FFI-RAPPORT

18/01830

Nuclear weapons capabilities and doctrines in North Korea

Halvor Kippe

Nuclear weapons capabilities and doctrines in North Korea

Halvor Kippe

Norwegian Defence Research Establishment (FFI) 18 February 2019

Keywords

Kjernevåpen
Kjernefysisk program
Missiler
Nord-Korea

FFI-rapport

18/01830

Prosjektnummer

5403

ISBN

P: 978-82-464-3158-1
E: 978-82-464-3159-8

Approved by

Hanne Breivik, *Research Manager*
Janet Martha Blatny, *Research Director*

Summary

The North Korean nuclear and missile programs have seen an accelerated development under the leadership of Kim Jong-un. We have analyzed official North Korean declarations in a nuclear weapons doctrine framework, and assessed to what degree their actual nuclear weapons capabilities support their declaratory doctrine.

After six underground nuclear tests and numerous missile flight-tests, the country can now credibly threaten military and civilian targets in Japan and South Korea with nuclear-tipped, medium-range ballistic missiles. Even US naval and air force assets on Guam seem to be within reach for one of the most modern North Korean ballistic missiles, the Hwasong-12. Furthermore, they have successfully flight-tested two types of missiles with the probable range to strike the continental US with thermonuclear warheads, the Hwasong-14 and Hwasong-15. Central questions regarding reliability, precision, and survivability during atmospheric re-entry still linger before we deem this capability credible. Still, US leaders can no longer rule out the possibility that Pyongyang under certain circumstances may succeed in destroying at least one of their major cities with such missiles. The strategic balance has changed in the favor of North Korea.

North Korea has through words and actions signaled a willingness to launch nuclear attacks on military targets on Guam, in Japan, and South Korea, if they assess that a US force buildup is underway as a prologue to an invasion or a major attack. This willingness to cross the nuclear threshold as a preemption of conventional aggression is called *asymmetric escalation*, and it constitutes a central part of the North Korean declaratory nuclear doctrine.

The possibility that North Korea may destroy major US cities with its most far-reaching missiles makes Pyongyang hope that the US will hesitate to retaliate a regional nuclear first strike against US and allied military targets in the region, as well as coming to its allies' assistance in other types of conflicts. This second key element of the North Korean nuclear doctrine has already started to manifest itself, even though the North Korean capability is far from proven, and its intercontinental ballistic missiles are still vulnerable to preemptive strikes. Such a deterrence through a less-than credible retaliatory capability is called *first-strike uncertainty*, as the adversary cannot be sure to take out all North Korean nuclear assets in a first strike. Such a force structure is strikingly similar to the one of China around 1980, although the strategic situation is quite different.

The new situation means that North Korea and the US must either reach a kind of stable, mutual deterrent relation, or resolve the security challenges that are really the reason for Pyongyang wanting a nuclear deterrent in the first place.

Sammendrag

Det nordkoreanske atom- og missilprogrammet har hatt en akselerert utvikling under Kim Jong-un. Vi har undersøkt offisielle nordkoreanske uttalelser om kjernevåpenbruk og analysert dem i en doktrinekontekst. Videre har vi vurdert i hvilken grad landets faktiske kjernevåpenkapabiliteter støtter den kommuniserte doktrinen.

Etter seks underjordiske prøvesprengninger og talløse ballistiske missiltester har landet nå en troverdig evne til å true militære og sivile mål i Japan og Sør-Korea med kjernefysiske ballistiske mellomdistansemissiler. Også amerikanske luft- og sjøstridskrefter på Guam ser ut til å være innen rekkevidde for ett av de mest moderne ballistiske missilene til Nord-Korea, Hwasong-12. Videre har landet med hell testet to typer ballistiske missiler med sannsynlig rekkevidde til å nå fastlands-USA med termonukleære sprengladninger, Hwasong-14 og Hwasong-15. Sentrale spørsmål om missilenes pålitelighet, presisjon og overlevelsesevne ved tilbakevending til atmosfæren gjenstår før denne evnen er troverdig. Amerikanske ledere kan likevel ikke lenger utelukke at Nord-Korea kan lykkes i å ødelegge minst én av deres storbyer med slike missiler. Den strategiske balansen er endret i Nord-Koreas favør.

Nord-Korea har signalisert med ord og handlinger at de er villige til å angripe militære mål i Guam, Japan og Sør-Korea med kjernevåpen dersom de vurderer at USA forbereder en invasjon eller et større angrep. Denne villigheten til å krysse den kjernefysiske grensen i forkant av konvensjonell aggresjon kalles *asymmetrisk eskalering* og er et sentralt element i den nordkoreanske deklaratoriske kjernevåpendoktrinen.

Nord-Korea har mulighet til å ødelegge amerikanske storbyer med de mest langtrekkende missilene sine. Dette gjør at Pyongyang håper at USA vil vegre seg for å gjengjelde et kjernefysisk førsteslag mot militære mål i regionen, og for å komme sine allierte til militær unnsetning i andre sammenhenger.

Dette andre hovedelementet i den nordkoreanske doktrinen har allerede begynt å gjøre seg gjeldende, til tross for at den nordkoreanske evnen langt fra er bevist og de langtrekkende missilene foreløpig er sårbare mot forkjøpsangrep. En slik avskrekking gjennom en mindre troverdig gjengjeldelsesevne kalles *førsteslagsusikkerhet*, siden motparten ikke kan regne med å slå ut alle nordkoreanske kjernevåpenstyrker i et førsteslag. En slik styrkestruktur er påfallende lik den kinesiske rundt 1980, men den strategiske situasjonen er en ganske annen.

Den nye situasjonen gjør at Nord-Korea og USA enten må finne en form for stabil, gjensidig avskrekkingsrelasjon, eller løse de sikkerhetsutfordringene som gjør at Nord-Korea ønsker kjernevåpen i utgangspunktet.

Content

Preface

This study is the main deliverable in a project funded by the Royal Norwegian Ministry of Defence (MoD), under their program for financing research on security and defence policy. The project title is "What can the North Korean nuclear and missile development tell us about the country's nuclear weapons doctrine?" The aim has neither been to produce a comprehensive discussion of the strategic relations in the Korean theater, nor of all types of nuclear doctrines among nuclear weapons states. Rather, we have chosen a more focused and interdisciplinary approach, where we first interpret official North Korean statements and texts in a nuclear weapons doctrine framework, and then assess whether or not their capabilities at hand actually support their declaratory doctrine.

The main effort of the project has been to investigate the research question, and document the findings in this report. In addition, the author has provided supervision to a master's degree student in International Relations with London School of Economics and Political Science, Ms. Pernille Sofie Sørensen, during her thesis work. The title of her thesis is "From "Rogue" to "Responsible" – The rationale behind North Korea's rhetoric in the Byungjin era."

The last deliverable in this project will be a short version of this study, written in Norwegian, and offered to the Norwegian Military Journal (Norsk Militært Tidsskrift).

Cognizant of the diplomatic thaw in 2018, we see this study as still relevant as long as North Korea has not dismantled its nuclear warheads, and destroyed the delivery vehicles. Arguably, enhancing and nuancing the understanding of these weapons' strategic role and abilities is paramount when addressing Pyongyang's security concerns in the context of any serious and comprehensive negotiating process aiming to remove the specter of nuclear-armed conflict on the Korean Peninsula.

I extend my gratitude towards Dr. Henrik Stålhane Hiim with NUPI for his generous effort in peer-reviewing this report.

1 Introduction

The years 2016 and 2017 saw an astonishing number of ballistic missile tests in North Korea, as well as three nuclear tests. Taking into account the success rate of the most significant of those tests, most pundits and observers agree that Pyongyang actually passed a number of important technological milestones in the nuclear and missile sectors. Still, although major strides have been made in areas such as submarine-launched ballistic missiles (SLBMs),[1] solid-fueled ballistic missiles, and ballistic missiles with potentially intercontinental ranges, North Korea's *well-proven* nuclear weapons delivery vehicles by 2018 include only ballistic missiles that are highly vulnerable to preemptive strikes during launch preparations, and that have *regional*, not intercontinental ranges. More advanced capabilities have either only been demonstrated (like the three successful intercontinental ballistic missile (ICBM) tests in 2017), not reliably tested over time, been paraded (like two suspected, solid-fueled ICBMs), or are under assumed development (like a longer-range SLBM). Pyongyang's most reliable nuclear weapons systems are thus, for the time being, vulnerable to a preemptive, counter-force attack from its main adversary, the US. This imposes severe limits to Pyongyang's possible nuclear weapons use and credible threat thereof.

In this report, we will utilize the terms *nuclear posture*, *nuclear doctrine*, and *nuclear capabilities* in the following way: By *nuclear posture*, we mean a state's combined *nuclear doctrine and the associated nuclear force structure needed to execute the doctrine*. By *nuclear doctrine*, we mean *the strategic rules of engagement for the nuclear forces of a state*, *i.e.* the circumstances under which a state will consider the use of nuclear weapons, and the overall targeting principles associated with usage under the given circumstances (for instance various degrees of counter-force, limited counter-value, or massive retaliation). We distinguish between *operational doctrine*, which is the actual set of rules of engagement and targeting principles (generally classified) associated with the nuclear posture, and *declaratory doctrine*, which is the communication of the alleged such set of rules and principles to the adversary [1]. The two may somewhat differ, in cases where a state either seeks to underplay or exaggerate the salience and/or abilities of its nuclear forces. By *nuclear capabilities*, we mean the combined means to launch a nuclear weapon upon an enemy target (not, for instance, nuclear fuel cycle capabilities), including the associated command and control installments. An example of the latter could be a nuclear-tipped ballistic missile of a certain range and reliability, with a certain explosive yield, response and preparation time, as well as the unit responsible for launching it, and the command and control systems necessary to order its launch, and to specify its target.

The two most dominant nuclear weapons states, Russia and the US, have got such a variety of nuclear weapons and associated delivery vehicles that their force structures may support a range of different doctrines. In contrast, a nuclear weapons state such as today's UK has chosen to deploy only one nuclear weapon system, namely Trident II D5 missiles on their Vanguard-class nuclear submarines, carrying thermonuclear warheads. The purpose of such a "one-legged" force structure is to communicate a doctrine of sole retaliatory nature. The US-developed

[1] We use many terms and abbreviations in this report. The A Appendix includes a list of these, including definitions.

Trident II D5 missiles have an impressive test record, and are widely considered both precise and reliable. This is crucial for the credibility of UK's second-strike capability.

Not all nuclear weapons states have the available tools to assume either a comprehensive nuclear doctrine (such as "massive retaliation" or, especially, "flexible response"), or a minimalist, credible, retaliatory doctrine (such as the UK and India). The former requires a plethora of capabilities, in terms of various delivery platforms, strike ranges, explosive yields, supported by advanced command and control (C2) systems, as well as intelligence, surveillance, and reconnaissance (ISR) capabilities. On the other hand, the latter mainly requires nuclear weapons systems that the opponent, in order to be deterred, should consider highly reliable and robust. In particular, any pure retaliatory doctrine requires weapons systems that are almost guaranteed to survive an incoming, nuclear first strike (counter-force attack). Typically, emerging and regional nuclear weapons states do not always have at their disposal all the capabilities necessary to support doctrines that require either high capacity (many weapons, and a variety of explosive yields and delivery platforms) or high reliability (and, ideally; survivability).

We may characterize such "developing nuclear weapons states" as having their doctrines very much reliant upon their capabilities at hand. In the case of North Korea, their nuclear toolbox has been significantly expanded in the later years, culminating in particular in the year 2017, which saw, *inter alia*, their highest-yield nuclear test to date (deemed by most experts as probably being a thermonuclear device), as well as their first three tests of two types of ICBMs ("Hwasong-14" and "Hwasong-15"). However, North Korea still lacks certain key capabilities, as well as the sufficient capacity, to support some of the mentioned types of nuclear doctrines. In particular, it is unrealistic even in the unforeseen future for the country to strive for strategic parity with its main adversary, the US. The US will retain for many years an unequivocal escalation dominance over the Democratic People's Republic of Korea (DPRK) in the nuclear field, meaning that the DPRK will have no prospect of winning a nuclear exchange with the US, no matter the circumstances in which the nuclear threshold is crossed. That renders the classic doctrines of the US and the Soviet Union during the Cold War, and those of the Russian Federation and the US today, quite irrelevant from Pyongyang's perspective. Rather, we should look for similarities and parallels among nuclear weapons states facing a superior nuclear adversary, such as France versus the Soviet Union during the Cold War,[2] and China versus the US to this day. In those cases, the nuclear inferior state is reliant upon the deterrent effect of either communicating a seemingly irrational willingness to be the first to use nuclear weapons (despite the risk of a massive nuclear response), or of the prospect of limited nuclear retaliation in case of an enemy first strike (nuclear or otherwise). However, the DPRK's nuclear capabilities are not nearly as mature as those of the current-day, abovementioned nuclear weapons states, so there is probably no one-to one correspondence in today's doctrines. On the other hand, there might be something to learn from earlier days.

[2] We exclude the UK versus China here, due to the UK's close integration with the US in the nuclear field, and its much stronger emphasis on NATO collective defense in comparison to France in that period.

2 Political and strategic considerations

Any analysis of the co-development of nuclear doctrines with nuclear capabilities would be futile if we consider the actor in question genuinely irrational, in the sense that it would be expected to act against its own interests of preservation. Consequently, and not with a lack of empirical support (including the CIA [2]), we assume that Pyongyang makes its nuclear decision-making (and security policy in general) on a rational basis, and with a set of primary, interconnected goals:

- Regime survival
- Securing territorial integrity
- Deterring military aggression

Some, such as [3], would also include the reunification of the two Koreas. Pyongyang could conceivably employ *nuclear coercion* in an attempt of forced reunification. While we do not exclude this possibility, we will consider it of secondary prominence compared to the three main goals stipulated above, not least based on North Korean statements to the effect that deterring and repelling US-led aggression is the sole aim of its nuclear weapons. In fact, in April 2013, the DPRK actually adopted a "Law on Consolidating the Position of Nuclear Weapons State," and spelled out the overall rules of engagement. Paragraphs 2 and 4, respectively, of that law states the following on the envisioned utilization of nuclear arms, according to the Korean Central News Agency (KCNA):

> "They serve the purpose of deterring and repelling the aggression and attack of the enemy against the DPRK and dealing deadly retaliatory blows at the strongholds of aggression until the world is denuclearized."
>
> "The nuclear weapons of the DPRK can be used only by a final order of the Supreme Commander of the Korean People's Army to repel invasion or attack from a hostile nuclear weapons state and make retaliatory strikes." [4]

This is to say that their nuclear weapons doctrine is not entirely of retaliatory nature, but includes the possibility of targeting even a conventional, US-led, military attack or even buildup, with nuclear arms. Paragraph 5 specifies a policy of no nuclear use against non-nuclear weapons states unless these join forces with a nuclear-armed aggressor against the DPRK:

> "The DPRK shall neither use nukes against the non-nuclear states nor threaten them with those weapons unless they join a hostile nuclear weapons state in its invasion and attack on the DPRK."

