	2	Liquid/liquid	2017	RD-250	ICBM	Soviet (Yangel/ Glushko design?)	Engines, design, missile?
KN-21	Precision Scud	250 km (1.2 t)	1	Liquid	2017	Scud	Scud B with terminal guidance?	Soviet (see Scud B)	Missile
Hwasong-15	KN-22	10,000+ km (~1 t)	2	Liquid/liquid	2017	RD-250	ICBM	Soviet (Yangel/ Glushko design?)	Engines, design, missile?
KN-08	*Hwasong-13*	*5,000–9,000 km?*	*3*	*Liquid/ liquid/liquid?*	*(2012)*	*SS-N-6?*	*Parade mockup*	*n/a*	*n/a*
KN-14	*Mod. KN-08*	*8,000 km?*	*2*	*Liquid/liquid*	*(2015)*	*SS-N-6?*	*Parade mockup*	*n/a*	*n/a*
Solidid ICBM	*MEL canister missile*	*?*	*?*	*Solid*	*(2017)*	*?*	*Canister at parade*	*n/a*	*n/a*
Solidid ICBM	*TEL canister missile*	*?*	*?*	*Solid*	*(2017)*	*?*	*Canister at parade*	*n/a*	*n/a*
Pukguksong-3		*?*	*2*	*Solid/solid*	*(2017)*	*PRC/PAK?*	*Wall sketch*	*n/a*	*n/a*
Solid SRBM	*"NK SS-26 copy"*	*?*	*1*	*Solid*	*(2018)*	*?*	*Parade mockup*	*n/a*	*n/a*

*First verified launch 2016. Possibly only ejection tests in 2015.

Appendix B: Test flight data

The following data compiled from multiple sources illustrates how missile test programs are typically executed. Testing is a requirement of missile development to identify problems. Therefore, a new missile will always fail some tests. Based on test results, changes and modifications are applied to the design and/or the manufacturing process.

Table B1. Operational test launch data as of 2013.[77]

Missile	Country	Time Frame	Total Launches	Launches per Year
R-13	SU	1960–1972	311	26
R-21	SU	1963–1989	228	9
R-12	SU	1965–1987	608	28
R-27	SU	1968–1988	492	25
Minuteman III	USA	1971–2010	200	5
R-27U	SU	1974–1990	161	10
Trident II D5	USA	1990–2013	148	6
Topol	RUS	1990–2010	49	~2
R-17/Scud B	GDR	1965–1989	80	3
Scud B	NK	1984–2013	9?	0.3
Scud C	NK	1990–2013	7?	0.3
Nodong	NK	1993–2013	6	0.3
Musudan	NK	2003–2013	0	0

Launches are counted when the status is officially declared "deployed" or "operational." Development launches are not included. The year 2013 was selected to highlight the low number of launches in North Korea before launches increased under the regime of Kim Jong Un in 2014.

Figure B1 illustrates an indigenous program. Every dot is a test launch; pink markings note failures. Manned launches are highlighted in blue (see online version for color).[78] Launches from the Atlas (ICBM and space launcher), the Titan II, and the Saturn programs are shown in Table B2.

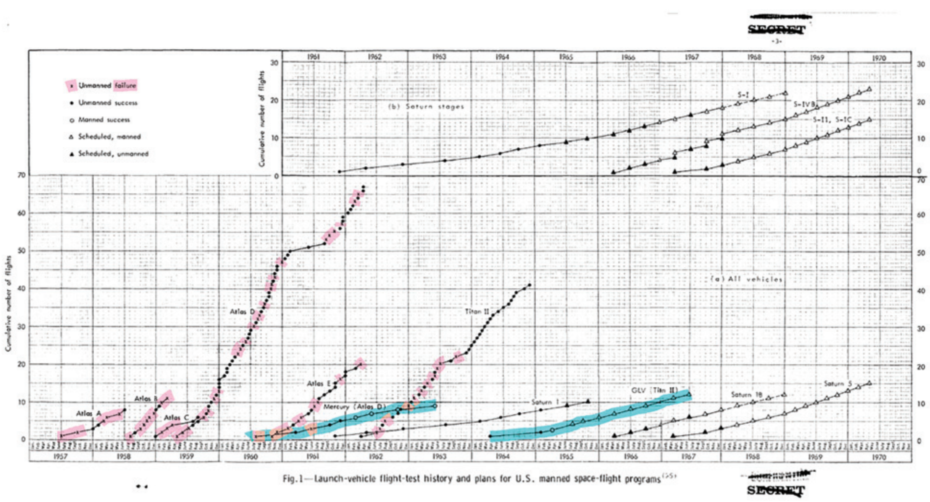


Figure B1. Launch vehicle flight test history and plans for early U.S manned space-flight programs.