Further, recent-years' decision-making have been guided by Pyongyang's officially declared *byungjin line*. The Central Committee of the Korean Workers' Party (KWP) introduced and adopted byungjin during a plenary meeting in March 2013. In short, it states that the nation should simultaneously develop the economy and its nuclear weapons [5]. While this may seem like a paradox, the logic is to avoid a much more expensive conventional modernization. That would be the alternative, in case there were no nuclear deterrent. Given a perceived need for a convincing military deterrence in one form or another, continuing and perfecting a nuclear and ballistic missile effort provide far more "bang for the buck" than would the conventional option. Nonetheless, this was widely seen as a strategic departure from Kim Jong-Il's *Songun* policy of military first, which emerged around 1995 [6].

The fall of 2017 saw what future historians might call a culmination of the byungjin era. A period of frequent nuclear and ballistic missile tests reached a climax with the sixth nuclear test on 3 September (see Section 4.1), and not least by two ICBM tests in July (Hwasong-14, see Section 4.3), and one more in the night of November 29 local time (Hwasong-15, also see Section 4.3). In a blink of an eye, what had long been a future threat of North Korea possibly succeeding in developing thermonuclear weapons and intercontinental-range missiles to deliver them, suddenly seemed like a reality. This happened amid ever-increasing tensions with the US, in a rhetorical sandbox quarrel on the world scene.

Following the successful first flight-test of the Hwasong-15, and a furious reaction to a new round of sanctions adopted by the UN Security Council on 22 December [7], North Korean official statements changed. In Kim Jong-un's New Year's address only days later, he stated:

> "An outstanding success our Party, state and people won last year was the accomplishment of the great, historic cause of perfecting the national nuclear forces."
> (…)
> "By also conducting tests of various means of nuclear delivery and super-intense thermonuclear weapon, we attained our general orientation and strategic goal with success, and our Republic has at last come to possess a powerful and reliable war deterrent, which no force and nothing can reverse.
>
> Our country's nuclear forces are capable of thwarting and countering any nuclear threats from the United States, and they constitute a powerful deterrent that prevents it from starting an adventurous war." [8]

At least two major takeaways from this speech are relevant for this analysis: First, Kim Jong-un underlines the deterrent and repellent nature of his nuclear forces, implicitly ruling out nuclear coercion in the context of forced reunification. Second, he declares the very completion of the development of the nuclear forces, including both the explosive devices and the delivery vehicles (ballistic missiles). This may be interpreted as a belief that no more nuclear or missile tests are necessary. However, just a couple of weeks earlier, the newspaper of the KWP, *Rodong Sinmun*, stated in a commentary:

> "No matter how severe the situation is and what manifold difficulties we may face, we will further bolster the deterrence for self-defense under the uplifted banner of the simultaneous development of the two fronts." [9]

This is consistent with retaining the possibility of future testing. In April 2018, Kim Jong-un provided a clarification of what is now understood as a new strategic line, after the claimed success of the byungjin era, in an address to the Central Committee of the KWP during a plenary meeting. In his speech, he emphasized that economic development would be at the forefront. KCNA cited Ri Un Chon, the vice-minister of the Ministry of Metallurgical Industry, as saying:

> "The great victory of simultaneously developing the two fronts enables us to concentrate our efforts on the economic building." [10]

The announcement came after a few months of multi-pronged diplomatic overtures, starting with the historic participation by the DPRK, and subsequent meetings between high-ranking officials from the DPRK and the Republic of Korea (ROK), during the Winter Olympics in Pyongchang in February 2018. Later that year, Kim Jong-un engaged in unheard-of summitry, meeting the leaders of China, South Korea, and even the US. Without indulging in too comprehensive political deliberations, this was clearly consistent with the new strategy of improving the economic situation. In concert with self-imposed moratoria on nuclear and long-range ballistic missile testing, as well as rather general statements supporting a future Korean Peninsula without nuclear weapons, there was no doubt that Pyongyang sought a new phase of relations with the outside world after an intense dash to achieve a formidable nuclear weapons capability during the byungjin years. Lifting economic sanctions would be key to boost its economy, and short of that, even less vigorous implementation of existing sanctions (in particular from its main trading partner, China) would go a long way in improving the situation.

Perhaps the Winter Olympics served as a natural turning point and an opportunity to pursue diplomacy for Pyongyang. The North Korean leadership surely did not make the decision of such a major shift based on a realization that its nuclear weapons delivery vehicles had completed their development and testing phase. Several of the most impressive ballistic missiles North Korea introduced in the last couple of years before they announced a testing hiatus, have only seen one or a handful of successful tests. From a technological and military point of view, it is puzzling that Kim Jong-un after the Hwasong-15 test declared that they "finally realized the great historic cause of completing the state nuclear force, the cause of building a rocket power," and shortly thereafter froze its test efforts (still in effect by late 2018). [11] Missile flight-tests are key to completing the development of new systems before deployment, although static ground tests also provide valuable (but insufficient) feedback. Testing space-launch vehicles (SLVs) embedded with some of the same technologies as a ballistic missile (such as the rocket engines, navigation and steering systems, and staging mechanisms) is another, indirect and suboptimal way of validating ballistic missile technology short of flight-testing the actual missiles. SLV flight-testing does not address all aspects of ballistic missile flight-testing. Two of the most important aspects that are not addressed, are the performance of the whole system in a minimum-energy trajectory (*i.e.* one that maximizes the horizontal range), and the survivability of a re-entry vehicle (RV) through the atmosphere in general, and under minimum-energy trajectories in particular (as SLVs typically fly in close to vertical trajectories).

It is arguably irresponsible to deploy nuclear weapons on delivery systems that are not properly tested. On the other hand, it is perhaps even more irresponsible for an adversary to the nuclear weapons possessing state to omit taking into account the possibility of such weapons actually working. In that sense, there might be some deterrence in effect even before one has documented a reliable arsenal through satisfactory and comprehensive testing. We dare extend this argument to states that are widely assumed able either to test a nuclear device within a short time, or even to successfully launch a nuclear weapon in an improvised way without ever having performed a live nuclear test. South Africa in the 1980s is an example of the former, while current times Israel is an example of the latter (with a caveat regarding the so-called “Vela Incident” in 1979, suspected by many to have been a secret nuclear test [12]). In fact, several regional nuclear weapons states rely on nuclear delivery systems with a conspicuously meager test record. There may be several reasons for this. One is that these states may be sensitive to “political fallout,” in some cases even including international sanctions, as a reaction to aggressive test programs. Another possible reason is that flight-testing is actually very resource demanding, and several of the regional or emerging nuclear weapons states have in periods both suffered economic struggles, and have been excluded from export control regimes (possibly slowing production). This may result in a deployment practice with far less rigorous demands than what is the case in for instance Russia or the US. Consequently, they may adopt a less ambitious doctrine, perhaps settling for less than assured, massive retaliation or one that only includes credible first-strike capabilities (cf. Chapter 4).

The argument made above fits well with the notion that North Korea’s primary purpose with its nuclear assets is deterrence, not warfighting. It at least plays well into the idea that Pyongyang has started to bank its deterrence credibility on intercontinental ranges (*i.e.* having the ability to threaten the continental US) before having completed the necessary testing of the relevant delivery vehicles. With regard to Pyongyang’s regional foes, the situation is different, as its nuclear-capable ballistic missiles with ranges to reach Japan and South Korea have a much more convincing test record, as we will elaborate on in Chapter 4. Test records, assumed ranges, precision and payloads are all relevant factors when we assess statements about North Korea’s ability to deter or even repel US-led aggression with nuclear weapons, *i.e.* claims about a regional counter-force capability. In a broader sense, reality checking North Korean statements about nuclear-doctrinal matters in general is entirely contingent on an updated and comprehensive understanding of Pyongyang’s nuclear weapons capabilities. This aim is a moving target, even in periods of test moratoria in the nuclear and missile sectors.

3 Doctrines and capability requirements

North Korea has faced a massive nuclear threat from the US since its inception. No doubt, they have been seeing nuclear weapons as the ultimate equalizer, reducing the perceived probability that the US would dare crossing the nuclear threshold in an armed conflict, and hoping to deter conventional aggression as well. Under Kim Jong-un, the nuclear weapons have become more than a theoretical deterrent, as both weapons designs and several delivery vehicles have been tested and in many respects repeatedly demonstrated. Along with that development, Pyongyang has started to signal its doctrine, as we discussed in Chapter 2. They are telling the world under what circumstances they would consider using their nuclear weapons, so that the weapons' deterrent effect is actually projected. In this period, nuclear weapons have only strengthened its position in the North Korean psyche, and the leaders in Pyongyang have even amended the constitution to include a passage describing the DPRK as a nuclear-armed state. [13] However, what kind of doctrines do best describe the body of North Korean statements on possible nuclear weapons use? Moreover, which capability requirements are associated with the most relevant doctrines in question?

3.1 The best describing doctrines

We have now explored to some extent the strategic situation, as well as some relevant North Korean statements with regard to the possible use of nuclear weapons. In the further, we seek to identify doctrines that best describe these declaratory doctrinal statements.

A purely retaliatory doctrine is likely the form of deterrence that best addresses the security dilemma, by providing no-first-use assurances to the adversary. In that way, the adversary is not incentivized to develop the ability to execute a massive, counter-force, nuclear first strike. Such a doctrine is thus less prone to drive an arms race than ones that do not exclude the possibility of a nuclear first strike. When opening for a first strike, on the other hand, the adversary is given incentives to expand and diversify its nuclear forces, to increase the likelihood of retaining a residual, useable nuclear arsenal after suffering a massive first strike. Following from that logic, it is hard to conceive why any state would assume and signal nuclear doctrines that include the option of nuclear first use. However in the case of the DPRK, the risk of spurring an arms race with its main adversary, the US, is minimal. In the foreseeable future, the US posture is set up to keep strategic parity with Russia, leaving the emerging nuclear threat from the DPRK of less impact (although that is not the case in the area of missile defense, where the North Korean ballistic missile threat is among the main justifications). Furthermore, there is a historic precedent for conventionally inferior actors to assume nuclear first-strike doctrines, in order to deter not only nuclear aggression, but also conventional aggression. NATO during the Cold War and Pakistan post-1998 are the most prominent examples of this.

In light of the above discussion, it is easier to comprehend why the DPRK has signaled a willingness to perform a preemptive nuclear attack against a conventional US force buildup in the region (specifically on Guam, in Japan, and in South Korea), as alluded to in Chapter 2.

When assured retaliation, as well as a debilitating counter-force first strike is unavailable, so-called *asymmetric escalation* becomes a real option in situations where regime survival and the territorial integrity seem to be at stake. Vipin Narang defines asymmetric escalation in the following way:

> "An *asymmetric escalation posture* develops capabilities and procedures that credibly enable the rapid and first use of nuclear weapons in the event of a conventional attack." [1]

To drive this point home beyond mere rhetoric, Pyongyang has recently transitioned from only *testing* nuclear-capable missiles to sometimes *exercising using them*. In 2016 and 2017, they practiced attacking the strategic port city of Busan in South Korea with a "No-dong" missile (described in Subchapter 4.2), and the US Marine Corps Air Station outside Iwakuni in Japan with a salvo of some advanced Scud-type missile (most likely the extended-range Scud, "Scud-ER," also described in Subchapter 4.2). [14] The logic of such a doctrine is not that it ensures regime survival, but that it provides some hope that it is possible to deter not only outright attacks from the US, South Korea, or Japan, but in fact deter even a force buildup in the region. Would the US dare even to prepare for military action if Pyongyang signals a seemingly reckless willingness to cross the nuclear threshold to preempt it? Indeed, if Pyongyang believes that a force buildup in the theater is necessary before the US is able to take out its nuclear assets, or even its leadership, such asymmetric escalation makes sense in a so-called "use 'em or lose 'em" mindset. [15] Inherent in this form of nuclear brinkmanship is a risk of miscalculation, that may lead to devastating nuclear war. Obviously, crossing the nuclear threshold invites a nuclear retaliation. This is where ICBMs may play an important role.

Some have pointed out the possible train of thought that Pyongyang may calculate that the US will rather withdraw from a conflict than retaliate with nuclear assets, as long as US cities are at risk in a North Korean nuclear second strike (cf. the comment on ICBMs above). That is tantamount to saying that the US would be far more efficiently deterred from regional aggression if not only targets in the East Asian theater are threatened by North Korean nuclear strikes, but also the US mainland. In effect, this entails a presumptive weakening of US alliance commitments to Japan and South Korea, leaving Pyongyang more flexible and emboldened in the region. Some strategists call this effect *alliance decoupling*, and it plays well into the notion some hold that Pyongyang sees nuclear weapons not only as a security assurance, but also as an enabler of regional expansionist goals (*i.e.* forced reunification). [16-18]

We may call the declaratory doctrine discussed above *deterrence through threat of regional, nuclear preemption, and of possible regional and intercontinental nuclear retaliation*. Note that the preemption component is aimed at both conventional and nuclear threats arising in the region, as both may be of existential severity from Pyongyang's perspective. We will discuss the credibility of the elements of such a doctrine in Chapter 4.

So why have we experienced a significant change in official North Korean rhetoric shortly after the successful tests of the Hwasong-14 and Hwasong-15 ICBMs in 2017? In addition to the statements following the nuclear and missile testing spree in 2017 that we quoted in Chapter 2, the Deputy of the Supreme People's Assembly (*i.e.* the parliament), Ri Jong-hyok, was quoted as saying:

> "Our nuclear deterrence is a sword of justice aimed at fighting (U.S.) nuke and Asia and any country in the world need not worry about our threats as long as they do not join invasion and provocations toward us." [19]

The emphasis was thus stronger on the US as the target for North Korean nuclear deterrence, rather than US allies in the region. This is indicative of the new strategic situation enabled by the demonstrated ICBMs, where the US mainland suddenly was theoretically within reach. It is tempting to interpret this shift as a first step in the direction of a doctrine more reliant upon retaliation than preemption. Indeed, talking points threatening nuclear preemption seem to have disappeared from North Korean statements in 2018. However, we should also understand this in the perspective of the diplomatic thaw in the exact same period, which very well may mean that the rhetorical restraint has been of temporary nature.

A major disadvantage of the abovementioned doctrine of asymmetric escalation by nuclear preemption, besides the obvious one of inciting a nuclear response from a major nuclear power, is that it provides incentives for a preemptive counter-force attack (nuclear or conventional) from the opponent. Two adversaries having incentives for striking first is hardly compatible with a wish for strategic stability. Who will be the first to blink? Adding to this complicated picture is Seoul's signaling of a doctrine of performing a high-precision strike against the DPRK leadership to preempt a nuclear launch command, a so-called "decapitation strike." [20] This, in turn, raises questions about the possible pre-delegation of launch command in the DPRK, a concept often called "fail-deadly," to enable nuclear retaliation even if the leadership has been eradicated. Pyongyang has by the end of 2018 never communicated the possibility of a de-centralized or pre-delegated nuclear launch command, which means there will at least be no deterrent effect in them actually having such.

A more attractive and potentially stabilizing option is a doctrine emphasizing retaliation, not preemption. With the unsurmountable challenge of taking out any unused US nuclear assets in a nuclear second strike, both in terms of numbers and capabilities, aiming to hold US population centers at risk in a counter-value attack seems a more realistic and achievable force goal in a retaliatory posture. In Chapter 4, we will discuss the emergence of the two above-mentioned ICBMs in this perspective, as well as other, potential second-strike assets. While Pyongyang has dampened its rhetoric in the direction of asymmetric escalation in 2018, we should not interpret this as a sign of them turning completely to a pure second-strike doctrine. As we will see in Chapter 4, they are still far from having a credible such posture. However, a shift in doctrines will likely be gradual, as certain nuclear assets develop and mature in the force structure, adding credibility along the way. As more strategic options emerge and exist in parallel, Pyongyang may enjoy increased strategic flexibility and perhaps a lower risk of inadvertent escalation. On a cautionary note, we contend that there will always remain an incentive for Pyongyang to keep an element of nuclear first strikes in its declaratory doctrine, as long as the US retains uncontended conventional and nuclear escalation dominance.

3.2 Capability requirements

To investigate whether a nuclear force structure supports an operational doctrine or not, one should identify characteristics that are relevant for various kinds of nuclear warfighting. Then, one may argue why certain characteristics are beneficent or even necessary to assume particular operational doctrines. A whole other discussion is whether the capabilities the weapons state choose to display and demonstrate actually represent combat-ready and deployed systems, or whether there are elements that (at least preliminarily) serve to communicate a declaratory doctrine that is more comprehensive than its operational doctrine. In such cases, where unproven capabilities are paraded and even declared operational, one may argue that the possessor state is trying to harvest a nuclear deterrent beyond its actual capabilities. Whether the adversary "calls the bluff" or not is not necessarily crucial, as long as the adversary is unable to rule out that displayed or emerging nuclear weapons capabilities may work in a crisis. Furthermore, the targets of strategic communication of this kind may not necessarily be the military planners and decision makers of the adversary (who probably have a rather realistic understanding of the actual situation), but rather a domestic audience and the informed and concerned public in the adversarial state.

This study obviously runs the risk of underscoring parts of Pyongyang's declaratory doctrine that are not parts of its operational doctrine, as long as we do not know the exact developmental or operational status of all known nuclear weapons systems. However, we seek to assess and question the status of each key capability in question in Chapter 4, to provide a judgment as sound as possible using open sources. One particular case of a North Korean nuclear delivery system that illustrates the issue of disparity between displayed and operational assets, is the "Hwasong-10" ballistic missile (discussed in more detail in Subchapter 4.2). [21] It was paraded in front of the North Korean public as early as 2007, and was also shown to foreign reporters in a major parade in Pyongyang in 2010, six years before its first official test (a visibly modified version). Although it now seems that Pyongyang has abandoned the system altogether after a series of mostly unsuccessful tests, and not least after the emergence of the more capable and successful "Hwasong-12" (cf. Subchapter 4.3), the Hwasong-10 was actually declared operational already after its first two tests, the first of which was a failure and the second a probable success.

In fact, Kim Jong-un was quoted by the official Korean Central News Agency (KCNA) that "we have the sure capability to attack in an overall and practical way the Americans in the Pacific operation theater." [22] In the years before Hwasong-12 entered the stage, various analysts assumed a range of different deployment numbers for the Hwasong-10. Perhaps it was actually mass-produced and deployed before completing its development and testing phase, but there is no basis for assuming that it ever represented a reliable delivery vehicle to threaten Guam with a nuclear payload, which was almost certainly its real *raison d'être*. Consequently, the Hwasong-10 was surely a key ingredient of the DPRK's declaratory posture in that period, but the military commanders did probably not see it as more than a potential emergency capability, at most.

While the Hwasong-10 was subject to significant attention mainly due to its potential to threaten major US naval and air force assets on Guam, there is a wide range of different ways to characterize nuclear weapons capabilities that are relevant in a doctrinal discussion. The most obvious is perhaps the sheer number of warheads or other nuclear explosive devices in the arsenal. Likewise is the number of delivery vehicles, such as airplanes or missiles, and the diversity of delivery vehicles. Further, these delivery vehicles may be more or less able to survive or avoid an enemy nuclear first strike. Specifically, that may entail either hardening (passive defense, such as underground missile silos) or various kinds of mobility and stealthiness. Command and control systems are also key to any nuclear weapon system, and especially relevant is whether launch command has been pre-delegated or decentralized, as we alluded to in Subchapter 3.1. We leave active defenses (first and foremost ballistic missile defense and traditional air defense) out of this discussion, as they do not directly couple to specific offensive capabilities in a nuclear posture.

Sub-sea mobility (*i.e.* submarines) is the ultimate form of mobility to avoid enemy counter-force attacks, at least as long as states respect the Outer Space Treaty of 1967. [23] Some states also have nuclear weapons on naval surface vessels, but these are easier to detect and track than submersed assets. Airborne assets at standoff distances are obviously difficult to detect, discriminate, and target, but do not enjoy the same endurance as submarines. On the ground, some states have deployed road-mobile and rail-mobile missiles throughout history, of which the former is less vulnerable than the latter. Keeping track of all mobile delivery vehicles is a daunting and resource-demanding task for enemy intelligence and surveillance assets.

Other features that are important with regard to survivability to first strikes include, *inter alia*, the visual signature (physical sizes, radar cross-sections, number of vehicles, *et cetera*), and in the case of pre-emptive first strikes, the response and launch preparation time. The visual signature is especially important for mobile launchers. A relevant example is the distinction between road-mobile missiles with solid and liquid propellants. While liquid propellant missiles certainly have some advantages (especially high energy density in advanced propellants), solid propellant missiles not only have significantly shorter launch preparation times, but also have a much more modest ground signature. The former is because liquid-propelled missiles most often are fueled at the launch site, since missiles rarely are able to withstand transportation in a fueled condition, and because the corrosiveness of the propellants prohibits pre-fueled missiles.

Solid-propellant missiles, on the other hand, have their fuel and oxidizer combination cast into the missile body under production. That potentially means saving from about an hour to several hours of preparation time compared to liquid-propellant missiles. Moreover, as a bonus, these launchers may travel without the same number of support vehicles that are required for their liquid-propellant cousins. That means they are harder to detect for an adversary surveying a suspected launch area for a possible pre-emptive strike, or even for early warning purposes. These advantages are the reason why the North Korean solid-fueled Pukguksong-2 represents such an important improvement from the Scud-derived, liquid-fueled, medium-range ballistic missiles already in service (including the various types of No-dongs), as we will see in Chapter 4, even though its range is not assessed to exceed that of the most advanced No-dongs.

Furthermore, flight time or sailing time may be a relevant parameter to consider in the context of response time, although in many cases the combatant parties rely on ballistic missiles with approximately the same flight time for the first round of nuclear exchanges. The Cuban missile crisis is an example that illustrates how the challenging of this situation may offset the strategic balance. Suddenly, the Soviet Union could target the US mainland with nuclear-tipped missiles with a significantly shorter warning time than for their ICBMs. This was a response to the US ability to target the Soviet Union by medium-range missiles deployed in Turkey and the UK. [24] Both sides backed away from the brink by agreeing to withdraw their land-based missiles with short flight times. A similar conflict arose during the so-called "Euromissile Crisis" 21 years later. [25] The threat to both NATO and Warsaw Pact countries of precise, intermediate-range ballistic (and later cruise) missiles with thermonuclear warheads, providing only a very few minutes warning before targeting major cities, eventually led to the Intermediate-Range Nuclear Forces Treaty (INF Treaty) in 1987. [26] This resulted in the complete elimination of land-based, medium- and intermediate-range ballistic and cruise missiles in the US and the Soviet Union, and a more stable mutual deterrence situation.

Having or not having nuclear capabilities that may weather out an enemy first strike makes a huge difference for nuclear planners. Having such capabilities allows for doctrines in which retaliation is a key part. There is, of course, another side to that line of reasoning. To have a credible first-strike capability, one should be able to target practically all enemy nuclear forces, as nuclear first strikes are about counter-force attacks, not counter-value attacks. One simply does not wipe out population centers before legitimate, military targets. Moreover, adopting a first-strike doctrine is hard to accept if there is a measurable likelihood of a nuclear retaliation by the adversary. Aiming for a credible first-strike capability thus often means increasing the total number of warheads and other nuclear explosives, as well as delivery vehicles, but it also means seeking qualitative improvements in the forces. These typically entail improved accuracy (it is harder to take out a military base than a large population area), more throw-weight per delivery vehicle (to allow heavier and/or more nuclear payloads, as well as decoys, pieces of radar reflecting materials – so-called "chaff," and other countermeasures to defeat active defenses), and not least the ability to deliver multiple payloads by a single vehicle.

Multiple, independently targetable re-entry vehicles (MIRVs) encompass several of these features. Most importantly, for a given total explosive yield delivered on a target area, several medium explosions impose more widespread damage than one large explosion. Typically, before the US and later the Soviet Union introduced MIRVs on their ballistic missiles, each missile would be fitted with a single warhead in the 1 – 20 megaton range. Nowadays, with US and Russian ICBMs and SLBMs carrying from three to ten MIRVs each, the yield per warhead is in the hundreds of kilotons range. Warheads are cheaper than long-range missiles, so MIRV technology represents an economical way of expanding a strategic arsenal, compared to unitary warhead missiles (all other factors taken to be equal). Significant advances in navigation technology made MIRV systems with less powerful warheads viable, by compensating for the reduced yield by striking closer to the target, and in the maneuverability of the so-called warhead bus. Carrying all the warheads, decoys and chaff, the bus is able to maneuver, adjust the trajectory, and deliver each warhead on different targets.

In addition to all the above-mentioned nuclear capability requirements, successfully adopting a first-strike posture requires an enormous and continuous intelligence and surveillance operation, to be able to keep sufficient track of the adversary's nuclear assets in real time. Combined, the price of beefing up all these capabilities probably grows exponentially with the scope of the nuclear force structure one seeks to target in a first strike. Moreover, putting an emphasis on first strikes, seeking to preempt a nuclear first strike by the counterpart, is not favorable to strategic stability, as we alluded to in Subchapter 3.1.

Previously in this chapter, as well as in the introduction, we discussed various extremes in the context of nuclear postures. On the one hand, we have "maximalist" postures that require large numbers of weapons of various kinds, and with specific qualities. These include massive first-strike doctrines, where one seeks the ability to take out the lion's share of the adversary's nuclear assets, hoping this will force an early surrender, as well as massive retaliation doctrines. Here, the ambition is to have as many survivable nuclear assets as are necessary to convince the counterpart that any first strike will fall short of preventing a nuclear retaliation, typically destroying all of the adversary's major population centers. Nuclear submarines with ICBM-range SLMBs, tipped with several thermonuclear warheads each, is the "gold standard" for achieving this capability. On the other hand, we have "minimalist" postures as the one of the UK, mentioned in the introduction. Here, the ambition is to have only a retaliatory force, sufficient to dissuade any potential aggressor by the threat of a counter-value attack killing millions, but no counter-force nuclear assets. This obviously requires a high degree of credibility in the forces.

However, for a state that has a long way to go to achieve either of these extremes, qualitatively and quantitatively, less-optimal alternatives such as the previously mentioned asymmetric escalation come into play. Furthermore, as the number of nuclear assets in a developing nuclear weapons state increase, it gets harder and harder for an advanced adversary to feel confident in its ability successfully to eliminate all the nuclear assets. Indeed, even less advanced systems that have survived an enemy counter-force, first strike, may deliver a devastating retaliatory strike on the aggressor. The prospect of this "residual retaliatory capability," dubbed "first-strike uncertainty" by strategist and missile scientist Wu Riqiang [27], and conceptually discussed earlier by, *inter alia,* Avery Goldstein [28], is relevant in the further deliberations. Here, a high number of units, various forms of mobility, and sometimes even obfuscation, compensate for a lack of assured second-strike capabilities.

The term "first-strike uncertainty" was coined in the context of China as an emerging nuclear power, facing the far more advanced rivals in the nuclear field, the Soviet Union and the US. The relevance of this term will be clearer in Chapter 4, as we will see that North Korea's nuclear force structure by 2018 is actually eerily reminiscent of the one of China around 1980. Back then, China had an arsenal that included possibly more than a hundred liquid-fueled "DF-2" and "DF-3" ballistic missiles with regional ranges, as well as probably a handful of

"DF-4" ballistic missiles capable of striking Moscow, and "DF-5" capable of striking even the US mainland. The former missiles could target US positions in North East Asia, as well as Russian positions east of Ural. Furthermore, like the DPRK in recent years, it pursued solid-fueled missiles ("JL-1") with medium ranges (cf. Table 4.1) to deploy first on its "Xia-class" ballistic missile submarine (commissioned in 1981), and then to adapt it to a land-based version ("DF-21"). [28] This is a striking resemblance to the DPRK's "Pukguksong-1" submarine-launched ballistic missile, and its land-based adaptation "Pukguksong-2," as we will revisit in Subchapter 4.4.

Both states lacked the ultimate platform for assured retaliation on intercontinental ranges; low-noise, nuclear-propelled submarines equipped with ballistic missiles of intercontinental ranges, as previously discussed. Additionally, both states sought to compensate for its vulnerability to nuclear first counter-force strikes by practicing cheaper tactics like opacity, ambiguity (some missiles may have either nuclear or non-nuclear warheads), road-mobility, and diversity and variability in basing options. Both enjoyed a comprehensive capability to attack regional targets with nuclear-tipped ballistic missiles, but a more dubious ability to project its nuclear powers on the US (and Russian heartlands). Second-strike capability (regional or intercontinental) was in no way a certainty, but something their main adversaries could not entirely rule out (*i.e.* first-strike uncertainty).

In Figure 3.1, we seek to illustrate some of the main differences between three extremes among nuclear postures, as discussed above. The arrows represent some of the development paths that one may pursue to move from one extreme to another, in terms of capabilities and capacities. We assess that Pyongyang's nuclear posture by 2018 belongs to the corner down to the right (asymmetric escalation, first-strike uncertainty).

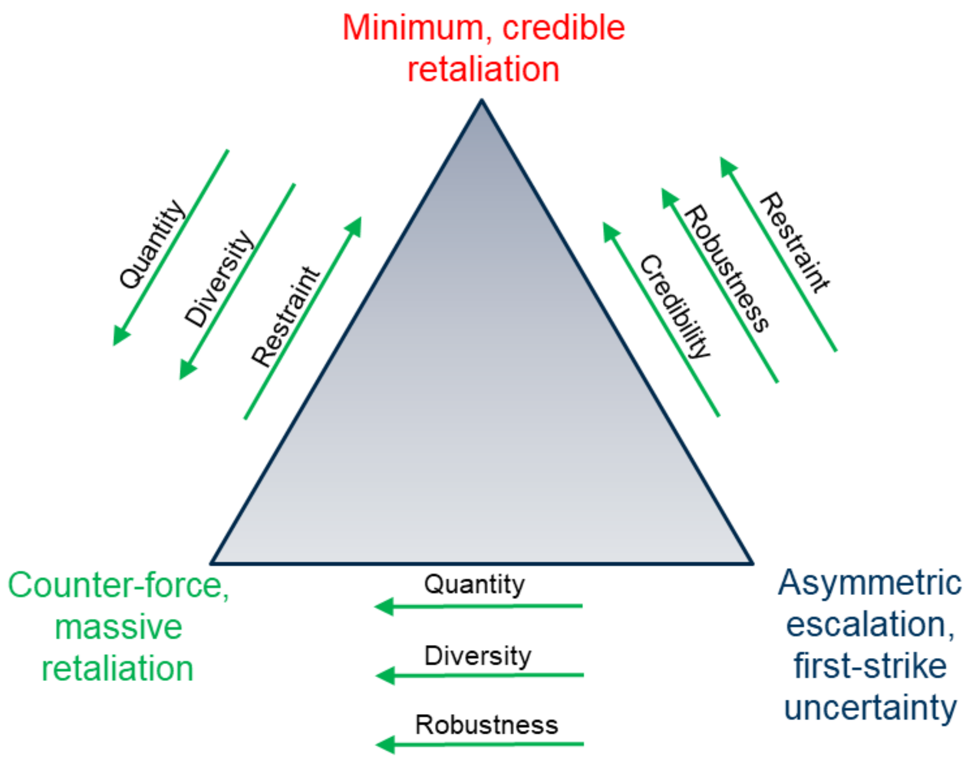


Figure 3.1 A conceptual illustration of some extreme types of nuclear postures, some capability development paths that relate them, and features that separate them.