Table B2. Early U.S. launch vehicle test flights.[79]

Program	Year	Launches	Success/Failure
Atlas A	1957	3	1/2
	1958	5	2/3
Atlas B	1958	8	2/6
	1959	3	1/2
Atlas C	1959	6	3/3
Atlas D	1959	16	9/7
	1960	31	20/11
	1961	12	6/6
	1962	8	6/2
Atlas E	1960	2	0/2
	1961	16	10/6
	1962	2	1/1
Titan II	1962	9	5/4
	1963	16	9/7
	1964	16	16/0

Appendix C: Soviet design bureaus and production sites

The Soviet industrial military complex was huge. Table C1 presents a selection of relevant design bureaus and missile related production sites.

Table C1. Overview of selected Soviet design bureaus and factories.

Soviet Designation	Lead Designer	Location	Current Name	Focus on	Exemplary Products	Exemplary Technology Lines	Year technology was observed in North Korea
Design Bureaus							
OKB-1	S.P. Korolev	Korolyov, Moscow, Russia	RSC Energia	Rockets	R-7, R-11		-
OKB-2	A.M. Isaev	Korolyov, Moscow, Russia	KB KhimMash (КБХМ)	Engines	Scud engine, SS-N-6 engine	Scud	1984
OKB-52	V.N. Chelomey	Reutov, Moscow, Russia	NPO Mashinostroyeniya (ЦКБМ)	Missiles	UR-100/SS-11 mod 1		-
SKB-101		Kolomna, Moscow, Russia	KB Mashinostroyeniya (КБМ)	Missiles	SS-21	SS-21	2007
SKB-385	V.P. Makeyev	Miass, Russia	Makeyev Design Bureau	Missiles	Scud B, R-27/SS-N-6	Scud, SS-N-6	1984, 2010
OKB-456	V.P. Glushko	Khimki, Moscow, Russia	NPO Energomash	Engines	RD-250 engine	RD-250	2016
OKB-586	M.K. Yangel	Dnipro, Ukraine	Yuzhnoye Design Office	Rockets	R-16/SS-7, R-36/SS-9	RD-250	2016
Production Sites							
Plant 235		Votkinsk, Russia	Votkinsk (воткинский завод)	Missiles	Scud B, Scud C, SS-26/Iskander, SS-27/Topol	Scud	1984
Plant 139		Zlatoust, Russia	Zlatmash	Missiles	Scud B, R-27/SS-N-6	Scud	1984
Plant 586		Dnipro, Ukraine	Yuzhmash	Rockets, engines	RD-250 engine, R-16/SS-7, R-36/SS-9	RD-250	2016
Plant 3		Miass, Russia	Miass Machine-Building Plant (ММЗ)	Rocket	components		

Appendix D: The Scud B weapon system

The Scud B weapon system consists of much more than just the R-17/8K14 missile and its TEL. To operate such a system, all elements must be available (Figure D1).

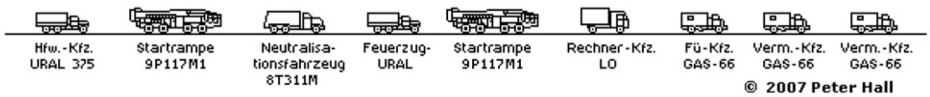


Figure D1. Scud B support vehicles.