4 Technical capabilities

North Korean nuclear assets strictly enhance existing non-nuclear deterrence; foremost by gun and rocket artillery with metropolitan Seoul and Incheon within range, ballistic and cruise missile with high-explosives payloads, suspected chemical munitions (underscored by the demonstrated capability of synthesizing the advanced nerve agent VX), and possibly a biological weapons program.

In discussing delivery vehicles and platforms for nuclear weapons in North Korea in this chapter, we will mainly give attention to ballistic missiles. The main reason is that ballistic missiles are commonly accepted as the most effective means of delivery of nuclear weapons in terms of range, speed, payload mass, and their ability to penetrate defenses. In addition, ballistic missiles always feature prominently in North Korean nuclear weapons propaganda. Nonetheless, there is reason to keep track of Pyongyang's development of cruise missiles as well, as these may provide some unique capabilities in the future nuclear force structure, especially with regard to target precision and the ability to strike moving targets (*i.e.* naval vessels). By late 2018, there is no indication that Pyongyang has deployed, or even developed, nuclear-tipped cruise missiles.

Table 4.1 shows the most common way of categorizing ground-based ballistic missiles by their ranges, as will be used in this report. In addition, we will use the abbreviation SLBM for "Submarine-Launched Ballistic Missiles." The B Appendix includes a list of key North Korean ballistic missiles in a nuclear weapons context.

Table 4.1 A common categorization of surface-to-surface ballistic missiles (BM) by their maximum ranges. [29]

Name	**Abbreviation**	**Range (km)**
Short-Range BM	SRBM	< 1000
Medium-Range BM	MRBM	1000 – 3000
Intermediate-Range BM	IRBM	3000 – 5500
Intercontinental BM	ICBM	> 5500

Less relevant than missiles are North Korea's combat aircraft, as these are highly vulnerable to the advanced air defenses and interceptor aircraft of Pyongyang's main adversaries, Japan, South Korea, and the US. There is little to suggest that this situation is about to change. North Korea's most advanced operational fighter aircraft are MiG-29s, of which around 35 are believed to be in service by 2018. These fourth generation multirole fighters of Soviet origin stand little chance against the US' fifth generation fighter jets F-22 and F-35 (also fielded by Japan [30]) in an intercept situation, let alone against advanced, ground-launched air defense systems. Pyongyang's bomber fleet of around 50 operational medium bombers Il-28 (cf. Figure 4.1) is even more outdated than its fighters are. The Il-28 had its maiden flight in the Soviet Union as far back as in 1948, and was retired by the Soviets already in the 1980s. [31] With a ballistic missile force the size, diversity, and maturity as the one of North Korea, it is simply difficult to justify why one would risk spending scarce fissile materials on much less capable nuclear gravity bombs for technologically inferior aircraft instead of warheads for ballistic missiles. Pyongyang likely has more than ten ballistic missiles available for each nuclear explosive device in the stockpile.

Figure 4.1 An Il-28 bomber (also called Harbin H-5) in a Chinese aircraft museum in 2008. (Photo: Allen Watkin, available at Wikimedia Commons.)

4.1 Nuclear weapons design

The principles of nuclear weapons design are well documented in open sources, even advanced, thermonuclear devices to some degree. States with an interest in nuclear weapons do no longer have to trial and err along paths that mature nuclear weapons states have long completed or abandoned. Nonetheless, the more compact and advanced a nuclear device, the more detailed engineering one needs to work out through calculations and testing before a working design is accomplished. The computer revolution, assisted by the general dissipation of credible nuclear weapons information, has significantly facilitated the theoretical part of such development. A prominent example of the latter is the meticulous efforts of the late Chuck Hansen, the author of a CD-ROM documentary compilation called *Swords of Armageddon: U.S. Nuclear Weapons Development since 1945* [32], the research for which led to the declassification of vast amounts of previously highly classified nuclear weapons information. (His efforts are described, *inter alia*, in a New York Times article [33]). Another significant and often-cited source of nuclear weapons information is Carey Sublette's *Nuclear Weapons Frequently Asked Questions*. [34] Adding to this picture is the wide proliferation of advanced manufacturing techniques. Even thirty years old computer-aided manufacturing equipment is often more than apt for the task of producing high precision, low-tolerance weapons parts. Specifications and requirements in the export control guidelines for nuclear dual-use goods of the Nuclear Suppliers Group reflect this assessment. [35] It simply gets easier and easier for a nation state to design and manufacture nuclear weapons as time passes, as knowledge and technology inevitably disperse. Figure 4.2 illustrates this point. It shows detailed schematics of the nuclear bomb dropped on Nagasaki in 1945. Such information was top secret in 1945, but is readily available today.

An important factor that experts and commentators often understate, or simply omit, in discussions about the sophistication of North Korean nuclear weapons, is the now common assessment that Pyongyang supposedly performed 70 – 80 so-called "hydrodynamic tests," allegedly between 1983 and 1993. [36, 37] This assessment is based on analyses of satellite imagery by several states. In such tests, one tests the implosion mechanism of a nuclear weapon design with high explosive lenses, but with inert (although mechanically similar) materials such as tungsten or depleted uranium instead of plutonium or weapons-grade uranium. Flash x-ray imaging and other techniques then provide diagnostics, which enable an evaluation of the viability of the design. Short of a full nuclear test, tests like these are key in the development of a working nuclear weapons design. Importantly, experience and know-how of that kind may have provided Pyongyang's bomb makers with the confidence to skip a few steps in their nuclear weapons design and development ladder.

The DPRK's six recognized underground nuclear tests by late 2018 (not taking into account suspicions of an additional, undeclared, and possibly partial, nuclear test in 2010, as some have suggested [38]) have demonstrated its ability to achieve explosive yields in the range of one to the order of a hundred kilotons of TNT equivalent, often denoted simply "kt." Figure 4.3 presents the seismic signals (so-called waveforms), estimated magnitudes, and nuclear yields according to the Norwegian seismic monitoring institute NORSAR. What these tests have not demonstrated, however, are the sizes and weights of the test devices. As to this issue, we are left to reason and to compare with other historical cases. Instead of starting with crude devices that were more or less guaranteed to provide yields in the ten kilotons range, but would only be deliverable by heavy bombers, North Korean nuclear weaponeers have more likely cut passed the first evolutionary steps, and tried out a design that could fit onto its most potent ballistic missiles available at that time. In 2006, by the time of the first nuclear test, the "No-dong" missile (see Subchapter 4.2) was the prime candidate for carrying a nuclear payload.

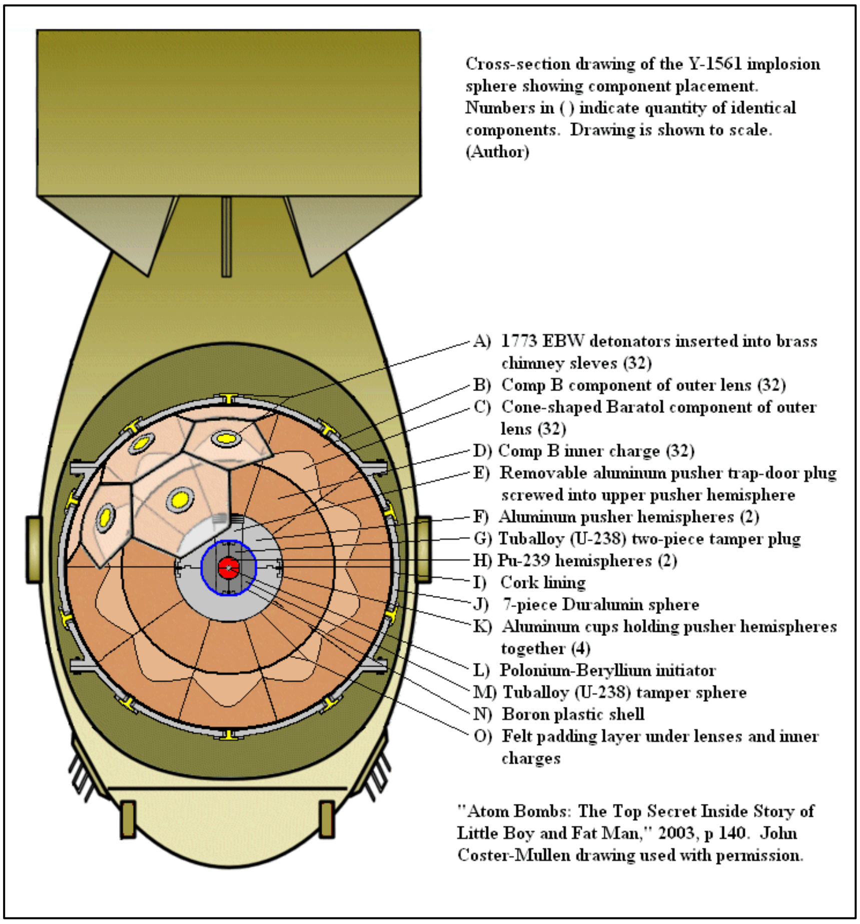


Figure 4.2 Schematics of the first nuclear implosion bomb used in warfare, Fat Man, *dropped over Nagasaki 9 August 1945. Based on descriptions in the book "Atom Bombs: The Top Secret Inside Story of Little Boy and Fat Man" by John Coster-Mullen (2003). (Image: Wikimedia Commons.)*

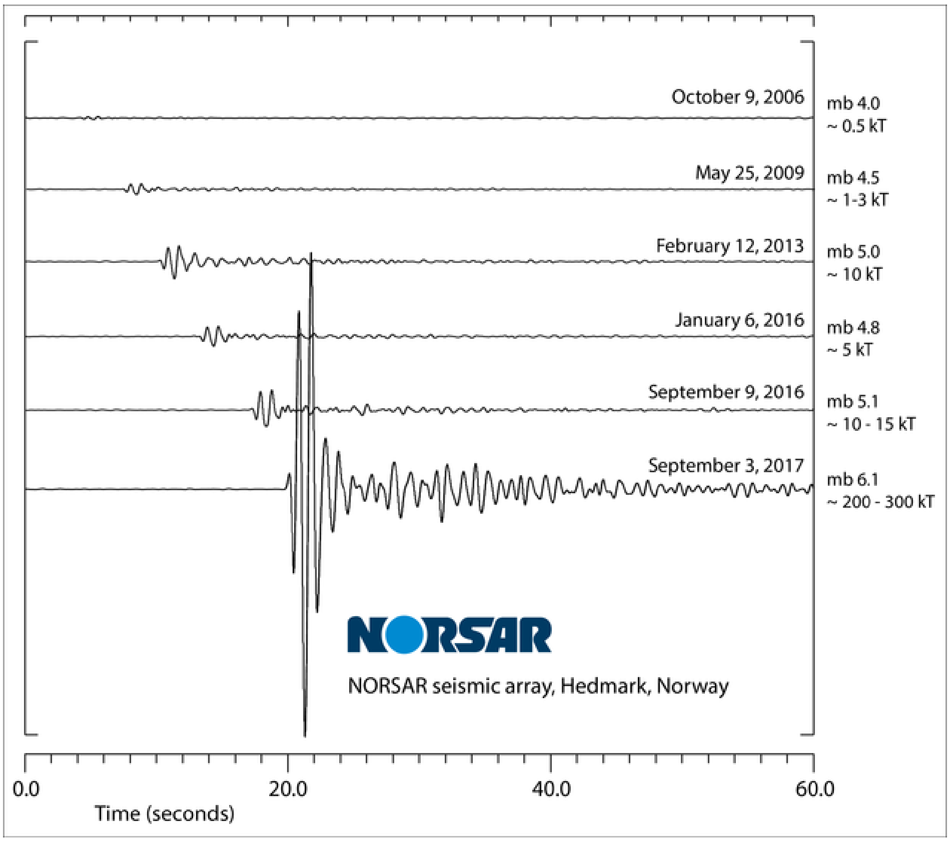


Figure 4.3 NORSAR's waveforms and estimates of magnitudes and yields of North Korea's six nuclear tests. [39]

At least six factors lend weight to the hypothesis that the first North Korean nuclear test in 2006 was in fact a quite compact and marginal design, rather than an "overengineered" design with large physical margins, such as Fat Man. One is that Pyongyang reportedly notified Beijing ahead of the first nuclear test in 2006, that it planned to set off a device with approximately 4 kt yield. [40] Considering that some of the leading specialists in nuclear test monitoring have estimated the yield of the next test, in 2009, to 4.6 kt (and most others have estimates in the same range) [41], it is likely that the latter was a more successful test of the same basic design as in 2006 (with only necessary modifications to make it work properly). It is a far more complicated task to aim for and achieve about 4 kt in a first nuclear test, than to achieve the more common 10 – 20 kt. The former requires much more precise manufacturing, and yields a higher likelihood of a "fizzle"[3] than less marginal designs do. If 4 kt was actually the target yield of the two first tests, the first test was really only a partial failure (depending on your exact success criteria), and the second test a probable success. After the second test in 2009, Pyongyang may very well have had to their disposition a pure fission plutonium implosion

[3] A nuclear detonation with an explosive yield substantially below the nominal yield.

design, compact enough to fit inside their medium-range (and possible some short-range) ballistic missiles.

Secondly, as part of Pyongyang's 2008 declaration of its stock of plutonium in the context of the Six-Party Talks, media reported that Pyongyang claimed to have used as little as 2 kg of plutonium in the 2006 test. [42] While one should hesitate to take this claim at face value, it is not implausible that it actually was an attempt at a compact, marginal device, as described above. Years of high explosives tests may have provided the necessary confidence to try this. Achieving a 4 kt yield from a 2 kg plutonium implosion device requires some skills in weapons design, but is certainly feasible. For reference, in a renowned report by Thomas B. Cochran and Christopher E. Paine (Natural Resources Defense Council) on the amounts of plutonium and highly enriched uranium (HEU) needed for pure fission weapons, they stipulate various expected yields for given masses of fissile materials. [43] According to their assessments, 4 kt is the actual expected yield from a pure fission implosion weapon of medium sophistication (or technical capability, as they term it), as illustrated in Figure 4.4. They based their assessment on official information about US nuclear weapons. Furthermore, the Soviet Union in 1953 supposedly tested a device called the RDS-5 with only 2 kg of plutonium, and achieved a yield of about 5.8 kt. [44] This test was only their sixth.