A typical Scud B launch battery requires several specially equipped vehicles. Figure D1 shows a former East German launch battery on the move.[80]

For a Scud B launch, the following vehicles were required for loading, preparation, launch, and cleanup:

1. TEL Launch vehicle (9P117, 9P117M, 9P117M1) (Figure D1)
2. Survey vehicle (GAZ-66T) with toolset (1T12)
3. Communication vehicle (GAZ-66T) with coded radio system (R-142)
4. Cleaning and neutralization vehicle (8T311, 8T311M)
5. Pressurized air vehicle (UKS-400W)
6. Missile transporter (2T3M)
7. Warhead transporter (9F21, 9F223)
8. Mobile crane (9T31M, 9T31M1)

Figure D2. TELs for Scud class missiles.[81]

9. Fueling vehicles, for oxidizer (8G17M, 9G30) and fuel (2G1U, 9G29), enough for one (oxidizer) and two (fuel) missile loads
10. Checkout vehicle for guidance system and self-destruct system (2W11)
11. Checkout vehicle for onboard systems, gyros, and fuses (9W41)
12. Maintenance, repair, overhaul vehicle (2Sht1)
13. Command vehicle (9S436-1).

The North Korean TEL is identical to the Soviet TEL based on the MAZ 543 truck. Only the auxiliary power unit vent was moved. The Chinese TEL for the DF-11 missile looks quite different. A vehicle indigenously produced in North Korea should also look different.

Appendix E: Scud missile cloning and reverse engineering: North Korea and Iraq

The drawing shows the same characteristics as the original Soviet R-17/Scud B propulsion system.

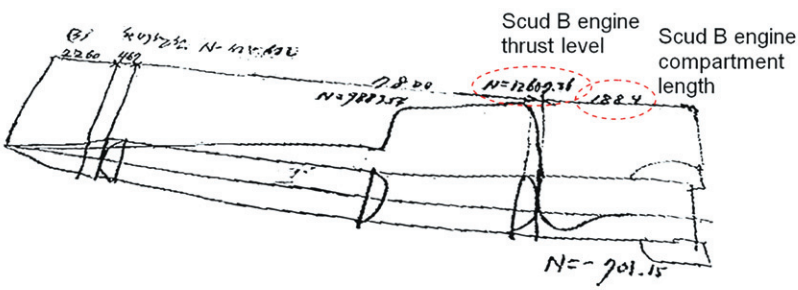


Figure E1. Scud B drawing from the North Korean freighter Kuwolsan, India 1999.[82]

The North Korean Scud is identical to the Soviet one, including Cyrillic letters and unimportant details.

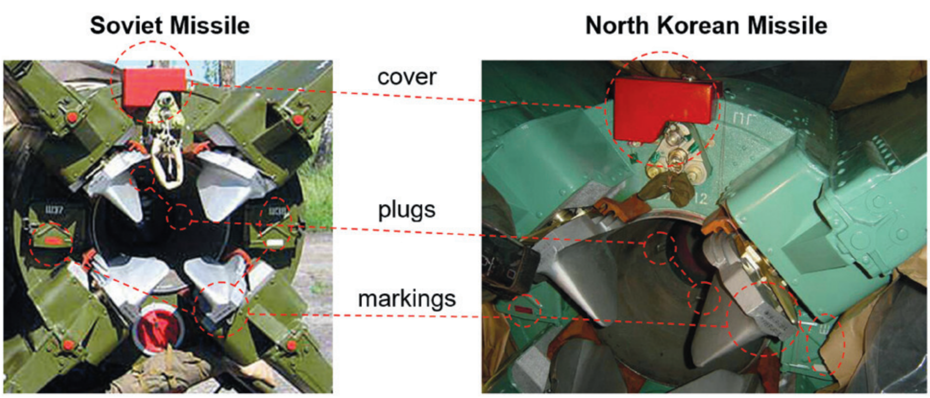


Figure E2. Scud B from the North Korean freighter So San, Gulf of Aden 2002.[83]

Scud parts produced during the Iraqi reverse-engineering effort look different than the originals.

Figure E3. Original and reverse-engineered Scud B parts.[84]

Appendix F: The KN-08 and KN-14

Both the KN-08 and the KN-14 were designated the Hwasong-13 in North Korea according to the plaquette at the parading TELs. Neither design was launched. The KN-08 (top) was first publicly seen on April 2012. In October 2015, a different design, the KN-14 (bottom), was paraded through Pyongyang, mounted on the same trucks as the KN-08 in 2012 (Figures F1 and F2).

The KN-08 program must have been initiated in the 2000s or earlier, since footage shows Kim Jong Il with what looks like a KN-08 first stage in the background. It already featured the twin-Musudan-propulsion-unit that was later fired on a static test stand.

The date of this footage is not known. The missile besides Kim Jong Il has not yet been clearly identified, but the one in the background looks like a KN-08 (Figure F3).

Figure F1. The KN-08 and KN-14 ICBM designs.[85]

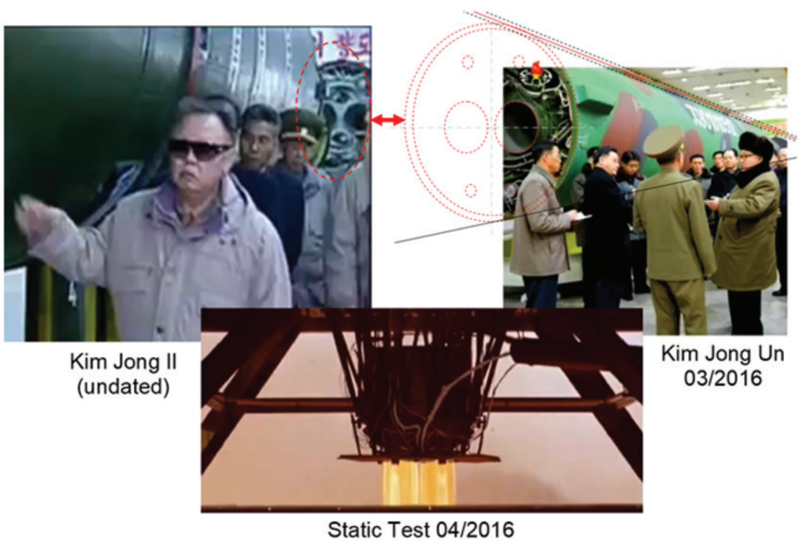
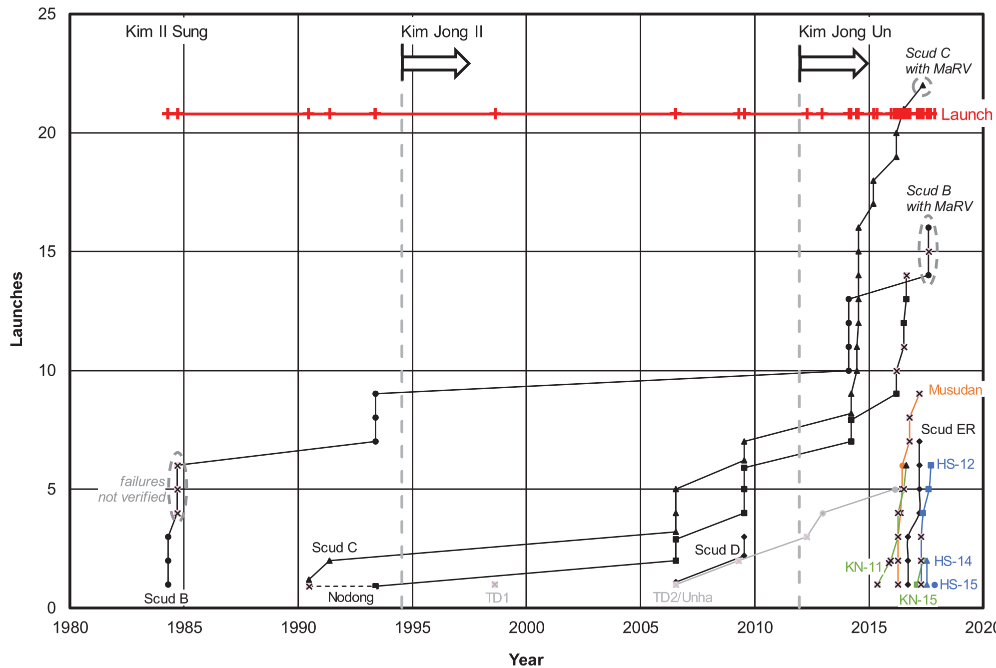


Figure F2. KN-08 propulsion unit.[86]

Figure F3. Kim Jong Il inspecting large missiles.[87]

Appendix G: Chronology of North Korean missile launches 1980–2020



Legend

Black	Scud related (Makeyev)
Orang	SS-N-6 related (Makeyev)
Green	Solid-fueled rockets
Blue	RD-250 related (Glushko/Yangel?)
Grey	Space launchers
Pink	Launch failures.

Figure G1. Chronology of North Korean missile launches 1980–2020.