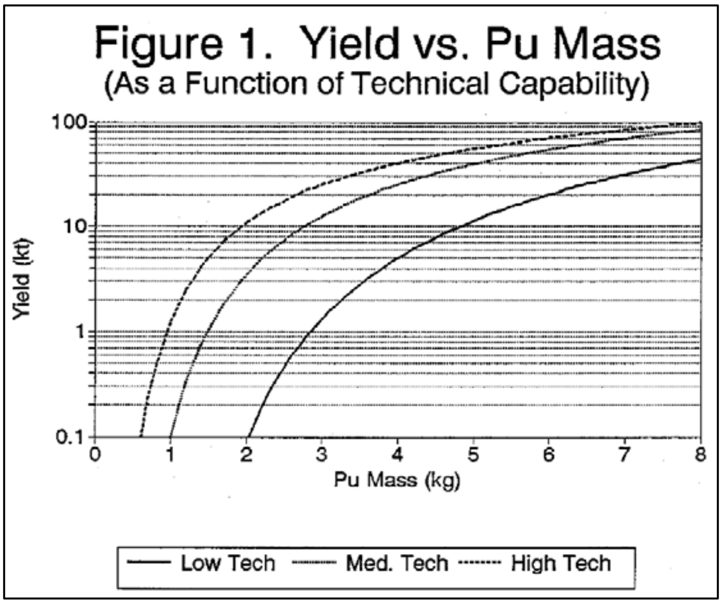


Figure 4.4 Estimated correlation between plutonium mass and explosive yield of a pure fission weapon for three degrees of technical sophistication, according to Cochran and Paine. [43]

For completeness, we note that the alleged North Korean statement about using 2 kg of plutonium in the 2006 nuclear test in itself does not exclude the possibility of a hybrid fissile material pit, with 2 kg plutonium in combination with a few kilograms of HEU. However, there is little credible information to suggest that HEU in kilogram amounts was available for the North Korean nuclear weapons program as early as 2006. Although foreign intelligence services knew about the North Korean uranium enrichment efforts since the 1990s (through the investigation of the A.Q. Khan nuclear supply network [45]), there were no reliable, open-source accounts of existing enrichment facilities until 2010. In November that year, Pyongyang revealed an ostensibly modern and operational gas centrifuge plant established in the old uranium-fuel fabrication plant in Yongbyon to a US delegation led by former director of the Los Alamos National Laboratory, Siegfried Hecker. [46] Most analysts assess that the Yongbyon enrichment facility is likely not the first of its kind in North Korea, mostly due to the short construction time and apparently successful operation on an industrial scale. In fact, the US intelligence community has recently opened up about their conviction of a second such facility near Pyongyang, which allegedly predates the one in Yongbyon. [47] The precise construction timeline is unclear, but satellite imagery does not rule out a production start of HEU in time for the 2013 nuclear test. Pyongyang, however, provided no hints or claims of the use of HEU (solely or in combination with plutonium) until after the fifth nuclear test on 9 September 2016. The KCNA stated:

> "The standardization of the nuclear warhead will enable the D.P.R.K. to produce at will and as many as it wants a variety of smaller, lighter and diversified nuclear warheads of higher strike power with a firm hold on the technology for producing and using various fissile materials. This has definitely put on a higher level the D.P.R.K.'s technology of mounting nuclear warheads on ballistic rockets." [48]

The third factor supporting the hypothesis of a compact device in 2006, as well as the North Korean claim of using only 2 kg of plutonium in that test, is the scarceness of plutonium at the time, and the modest production capacity for more plutonium. By June 2006, the much-cited Institute for Science and International Security (ISIS) in Washington, D.C., estimated that North Korea had separated between 20 and 53 kg of weapons-useable plutonium, sufficient for about 4 to 13 nuclear weapons (depending mostly on weapons design and process losses and recovery). [49] In addition, the annual plutonium production rate was, and still is, less than impressive for a nuclear-weapons program. Typically, the plutonium-producing Reactor Two in Yongbyon produces between 10 and 15 kg of high quality plutonium during a campaign of about one and a half to two years. Cooling time of a few months after reactor shutdown, and a few weeks of reprocessing, adds to the time before fresh plutonium is available for weaponization. This is an obvious incentive not to squander any plutonium in a weapons design that perhaps would not even fit inside the missile RVs at hand.

That leads us to the fourth factor, which is their needs. While the US designed the Fat Man bomb (which was dropped on Nagasaki in 1945) to be deliverable by their heaviest bomber at the time, the B-29, Pyongyang very likely put their faith in the No-dong medium-range ballistic missile (cf. Subchapter 4.2) for their first batch of nuclear weapons. This put some real, but far from insurmountable, constraints on the mass and especially dimensions of the device they sought to develop. It would be a hard sell for the nuclear weapons engineers to settle for a less compact device for the first test, simply for the sake of proving that they could set off a nuclear explosion.

In fact, and as a fifth factor supporting the hypothesis, there is good reason to suspect that North Korean nuclear weapons designers, since its dealings with A.Q. Khan in the 1990s, had available at least two implosion designs provided by the supply network. While these were allegedly based on HEU, especially the most advanced one likely contained design features which would enable compactification of a plutonium device as well. The first design was found in Libya in 2003, and was a Chinese design from the 1960s. The second design, found on a computer in Switzerland in 2008, was developed by Pakistan, and allegedly tested in their 1998 test series. Significantly, this design was said to be compatible with ballistic missiles derived from the North Korean No-dong, namely the Ghauri in Pakistan and the Shahab-3 in Iran (and their many variants). [50, 51]

The sixth factor is Pyongyang's sensitivity to international reactions. The Cold War superpowers in the 1950s and early 1960s had quite different political circumstances than what has been the case for states that have tested nuclear weapons since the end of the Cold War. France received many negative reactions after their (so far) final nuclear test campaign in the South-Pacific in 1995. The UN Security Council subjected India and Pakistan to a sanctions resolution following their nuclear tests in 1998. [52] Even an isolated state such as North Korea is not entirely indifferent and immune to outside reactions, especially from its main benefactor, China. Indeed, China has been seen to implement UNSC sanctions on North Korea more eagerly in the wake of nuclear tests by the latter [53]. This amounts to an incentive to perform only a strictly necessary number of nuclear tests.

Why do we elaborate so thoroughly on the two first devices North Korea tested? The main reason is that more advanced weapons designs rely entirely on techniques necessary to enable compact, pure fission designs (especially the principle of levitated and hollow pits). Thus, the assessments of all later tests are dependent on what we think about the first two devices. Further, there is no doubt that stage-separated thermonuclear weapons have been a key development goal for Pyongyang to be able to hold US population centers at risk. The explosive yield of their sixth underground test on 3 September 2017 was on the order of 200 kt by most estimates, which is about ten times that of Fat Man. That is, is fact, entirely consistent with a successful, two-stage thermonuclear device, even one of a rather compact size and shape corresponding to the model shown to Kim Jong-un days before the test (cf. Figure 4.5). Noting that it is possible to exceed such an explosive yield with a pure fission weapon (the most powerful to date being the US "Ivy King" shot of 500 kt in 1952 [54]), it would have been a wasted opportunity to spend a politically costly nuclear test on a very large fission device. It would have meant consuming precious fissile materials, but not advancing the program towards deliverable weapons in the hundreds of kilotons range.

Figure 4.5 *Top: Kim Jong-un inspects a model of a North Korean, two-stage thermonuclear device in front of an RV heat shield. The safing, arming, fuzing, and firing (SAFF) unit is in the foreground. A Hwasong-14 shroud is in the background. (Photo: Reuters.)*
Bottom: Renders of a possible integration of the model thermonuclear warhead into an RV of dimensions as the one in the upper image (left), and then in the Hwasong-15 (cf. Subchapter 4.3) payload chamber (right). (Developed by Thegius Ltd. based on press imagery.)

A more likely alternative assessment of the sixth test device is that it was a so-called *boosted fission device*. Boosting a nuclear weapon means increasing the efficiency of the fission chain reaction by inserting a few grams of deuterium (D) and tritium (T) gas into the device. The intense pressure and density generated by the fission chain reaction then makes D and T fuse. The direct energy contribution from this fusion process is small, but leads to enormous amounts of very fast neutrons, which then induce fission in much of what is then left of the fissile material. Boosting is a standard technique in all modern nuclear weapons, and is key not just to increasing the yield of a weapon of a given size, but more importantly to reduce the size of a fission primary of a staged thermonuclear weapon. One may boost a weapon of nominal yield in the sub-kiloton range to several kilotons, sufficient to create the necessary physical conditions for fusion in the second stage of a thermonuclear device. At the same time, a compact, boosted fission device is of significant operational value in itself, as it enables modest-sized missiles to deliver nuclear warheads with yields in the tens of kilotons range. [32, 34]

In Yongbyon, North Korea has two nuclear reactors in which tritium may by produced by neutron irradiation of lithium-6 targets. Furthermore, geospacial imagery suggests they have established the proper laboratory facilities to extract tritium from lithium-6 targets there as well. [55, 56] North Korean academic publications and procurement data support the assessment that Pyongyang produces lithium-6 indigenously for tritium production. [57, 58] Perhaps in an attempt to drive the point home, a North Korean diplomat with their embassy in Beijing in 2017 advertised online an offer to sell 10 kg of lithium-6 every month. The veracity of the offer is hard to confirm, but the message was clear: North Korea was signaling a surplus capacity in separating lithium-6. [59]

If the sixth test were in fact of a boosted fission device, it would probably have been a more bulky design, less suited to be mated with the existing missiles. Thus, we assess that it is most likely that the sixth test was in fact a true, two-stage thermonuclear device with a small, boosted fission primary. Further, it is then likely that at least one of the tests between the first two (2006 and 2009) and the sixth (2017) was of a compact, boosted fission device. After test number four (6 January 2016), estimated to a few kilotons (probably less than 10 kt), the North Korean state television broadcaster claimed it had successfully tested its first “hydrogen bomb.” While most experts reserve the term “hydrogen bomb/weapon” and “thermonuclear bomb/weapon” to weapons that have most (or at least a very significant part) of their explosive yield coming from fusion, it is possible to argue that boosted fission weapons deserve the same label, because of the fusion mechanism involved (although the direct energy contribution from fusion is almost negligible). If the January 2016 device was in fact designed with the purpose of serving as a boosted fission primary of a true thermonuclear device (for instance the one tested in September the next year), the test may have been a complete success, as such as yield would be expected from a device like that.

It is perhaps less clear what to make of the third and fifth nuclear tests, yielding approximately 10 kt in January 2013 and a bit more (10 – 15 kt, according to NORSAR) in September 2016. From a perspective of the explosive yields, both tests could have been boosted fission devices of a somewhat larger size than the device tested in January 2016 (if that was in fact a boosted device). However, given the proclamation of the first hydrogen bomb after the latter test, it is at least not very likely the case for the 2013 test (the third one in the series). The September 2016 test, however, could well have been such a device. According to official North Korean statements following the test, its significance was not primarily the higher explosive yield, but that it was in fact a compact device:

> *(the warhead tested was) "standardized to be able to be mounted on strategic ballistic rockets"*
> *(…)*
> *"The standardization of the nuclear warhead will enable the DPRK to produce at will and as many as it wants a variety of smaller, lighter and diversified nuclear warheads of higher strike power." [60]*

Similar words were used in connection with Kim Jong-un visiting a missile factory in March the same year, where the North Korean leader was photographed posing with an alleged (and in that case a mock-up) compact nuclear implosion device, allegedly small enough to be mounted on an ICBM (cf. Figure 4.6). Certain features of the displayed model device may be indicative of a mechanism to insert D-T gas, in that case making it a boosted fission device. It seemed small enough to be mated with the ICBM development prototypes shown to the world by that time, as well as the ones that were paraded and tested in 2017 (cf. Subchapter 4.3). While the exact diameter is not established in open sources, it may even be small enough to fit inside the re-entry vehicle (RV) of a No-dong missile (meaning its diameter is not exceeding approximately 60 cm). Note that the official claim focused on it being possible to mate with an ICBM, not shorter-range missiles. [61] Furthermore, Kim Jong-un was cited by Rodong Sinmun as describing the device as:

> "Korean-style structure of mixed charge … adequate for prompt thermonuclear reaction." [61]

"Mixed charge" probably meant a mixture of both HEU and plutonium. "Adequate for prompt thermonuclear reaction" may either mean that it was viable as a fission primary in a staged thermonuclear weapon, or, more likely given the other indicators, that it employed D-T boosting. The two interpretations are not mutually exclusive, however, as a fission primary would be a boosted one. Thus, we cannot rule out that the device shown in March 2016 was actually a model of the primary stage in the device tested in September 2017, although it is not clear from the released imagery of the two model devices that the former would fit inside the largest bulge seen in Figure 4.5.

Figure 4.6 Kim Jong-un with a model nuclear implosion device during a visit at a missile facility 9 March 2016. A development prototype of one version of the so-called KN-08 ICBM is in the background. (Photo: Reuters.)

To sum up this discussion, we assess that North Korea likely master the art of producing pure fission implosion devices, boosted fission devices, and even stage-separated thermonuclear devices with boosted fission primaries. Although neither of these are probably as compact as the most developed designs in the advanced nuclear weapons states, there is reason to assess that the two former kinds are deliverable by Pyongyang's medium-range, intermediate-range, and intercontinental ballistic missiles, discussed in the next subchapters. The most compact of these may also be deliverable by missiles with less throw-weight and smaller diameter payload chambers, such as the short-range Scud variants ("Hwasong-5" and "Hwasong-6" in North Korean designations, cf. Subchapter 4.2). Furthermore, we assess that North Korea might actually have succeeded in constructing a thermonuclear device similar in size and shape to the display model shown in Figure 4.5. Such a modest-size thermonuclear design is no doubt deliverable by North Korea's two tested ICBMs, the Hwasong-14 and Hwasong-15 (as illustrated in Figure 4.5), and possibly by the intermediate-range "Hwasong-12." To conclude on these assessments, detailed engineering studies outside the scope of this project are necessary.

What is less than proven, however, is whether North Korean warheads based on these designs include the fuzing technology needed to set off the payload at the optimal altitude for maximum mechanical ground damage. In addition, and equally important, are lingering questions on whether they are equipped to survive atmospheric re-entry. Concerning the first question, we note that Pyongyang has already succeeded in launching micro satellites into low earth orbit, and enjoys experience from a myriad of ballistic missile tests since the 1980s. These advances require proper sensor technology to perform successful stage separation and entry into orbit, including functional altimeters and inertial navigation systems (INS). Radar altimeters, augmented by position, velocity, and acceleration data from the INS, is the most prolific fuzing technology for nuclear RVs.

The US actually employed radar altimeters to ensure successful airbursts already in their nuclear attacks on Japan in 1945, albeit with gravity bombs, not with much faster missile RVs. Furthermore, North Korea has a comprehensive, albeit in many areas outdated, munitions industry. Proximity fuzes, developed already in World War II, are key in modern artillery shells and anti-aircraft shells. Doppler radars have traditionally served as a distance sensor in such fuzes. Taken together, it is unlikely that fuzing technology necessary to ensure an airburst a few hundred meters to more than a kilometer above ground (optimal for a nuclear-equipped RV) remains a bottleneck in an otherwise quite advanced nuclear weapons program. The second question alluded to in the start of this paragraph regards whether the nuclear-armed RVs are able to survive the thermal and mechanical loads associated with atmospheric re-entry. This deserves a more comprehensive, technical assessment than what there is room for here, but we will point out some relevant aspects in the following subchapters.

4.2 Regional first-strike capabilities

North Korea established the ability to mass-produce, export, and operate Soviet-origin Scud ballistic missiles of various types during the 1980s. These are well-proven weapons with an actual operating history in, *inter alia*, the Iran – Iraq war in the years 1980 – 1988, and are found in many countries. Most of North Korea's arsenal of different types of Scud missiles have ranges to reach all of South Korea, and some have the ability to threaten parts of Japan. Scuds in the Soviet Union had the option of either conventional, chemical, or nuclear warheads. [62] However, the available space and throw-weight put serious constraints on any nuclear payload, meaning it would require a quite compact warhead. For comparison, a standard Scud missile has a diameter of only 0.88 m, while No-dong missiles have diameters of approximately 1.2 – 1.3 m. That is probably the main reason analysts rarely mention the numerous North Korean Scud missiles as likely delivery vehicles for nuclear warheads. Another reason is the timing: By the time the outside world assessed that Pyongyang could conceivably have manufactured its first nuclear device (in the case of the CIA; in late 1993 [63]), they had already started testing the Scud missile's bigger cousin, the so-called No-dong. Later, Pyongyang likely has possessed more No-dongs (and bigger missiles) than nuclear warheads at any point in time.

Scud is a NATO designation for what Russians call the "R-11" (Scud-A) and the "R-17" (Scud-B), and the North Korean call "Hwasong-5" and "Hwasong-6" (Scud-B and Scud-C, respectively). A North Korean specialty is the extended range Scud, the "Scud-ER" (also known as ER-Scud and Scud-D[4]). Hwasong-5, Hwasong-6, and Scud-ER have estimated ranges of 300 km, 500 km, and 700 – 1000 km with typical payload masses. Hwasong means

[4] There are claims that the North Korean designation is "Hwasong-9," but this is not entirely clear.

planet Mars. In contrast, the Americans named No-dong simply from where it was first observed in satellite imagery, in a place called No-dong ("Dong village"). The North Koreans call it the "Hwasong-7." The many versions of the No-dong can all carry a heavier payload than the smaller Scuds to ranges from 900 km to allegedly 1300 km or more (depending on what one would still consider a No-dong). Most of Japan is thus within the range of all types of No-dongs. [64, 65]

For completion, we mention a solid-fueled SRBM called "KN-02 Toksa" in US designation, and "Hwasong-11" in North Korean designation. It has an assumed range of 120 – 220 km (the latter assuming reports of an extended range version are true), and it is commonly believed to be the most precise of North Korean ballistic missiles with quite advanced guidance systems. [66] The payload mass of its Soviet origin, however, is only 482 kg, compared to a nominal one ton for the standard Scud-B (thus also the Hwasong-5). [67] The limited range and payload mass make this missile potentially useable for tactical (counter-force) missions, but with a more compact warhead than what its larger, liquid-fueled cousins can carry. Few analysts assess that North Korea has deployed nuclear warheads to this missile. The abundance of longer-range missiles with heavier payloads is key to that assessment. This may change with a growing warhead stockpile and the potential availability of even more compact and low-yield nuclear warheads in the future.

Missile flight tests are observable by other states' remote sensors (especially radars). That means we can extract quite reliable information on flight paths, and thus potential range. It is much harder to estimate a missile's precision, as we rarely know precisely where they were aimed in a test. Additionally, it would take a significant number of flight tests with known targets to provide a statistically sound estimate. Oftentimes these estimates are instead based on a missile's known origins, such as for all the various well-known Scud derivatives. In such cases, we may know both the statistically derived precision measure, as well as the navigation technology employed (most often based on inertial navigation sensors, *i.e.* accelerometers and gyroscopes of various qualities). First order estimates of the precision of for instance North Korea's Hwasong-5 and Hwasong-6, then, are that they have a so-called *circular error probable* (CEP) of a few hundred meters. Likewise, the basic No-dong is often estimated as having a CEP of as much as a couple of kilometers. [68-70] A CEP is an error circle within which 50 percent of the shots are expected to hit (although an ellipse is a more realistic representation of the true error measure). A CEP measure is given by its radius. CEP estimates of North Korean missiles vary significantly among different sources, however. In addition, there is reason to assume that some of the missiles of the various kinds are equipped with a more advanced INS than the basic kinds are. Nonetheless, North Korea's Scud derivatives, and various No-dong variants, are not precision strike weapons. These are weapons best suited to strike major population centers, not for instance advancing enemy forces or even fixed military bases, unless they are equipped with a nuclear payload. We will revisit the latter point shortly.

While we may characterize the abovementioned missiles as 1960s vintage technology, they are indeed well proven through a high number of flight tests since the 1980s (the North Korean ones). As for the key issue of payload survival during re-entry, consider this as resolved for the true Scud derivatives, as several countries actually put into service their Soviet cousins. The No-dong, with the longer range, suffers from somewhat larger thermal and mechanical loads during flight and re-entry. However, given the combined development and testing effort in North Korea, and including the No-dong-based missiles Ghauri and Shahab-3 in Pakistan and Iran, respectively, we find no reason to doubt Pyongyang's ability to ensure re-entry survival for these kinds of missiles as well. The technological challenges of developing a proper heat shield, and to secure the payload from destructive mechanical resonances, are not comparable to other, more demanding obstacles North Korea has surmounted with their nuclear, missile, and space programs.

This is, however, less obvious for their longer-range missiles, alluded to in Subchapter 4.3. This is mainly because the heating rate of the RV during re-entry is proportional to the re-entry velocity of the RV to the third power (and linearly proportional with the local air density), and that the atmospheric drag forces are proportional to the re-entry velocity to the second power. [71] Peak re-entry velocities of ballistic missiles on standard (minimum energy) trajectories increase monotonously (but not linearly) from typically just under three kilometers per second for 1000 km range missiles to more than seven kilometers per second for 10 000 km range missiles. [72] It is thus obvious that the thermal and mechanical loads on an ICBM during re-entry are about an order of magnitude more severe than for a short- or medium-range ballistic missile. Indeed, a 1000 km range ballistic missile on a standard trajectory will suffer a maximum deceleration of around 16 G (somewhat dependent on the shape of the nose or RV), while one with 5000 – 10 000 km range will experience a devastating 50 – 60 G peak deceleration.[5] [73] That corresponds to the deceleration a person with a seat belt on would experience during a car crash in a wall with a speed of approximately 55 km/h, only sustained for seconds, not milliseconds.

All of North Korea's land-based ballistic missiles are transported and launched from road-mobile launchers, almost exclusively of the self-propelled type called *transporter erector launchers* (TELs) with the launcher integrated on the transport vehicle itself (in contrast to towed launchers, so-called *mobile erector launchers*, MELs). It is demanding to estimate with any degree of certainty the number of missiles and launchers in North Korea based on open sources only. That is partly because these are mobile assets, not fixed facilities. Consequently, various sources claim very different numbers. Most sources estimate the number of Hwasong-5 and Hwasong-6 missiles in the high hundreds, while at least one quite authoritative source holds the number of TELs for these missiles to be fewer than one hundred by 2017. [65] The same source estimates the number of TELs for No-dong missiles (which are somewhat larger than the Hwasong-5 and Hwasong-6 TELs) to also be fewer than one hundred. Sources put the number of actual missiles in the low hundreds already more than a decade ago (per 2018). [70]

The Hwasong-5, Hwasong-6, and No-dong ballistic missiles are scattered around in the country, hidden in tunnels, ready to roll out to designated launch sites accompanied by an entourage of, *inter alia*, a command and control unit, force protection units, and propellant tank trucks. [74]

[5] Because the angle-of-attack becomes flatter as the range approaches Earth's radius, the deceleration converges at below 60 G.

The whole process from arrival at the launch site probably takes at least one hour for the Scud derivatives, and possibly a little longer for the No-dong variants (due to larger volumes of propellants). [62] The significant visual ground signature, combined with the rather long preparation time, means that these kinds of ballistic missiles are vulnerable to preemptive strikes at the launch site. Such strikes would most likely be performed by air or ship launched cruise missiles. However, the sheer number of missiles allows North Korea to stage a coordinated, simultaneous massive salvo across the many bases, making it extremely resource demanding to preempt completely. The high number of missiles is also key in defeating ballistic missiles defenses in Japan and South Korea by simple saturation, as these all have a more limited number of interceptors by 2018 (including the US THAAD regional ballistic missile and air defense system based in South Korea, with 48 interceptors available for six launchers [75]). Nonetheless, the preemption vulnerability of liquid-fueled ballistic missiles is less than optimal, and provides an incentive for Pyongyang to develop and master more robust systems, more or less immune to preemption. These include solid-fueled ballistic missiles, both road-mobile as well as submarine-launched ones, as we will revisit in Subchapter 4.4 in the context of capabilities with second-strike qualities.

A relevant question for any military planners considering a disarming first strike (conventional or nuclear) on Pyongyang's regionally ranged, liquid-fueled ballistic missiles, is whether one can be fairly sure to be able to take out all the launchers and/or missiles, or the ability to mobilize these. In practical terms, for all launchers and missiles that are in their tunnels, the attacker needs to know all the entrances and destroy these as well as any launchers and missiles outside. Although these missiles are far from representing an ensured second-strike capability, their large numbers increase the likelihood that at least a few will survive a surprising first strike, and then being available for retaliation against population centers in the region. That would require TELs and other key support vehicles and equipment also to survive in sufficient numbers. In that sense, and again due to their multiplicity, even these missiles have the potential to provide some degree of regional second-strike capability, although not an assured one. Another way of putting it would be that the adversary would have a hard time ascertaining their complete elimination in the battle damage assessment following an air campaign.

How effective would these missiles be against targets in Japan and South Korea, however? Counter-value targets, *i.e.* major population areas such as Tokyo and Seoul, are on the order of 10 km wide, whereas typical counter-force targets, such as military airports and naval bases, are on the order of 1 km wide. Pyongyang may choose to target for instance the Kadena Air Base on Okinawa, where the US stations, among other assets, its most advanced fighter jet, the F-35. Situated approximately 1300 km from North Korea, it is likely within range of the most advanced No-dong missiles (as well as longer-range missiles discussed in the next subchapter). According to an online tool for estimating effects of nuclear weapon strikes, the so-called "Nukemap" by Alex Wellerstein, a 10 – 20 kilotons airburst will result in a blast radius of approximately 1.5 – 1.9 km, where most residential buildings (but not necessarily all hardened aircraft shelters) will collapse. [76] The base is about 2.5 km wide. Given the assumed precision of the No-dong (CEP in the 2 km range), and taking into account a certain failure rate not related to the precision, two shots with 10 – 20 kilotons of yield would provide high confidence of rendering the airfield useless, and damaging lots of the buildings and any aircraft that are not in hardened shelters. That is if there is no ballistic missile defense deployed on site, such as the Patriot Advanced Capability-3 (PAC-3, operated by both Japan and the US in Japan). If, in fact, there is a ballistic missile defense system in place, Pyongyang may choose to precede the nuclear-tipped No-dongs with a few conventionally armed ones, to overwhelm and deplete it. Air defense radars do not reveal the payload type, so ballistic missile defense operators must engage all incoming missiles under the same assumptions. In any case, North Korea probably has enough fission warheads, and enough conventionally armed No-dongs and Scud derivatives, to take out successfully a handful of major military targets (primarily US bases) in Japan and South Korea, in a first wave of missile attacks, even with the missile defense assets available in the theater by 2018. Consequently, we assess Pyongyang's regional, nuclear first-strike capabilities to be credible, although not entirely proven.

4.3 Long-range, first-strike capabilities

In the previous subchapter, we focused on capabilities that could hold targets in Japan and South Korea at risk in a nuclear first strike. These are ballistic missiles counted in the hundreds, and most of them have been tested numerous times. In addition, Pyongyang has succeeded in developing and testing ballistic missiles with ranges to threaten American air and sea assets on Guam (about 3400 km), Pearl Harbor (about 7000 km), and even the continental US (10 000 – 13 000 km). These are also liquid-fueled, road-mobile ballistic missiles with significant ground signatures and launch preparation times. That makes them mainly suited as nuclear first-strike weapons at longer ranges than the missiles described in the previous subchapter, as we cannot expect them to weather out an incoming, massive first strike, even if they, too, are based in tunnels and/or hardened shelters. By 2018, there is no open-source evidence to suggest that Pyongyang possesses large numbers of either intermediate-range (capable of striking Guam) or intercontinental ballistic missiles (capable of striking the US mainland), although there are reports of production of such missiles. [77] Thus, multiplicity does not compensate for first-strike vulnerability in this case. Furthermore, these missiles are even more vulnerable to preemptive strikes than their shorter-range cousins, as they are easier to detect and have even longer launch preparation times due to the larger volumes of propellants to be fueled. Consequently, even with these powerful capabilities at hand, Pyongyang is still left with strong incentives to pursue not only solid-fueled, road-mobile ballistic missiles, but also SLBMs with intercontinental ranges, as we will discuss in the next subchapter.

Ever since North Korea without warning launched what was widely interpreted as a three-stage missile (with only two stages igniting in the flight test) across Japan in 1998, a North Korean ICBM has been anticipated. [78] The missile, dubbed "Taepodong-1" by the US (after the old name of the launch site area, Musudan-ri) and "Paektusan" by the North Koreans (after the holy Paektu Mountain), later turned out to be a space-launch vehicle (SLV) technology demonstrator for the nascent "Kwangmyongsong" satellite program. Although it was an SLV, the launch proved that North Korea was about to develop the ability to produce much longer-range missiles than the No-dong (reportedly only tested three time by 1998, first in 1990). The rocket was based on a No-dong first stage, a Hwasong-6 second stage, and a small, solid-fueled third stage to put a satellite into low-earth orbit. This was the first multi-stage rocket or missile test, which was a breakthrough for Pyongyang's ambitions in the fields of both SLVs and ICBMs. Although an ICBM based on this rather outdated technology would be bulky and virtually impossible to make road-mobile, the effort was no doubt useful for the development of future SLVs and ICBMs. Not surprisingly, it raised eyebrows all over the world in a time when news stories from North Korea was mostly about famine and backwardness. [79]

After a moratorium on long-range missile flight test from 1999, North Korea resumed missile testing 5 July 2006 local time zone, and 4 July in US time zones, symbolically. An enlarged version of the Taepodong-1 with four No-dong engines in the first stage, dubbed "Taepodong-2" by most of the world and "Unha-1" by Pyongyang, failed shortly after launch. [80] In the coming years, with more tests, outside observers were gradually more convinced that the Unha series of SLVs was actually intended for space exploration, and that ICBM development took other, more viable paths. Nonetheless, much of the technology in the Unha SLVs has its origins in ballistic missiles. Many of the key challenges associated with both kinds of launches are similar, re-entry survivability being the most notable exception. Each SLV launch thus provides highly useful experience and know-how transferrable to the ballistic missile sector. This duality is reflected, *inter alia*, in the text of the United Nations Security Council Resolution 1874 (2009):

> *(…)* Demands *that the DPRK not conduct any further nuclear test or any launch using ballistic missile technology; [81]*

An ICBM based on engines and the propellant combination used in Hwasong-5, Hwasong-6, No-dong, and the first stage of Taepodong/Unha[6] [82], would be 30 – 40 meters long, and in practice stationary (either in a silo or in a gantry tower). Launch preparations would take many hours. For operational purposes, this is unattractive compared to the option of developing more modern, road-mobile ICBMs, typically 20 – 25 meters long. With the US' nuclear counter-force capabilities (in terms of precision, range, and yield), silos can never be made hardened enough. The key to achieving road-mobile ICBMs is to have propellants that are more energetic, and higher-thrust engines than what Scud-derived technology offers.

In the mid-2000s, reports emerged of an alleged sale of a more advanced, road-mobile MRBM or IRBM, by then called BM-25, from North Korea to Iran. [83] Later, US sources called it the "Musudan" (after the missile test range on the east coast, where it was first observed), and contended it was adapted from a Soviet 1960s vintage SLBM called SS-N-6 "Serb" (R-27 in Russian/Soviet designation) with a 2400 – 2500 km range. The North Korean designation, "Hwasong-10," became clear years later. The original version of the Hwasong-10, first publicly displayed in a parade in 2010, was apparently a lengthened and land-based version of the SS-N-6, with a similar, but not identical, "baby bottle" nose section. Although several analysts assessed that it could potentially threaten Guam with a nuclear payload, its real significance was its much more advanced engine and propellant combination, compared to existing systems.

[6] An open-cycle, single-chamber engine; inhibited, red fuming nitric acid, IRFNA, mixed with smaller amounts of nitrogen tetroxide, NTO, as oxidizer, and kerosene mixed with some gasoline as fuel.

This technology could have turned out to be key to enable Pyongyang to develop road-mobile ICBMs, many analysts have contended. [21, 82, 84] At least two features made this a much more demanding technological path, however.

Firstly, to enable having more propellant mass in the confined space of a submarine launch tube, the engine of the SS-N-6 was submerged in the lower propellant tank. Secondly, the main engine itself was much more complicated, utilizing the principle of so-called “staged combustion,” in contrast to the simpler, one-stage, open-cycle engines mentioned earlier. This may have resulted in the huge challenges Pyongyang has faced in developing and testing the Hwasong-10. Ten years after the reports of the export to Iran of these missiles, Pyongyang could finally celebrate the first successful flight test in the seventh attempt. By then, the missile had undergone several modifications, including the readily observable inclusion of so-called “grid fins” for flight stability. Despite the long-awaited success, the next test was again a failure. By late 2018, different versions of the missile have been flight-tested eight times with only one success. [85]

On 18 March 2017, North Korea tested what Kim Jong-un dubbed the “18 March Revolution Engine.” The coloration of the plume was consistent with the same advanced fuel and oxidizer combination as in the Hwasong-10, but the single combustion chamber was not submerged in a propellant tank. In addition, an exhaust nozzle from a turbopump was clearly visible, meaning it did not utilize the cumbersome staged combustion principle, but instead used the more familiar open combustion cycle. [86] This engine surely lived up to its name. Later the same year, Pyongyang used it in flight tests of two missiles that were both unknown to the outside world before 2017, the Hwasong-12 one-stage IRBM (cf. Figure 4.7), and the Hwasong-14 two-stage ICBM (depicted in Figure 4.8). Furthermore, a two-chamber version (with a common turbopump) was employed in the successful (and by late 2018; the only) test of the Hwasong-15 two-stage ICBM. Taking into account the remarkable success record of these tests (as we will revisit shortly), and the added capabilities these systems represent, it is reasonable to view the emergence of this engine as one of the most significant breakthroughs in Pyongyang’s more than two decades long pursuit of an ICBM.

Figure 4.7 Launch of a Hwasong-12 IRBM sometime in 2017 (image released 16 September 2017). The plumes from the main engine and four vernier engines (probably of the SS-N-6/Hwasong-10 type) are clearly visible. Credit: AFP.

Not unlike all other flight-tested, liquid-fuel rocket engines in North Korea, the 18 March Revolution Engine shares an overwhelming resemblance to certain engines in the former Soviet Union. The two-chamber version is hard to tell from an engine called the "RD-250," which is the basis for the power plant in the world's heaviest ICBM, the Soviet/Russian "SS-18 Satan" ("R-36" in Russian designation). (In the SS-18, a cluster of three two-chamber R-250s constitutes what is known as the "RD-251" propulsion system, delivering approximately three times the thrust of the Hwasong-15 main engine to enable almost 9 tons of payload mass.) After the revelation of the one- and two-chambered versions of this engine in North Korea, analysts have debated whether it is plausible that it was produced indigenously. Some have claimed that complete engines were probably imported from Ukraine (where such engines were produced) or Russia (where such engines were mounted onto missiles), while others assessed that perhaps only the technology and know-how was transferred from one of these states to North Korea. [86, 87] We do not provide an absolute judgement on this issue, but underscore the obvious "genetic" similarities, in line with scores of other similarities in the missile and space sectors of these countries.

Figure 4.8 Launch of a Hwasong-14 ICBM at night in July 2017. (Wikimedia Commons.)

At a minimum, the 18 March Revolution engine is a very impressive, and functional, replica of the RD-250 engine, and a definite game changer for the North Korean missile program (and potentially its space program as well). As a final comment on that subject, we note two reports: First one that cited US intelligence sources contending they did not believe that complete engines were transferred, and that North Korea probably were able to produce such engines indigenously (given recent advances in high-precision manufacturing equipment), although not necessarily without assistance from abroad. [88] Secondly, we note a press report from the US Treasury Department in January 2016, declaring economic sanctions on several Iranian entities for assisting North Korea in various key procurements for the development of an “80-ton rocket booster.” The thrust of the first-stage engine of the Hwasong-15 is usually estimated to around 80 tons (more conventionally: 788 kN) at sea level. [89] Procurement of individual parts is indeed consistent with indigenous production, although far from evidence for such.

Figure 4.9 A Hwasong-15 ICBM inspected by Kim Jong-un before its first launch on 29 November 2017. Credit: Reuters.

Pyongyang's quest for an ICBM seems to have taken several parallel tracks. We may consider the Taepodong/Unha SLV development path as a useful testbed for ICBM technology (especially stage separation, guidance, stabilization control, long-range telemetry, and engine clustering). In addition to the space program and the two demonstrated ICBMs, North Korea has paraded as many as four other ICBM systems in the later years, without successfully testing any of them by the end of 2018.[7] [90] The first two (KN-08/Hwasong-13 and KN-14/Hwasong-13) share the same North Korean designation, but are three- and two-stage versions of more or less the same system, and with different shape re-entry vehicles. These were most likely reliant upon the complicated engine technology (main engine and verniers, *i.e.* small steering motors) from the Hwasong-10 and SS-N-6, as alluded to above. There are reports that North Korea has abandoned this development path entirely as a consequence of the struggles with the Hwasong-10, and of the so-far successful tests of Hwasong-14 and Hwasong-15. [91]

Furthermore, it is highly likely that the Hwasong-10 itself has also been abandoned for the same reasons. That would mean the Hwasong-12 now serves as the weapon of choice in holding US

[7] With the caveat that some have suggested there may have been at least one unsuccessful test of a KN-08, in what most deem was a failed test of the Hwasong-10 instead.

assets at Guam at risk with a nuclear payload, with a demonstrated range of 3700 km. [92] Having in mind and comparing with the poor test record of the Hwasong-10, North Korea tested the Hwasong-12 six times in 2017, with at least two tests being successful. In addition, two successful (and by late 2018; only) tests of Hwasong-14 in July the same year, with the same main engine and four verniers as the Hwasong-12, should be counted in considering the track record of flight-testing the common propulsion system of the two types of missiles. [85] Hwasong-12 offers more reliability, and a longer range, than the Hwasong-10. We do not possess any reliable information on any differences in precision between the two missile types.

As for the two other, non-tested ICBM systems that Pyongyang has displayed, we do not know a lot. In fact, we have not seen any actual such missiles, only the TELs with launch canisters in a massive parade in Pyongyang on the 105th anniversary of Kim Il Sung's birth, 15 April 2017. It is normal to parade mock-up missiles, not the real thing, but there is no way to tell whether the canisters displayed on "The Day of the Sun" even contained such. However, the two different launcher and canister combinations looked eerily like three familiar systems. One was an integrated TEL that strongly resembled both the TEL for the Russian "Topol-M," and the one for the Chinese "DF-41," both solid-fuel, road-mobile ICBMs. [93] The other one was a truck-type MEL, that was hard to tell from the Chinese "DF-31" MEL, also a solid-fueled ICBM. [94] Canisterized ballistic missiles have historically almost exclusively been solid-fueled. The takeaway from this is that Pyongyang is telling the world they are developing solid-fueled, road-mobile ICBMs. However, we learned nothing about the status of any actual missiles in development, only that the transport and launch systems seemed to be in place. The resemblance to known systems obviously presents lots of questions regarding the origins of the technology, that we are not able to address here. We will revisit the significance of these prospective systems in the next subchapter.

The Hwasong-14 and Hwasong-15, on the other hand, were both successfully tested in 2017. We previously mentioned that the Hwasong-14 was tested twice in July 2017. Both times it was launched on a highly lofted trajectory, to avoid entering into foreign air space. However, the flight trajectory data made it possible to ascertain that the same missile could threaten the North West corner of the continental US with a not-too-heavy nuclear payload, almost certainly excluding warheads based on the thermonuclear display model shown in Figure 4.5. [95] Perhaps the Hwasong-14 is designed to deliver a low-weight, boosted fission device of 10 – 20 kt? To hold convincingly at risk all major US cities, Pyongyang must, per late 2018, rely on the more powerful Hwasong-15.

While most outside analysts were still debating the capabilities of North Korea's first flight-tested ICBM, Pyongyang took most by surprise in the early hours of 29 November 2017 (local time) by successfully launching an ICBM that dwarfed the Hwasong-14 in terms of size, and to a certain extent technology. The most conspicuous technical advance was that the main engine was "gimballed," meaning it was steerable with a ball joint, making control surfaces such as jet vanes or external fins, as well as vernier engines, redundant. The impressive Hwasong-15 (cf. Figure 4.9), more than 20 meters long and approximately 2 meters wide, was launched on a very steep trajectory, as has been customary for recent years' North Korean launches, reaching approximately 4500 km, or eleven times higher than the orbit of the International Space Station. Held together with the fact that it flew about 960 km into the Sea of Japan, analysts could calculate its maximum range on a standard trajectory, an astonishing approximately 13 000 km with the same payload mass as in the test. [96] That is most of the world. Further analyses indicate that this missile can deliver heavy payloads to all US cities. In addition, the voluminous RV could possibly house either more than one compact nuclear warhead, or missile defense countermeasures. [73] The RV's size and the missile's throw-weight allow a thick heat shield to protect the payload during re-entry. The blunt shape of the RV makes the re-entry phase less violent than a more streamlined one (like the one on Hwasong-14) does, but on the expense of precision. [71] While the Hwasong-14 may marginally threaten the US mainland, the Hwasong-15 may hold all of North America at risk when it is truly operational.

The status of the Hwasong-12, Hwasong-14, and Hwasong-15 by late 2018 is that they have all been demonstrated on lofted trajectories, and the Hwasong-12 once on a standard trajectory. We thus only know that these missiles *may work* as intended in a real situation, but the short test records mean they are far from *reliably proven*. Furthermore, we have no solid information on the guidance and control capabilities of these systems, and the test records would anyway not offer any real statistics from which to deduce CEPs for these systems, even if we knew where they were aimed. Some experts have suggested CEPs in the range of 7 – 18 km by extrapolation, and the assumption that the inertial navigation technology is comparable to vintage Soviet systems. It is reasonable not to exclude the possibility of Pyongyang having succeeded in acquiring far more advanced INS units for deployment in its most important missiles. In that case, the CEPs of both Hwasong-12, Hwasong-14, and Hwasong-15 may be significantly smaller than what simple extrapolation and heritage considerations would suggest. [97] Nevertheless, until we have solid information on this issue, we assess that Pyongyang may need more than one shot to target military bases a few kilometers wide on the continental US with these missiles. Held together with the fact that the most important military targets in Pyongyang's eyes would be in the East Asian and Pacific Theaters, we consider these missiles as pure counter-value weapons.

Another major question mark that lingers around these missiles is, as we have previously touched upon, whether or not the RVs adequately protect their payloads during re-entry. While there is some open-source evidence that enables some assessments on this point in the case of Hwasong-14, the question is far from resolved. [98] Consequently, we consider it as a temporary unknown, as we have no reason to ascertain that this particular technological hurdle is harder to surmount than others North Korea has overcome in their missile program.

A potential key bottleneck in Pyongyang's arsenal of Hwasong-14 and Hwasong-15 missiles is the number of available launchers. So far, only six TELs large enough to carry these missiles have taken part in parades. These were almost certainly part of eight such vehicles exported as lumber trucks from China. [99] North Korean technicians have since fitted hydraulics, erector arms, and other specialized equipment to enable them to transport missiles, erect them, and place them on a detachable firing table. [100] Pyongyang uses detachable firing tables on

Hwasong-12, Hwasong-14, and Hwasong-15 TELs, so the vehicle can be spared from explosions in failed launches, and so that the vehicle may be called back to pick up another missile without having to wait for the first one to launch. We are not aware of any open-source evidence suggesting that North Korea is able to produce these heavy-duty, eight-axle or nine-axle vehicles (Hwasong-14 and Hwasong-15 TELs, respectively) indigenously, although there are indications that they seek to produce alternative, less agile trucks to do the job. [101] (North Korean engineers have probably modified some of the eight imported vehicles to include an extra axle, to accommodate the longer and heavier Hwasong-15. [102])

Summing up, we assess that the Hwasong-12, Hwasong-14, and Hwasong-15 all provide Pyongyang with unprecedented capabilities in terms of being able to hold at risk US military targets on Guam, as well as major US cities. While we consider all three missiles still in the testing phase, we cannot exclude the possibility that Kim Jong-un may have ordered a few of them deployed on a preliminary basis, ready to be launched in a contingency situation. Indeed, there are indications that Pyongyang has already prepared bases for these new weapons. [103] The missiles' reliability, precision, and re-entry technology are still highly uncertain. All these missiles may carry a boosted fission warhead to US military and/or civilian targets. However, packing a thermonuclear payload with dimensions consistent with the displayed model previously alluded to would seriously impede their effective ranges. While the Hwasong-12 probably would still be able to strike Guam with a heavy nuclear payload, the Hwasong-14 would likely only be able to reach a small part of the North West corner of the US mainland (as well as Guam and Hawaii). That is not the case with the Hwasong-15, which could very likely deliver a heavy, thermonuclear payload to any major US city (given it survives atmospheric re-entry), and even bring along ballistic missile defense countermeasures such as chaff and decoys.

By late 2018, the number of missiles as well as their launchers almost certainly remain modest. However, despite high-level promises of disarmament and moratoria in the nuclear and missile sectors, production seems kept apace. [104] In contrast to the previously mentioned missiles with regional ranges, which are counted in the hundreds, these three systems are probably still counted in the tens at most, and North Korea may only have eight suitable TELs for the two ICBM classes. Taking into account launch preparation times of several hours,[8] we assess that these forces do constitute a long-range, first-strike capability, but one that is vulnerable both to a nuclear first strike, as well as a conventional preemptive attack. This is supported also by the fact that their visual ground signatures are quite significant with several support vehicles, as is customary for liquid-fueled missiles. While the vast number of regional-range missiles are hard to take out entirely either in a surprising first strike, or in an enduring series of preemptive strikes, the still few longer-range missiles do not currently enjoy this "resilience through numbers." Still, until more survivable systems materialize, the Hwasong-12 has most likely been given the mission of threatening US forces on Guam (*i.e.* a counter-force role), where the regional-range missiles cannot reach. Hwasong-14 and Hwasong-15, on the other hand, are

[8] North Korea has indicated that they are fueling these missiles inside their bunkers, but that is quite doubtful and historically unusual, as it would put enormous strain on the missile airframes during subsequent transport to the launch site.

primarily useful in a counter-value, retaliatory role, being able to destroy major US population centers. It is almost unthinkable that Pyongyang will expend these missiles early in a war with the US and/or its regional allies, as it makes little sense to target soft targets before hard (military) targets. That perspective underlines the importance of having retaliatory capabilities that have a fair chance of riding off the adversary's first strike. Even though Hwasong-14 and Hwasong-15 are impressive weapons, they do not offer an assured second-strike capability, only a demonstrated, but not proven, first-strike counter-value capability on true intercontinental ranges (more than 5500 km), which makes little strategic sense (as explained above).

4.4 Second-strike capabilities

The ultimate end goal of an ambitious nuclear weapons program, geared towards stable deterrence, is to have an assured retaliatory capability against any thinkable adversary. That means being able to threaten large population centers with weapons that have survived an incoming, massive nuclear first strike. Somewhat dependent on the enemy's capabilities and localization, this generally entails having long-range delivery systems carrying warheads with substantial explosive yields, and with a high degree of mobility, and preferably with little ground signature. The preferred choice among the established nuclear weapons states for a system that fulfills these requirements is nuclear-propelled submarines with nuclear-tipped, long-range missiles (SLBMs). Indeed, the UK actually depends solely on its nuclear submarines with US-made Trident II D5 SLBMs, as mentioned in the introduction.

North Korea is not much different from the established nuclear powers in this respect and in many others. In 2015 and 2016, they tested a two-stage, medium-range SLBM from outside Sinpo Shipyard on its east coast a total of six times, of which two or three were more or less successful.[9] Some of the tests were from a submerged barge, while others were from a testbed submarine. The missile is called Pukguksong-1 (as mentioned already in Subchapter 3.2), which means "Polaris-1," reminiscent of the first US Navy SLBM, the "UGM-27 Polaris," with which it also shares some outer characteristics. As it turned out, the missile had liquid fuel in the first few tests, with only one partial success, and then solid fuel in all the latest tests. Analysts have estimated its potential range from in excess of 1000 km to around 1250 km. Such estimates are based on flight trajectory data from one lofted flight test, missile dimensions, estimates of its mass, and assessments of the thrust of typical solid-fueled engines sized to fit missiles of such diameters (around 1.5 meters). [105, 106] That would put all of Japan and South Korea within range, when launched from the Sea of Japan.

Although there is only one designation for North Korea's first SLBM (Pukguksong-1, also called "Pukkuksong-1," "Bukkeukseong-1," and "KN-11"), there were really two different, competing systems that were developed in parallel. Images from some of the first few ejection and engine ignition tests of the Pukguksong-1 revealed that the fuel was liquid (from the coloration of the efflux), and probably based on the complicated staged-combustion engine from the SS-N-6 (R-27) discussed in Subchapter 4.3. The missile is approximately 9 meters long,

[9] Tests are not always of the full capability, but for instance just an ejection or engine ignition test.

which means its outer dimensions are for all practical purposes the same as the SS-N-6. However, all later tests have left no doubt that the Pukguksong-1 is now based on solid fuel, which is much more practical in an SLBM for operational and safety reasons. [107] Liquid fuels, especially the highly energetic hydrazine-type fuels such as UDMH in the SS-N-6 and the Hwasong-10-through-15, are extremely toxic, and their oxidizers are highly corrosive. There is no reason to expect a reemergence of liquid-fueled SLBMs in North Korea.

Pyongyang may have pursued the liquid-fueled version for two possible reasons, despite all the advantages of solid fuel and hazards and impracticalities with liquid propellants: If in fact the liquid-fueled Pukguksong-1 were indeed more or less a replica of the SS-N-6, we would expect its range to be around 2500 km with a 650 kg warhead. With a lighter warhead, and a submarine with an operational range of a few hundred kilometers, Guam might have come within its reach. Secondly, we do not know what confidence Pyongyang had in its large solid-fuel engine development program before its apparent success in 2016. With no guaranteed success in that effort, it made sense to entertain the liquid-fuel option, especially given the apparent political pressure to succeed in a “missile development dash” ending a little time before the 2018 Winter Olympics.

The well-known cooperation between Iran and North Korea in the missile and space launch sectors has led some analysts to speculate that the engine in the Pukguksong-1 is related to the second-stage engine in the Iranian “Sejjil” MRBM, which has more or less the same diameter as the Pukguksong-1. [82] We are not able to verify that hypothesis, but if it is true, it would point in the direction of increased confidence, know-how, and shared experience with large, solid-fueled engines among the two countries. There is no doubt, however, that North Korea produces solid-fuel missile engines indigenously. In fact, production is increasing, which underscores the expected significance of solid-fuel missiles for Pyongyang in the near future. [108] Mastering the art of reliably producing solid-fueled engines large enough for an ICBM usually takes many years, and even decades for some countries.

In the most prolific year of North Korean missile testing so far, 2017, the Pukguksong-1 was never tested. A possible explanation is that the missile, along with the so-called “Sinpo-class” (also called “Sinpo-B” or “Gorae,” which means “whale”) diesel-electric submarine from where it has been test-launched, is more of a testbed than an operational system, and that the results so far are sufficient to pursue more capable systems. Indeed, many observers have discarded the Sinpo-B as a possible operational SLBM platform, mostly because it is considered too small and noisy, and thus too easily detectable by anti-submarine warfare assets. (We will nuance that assessment shortly.) The country’s first operational SLBM may instead turn out to be a missile called the “Pukguksong-3.” The existence of this missile is by late 2018 known from a press photo taken during a visit by Kim Jong-un to the plant where, *inter alia*, solid-fuel engines are produced. A poster in the background simply showed a sketch of a missile of unknown dimensions, which was called Pukguksong-3. Other images from the same visit showed equipment associated with the production of composite material parts. This may indicate that either the Pukguksong-1 (and Pukguksong-2, which we will revisit shortly) will be upgraded with a lighter airframe, extending its range, or that the next generation solid-fuel ballistic missile (the Pukguksong-3, expectedly) will have a lighter and stronger airframe than current systems. [109] Taking into account reports that a new, larger, and probably more modern submarine, called "Sinpo-C" by outside experts, is under construction, it is possible that the first operational SLBM in North Korea will be the Pukguksong-3 onboard a Sinpo-C. [110]

Although North Korean submarines are far less advanced, and much noisier than the ones of South Korea and the US, they do have a reasonable chance of operating undetected during a crisis, when running on batteries. That is especially true if they are deployed in the Yellow Sea, rather than the Sea of Japan where the Sinpo Shipyard is situated. The shallow waters of the Yellow Sea provide very poor conditions for acoustic sensors trying to detect and track a submarine. [82] A huge advantage of any SLBMs compared to Pyongyang's land-based missiles with regional reach, is that they may beat US missile defenses in at least two ways. First of all, the radar of the ballistic missile area defense system THAAD has an angle of view of 120 degrees pointing to the north. By simply sailing far enough to the south, an SLBM will not be detected by the radar associated with the THAAD battery deployed in the southern part of South Korea. Secondly, because of the possibility of launching a missile from much closer than its maximum range, it can be launched on a highly lofted trajectory. That would result in a very high re-entry velocity, and an unusually steep angle-of-attack, that in sum may make it challenging to detect, track, and intercept for the THAAD system. [111]

Besides the obvious and significant tactical advantages alluded to above, the Pukguksong-1's relative success constituted a major breakthrough for Pyongyang's missile program in a much broader sense. Developing and reliably producing large solid-fuel missile engines is a highly demanding task. There are very strict requirements on purity and homogeneity in the fuel, oxidizer, and binder mix, which is cast as a rubber-like substance inside the missile airframe (as mentioned in Subchapter 3.2). Only small deviations and impurities (like cracks and bubbles) may have fatal implications, possibly resulting in the missile exploding during launch. A less dramatic consequence is that imperfections lead to variations in range, and thus precision, between missiles from the same production line. It usually takes many years of trial and error, and valuable experience gathering, fully to master this process. The long-term bonus, however, is the prospect of successfully developing, producing, and deploying the ultimate second-strike nuclear delivery vehicles: Solid-fueled ballistic missiles with intercontinental ranges.

We have not seen any solid-fueled SLBMs or road-mobile missiles with intercontinental ranges in North Korea by late 2018. Having such would provide Pyongyang with the most robust and agile weapons of massive retaliation that are available. It would not be surprising if Kim Jong-un nurtures long-term ambitions for at least one of these types of systems, but its possible realization may be many years away. The strongest hints of the development of road-mobile ICBMs with solid fuel are firstly the display of new ICBM TELs with launch canisters, as mentioned in Subchapter 4.3. Secondly, and indirectly, we note the emphasis put on large, solid-fueled engines seen in Pukguksong-1 and Pukguksong-2, as well as the expansion of the manufacturing capacity for such engines. [108] Thirdly, and as mentioned above, we have seen sketches of some missile called Pukguksong-3, which would be expected to have an improved range and payload performance compared to its predecessors in the Pukguksong family, either if it is developed as an SLBM or as a land-based missile. Perhaps, and probably, the Pukguksong-3 will have a range in the MRBM or IRBM categories, if it ever materializes, but its possible existence is hint of ambitions in the solid-fueled ballistic missile area beyond Pukguksong-1 and Pukguksong-2.

As for the Pukguksong-2 (also called “KN-15”), this missile is more or less a land-based version of the Pukguksong-1, transported and launched from a canister on a tracked TEL, constructed from an indigenously produced tank (cf. Figure 4.10). While the range of this missile is probably closer to the No-dong than to the Hwasong-12 (estimated to 1200 – 1300 km [112, 113]), the main advantage compared with the systems discussed in Subchapter 4.2 is its agility and short launch preparation time, as we have mentioned earlier. The day Pukguksong-1 and Pukguksong-2 are sufficiently tested, they may very well constitute a credible, regional second-strike capability, holding all of South Korea and all of Japan at risk. However, by late 2018, we should consider them as *demonstrated* capabilities, not proven ones. That does not mean they will not be deployed in a crisis, or that they will fail in bringing massive destruction to their targets if they are actually launched. It just means that the chances of a successful launch, and a successful target destruction, are unknown, and probably much lower than they will be after completing a sound and rigorous test and evaluation program. Despite that Pyongyang has only flight-tested the Pukguksong-2 twice by late 2018, Kim Jong-un actually declared it as operational already after the second test in May 2017, and ordered its mass production. The first test was in February the same year. Both tests were successful, and on lofted trajectories into the Sea of Japan. [112]

By simple measurements and scaling, we estimate the RVs of the Pukguksong-1 and Pukguksong-2 to be around 2.5 m and 2.0 m long, respectively, or about the same as (or a little longer than) the No-dong RVs (conical and tri-conical variants). Adding the fact that the base diameter of both the two solid-fueled missiles is in the 1.4 – 1.5 m range, and that the No-dong has a base diameter of 1.2 – 1.3 m, there is little doubt that the Pukguksongs are at least as suited to carry a nuclear payload as the No-dongs. A more difficult question is whether they are able to carry Pyongyang’s current thermonuclear warhead. Answering that question satisfactorily requires detailed analyses. However, a rough estimate of the dimensions of the device shown in Figure 4.5 indicates that it would not fit inside the RV of the Pukguksong-2, but possibly, with a small margin and not too thick a heat shield, within the RV of the Pukguksong-1, which is a little longer. Here, we assume that the RVs either separate at what appears to be separation planes in both missiles (black rings where the cylindrical part of the airframe transitions to the conical or tri-conical/”baby bottle” part), or that the propellant section extends to that point in case of a non-separating RV (which we deem unlikely). The significance of this question is whether the missiles are able to deliver yields in the hundreds of kilotons range, or only in the tens of kilotons range. As these missiles may assume the role as pure retaliatory weapons for regional targets, they would be candidates for carrying thermonuclear “city busters.” However, if they by now are unable to do that, they would still represent formidable counter-value assets, as they may achieve a much better precision than the ICBMs due to the shorter ranges, so perhaps only one shot with a boosted fission device in the tens of kilotons range on a major city would do the job.

Summing up this subchapter, we conclude that by the end of 2018 Pyongyang has made strides to establish an assured, regional second-strike capability, but that some testing and development remains for this to be considered operational and credible. Assured retaliatory capabilities on intercontinental ranges are even further into the future, but are by no means an impossibility. Until that day, we expect Pyongyang to capitalize on the concept of "first-strike uncertainty," as alluded to in Subchapter 3.2, for its deterrence against an enemy nuclear first strike.

Figure 4.10 Pukguksong-2 solid-fueled ballistic missiles paraded on Kim Il Sung's birthday 15 April 2017. (Photo: AP.)

5 Findings

We perceive a North Korean counter-force, first-strike doctrine with a regional target set to be increasingly convincing, as Pyongyang now has at its disposition a range of capabilities capable of carrying nuclear payloads in the tens-of-kilotons range. Short of a true, nuclear counter-force attack, there is also the option of performing a full demonstration of a nuclear-tipped missile, for instance into the Pacific Ocean, with the aim of defusing enemy aggression. Although Pyongyang still has not proven successful atmospheric re-entry to the outside world, this should not be a bottleneck for regional-range missiles, and we have little reason to doubt that they master it. Furthermore, although these missiles' precision is probably less than impressive, this is compensated by the enormous explosive yields of even a pure fission weapon, as well as the possibility of firing several shots at the same target. Furthermore, the sheer number of such missiles both makes it almost impossible to eliminate them completely in a preemptive strike, and allows Pyongyang to overwhelm the various ballistic missile defense systems in the region by firing missile salvos including both conventional and nuclear payloads.

We find it unlikely, but not entirely impossible, that Pyongyang intends to equip any MRBMs in its current (by 2018) arsenal with thermonuclear warheads delivering yields comparable to the nuclear test in September 2017 in the 200-kiloton range. Most likely, such warheads are reserved for the ICBMs that could threaten cities in the continental US, perhaps the Hwasong-14, and almost certainly the more capable Hwasong-15. Furthermore, we do not believe that a North Korean first nuclear strike would be a thermonuclear one. Any nuclear exchange would most likely erupt in the East Asian theater, and Pyongyang's first nuclear strike would be one of a counter-force nature under the most likely circumstances, targeting the strategic military assets of the US and its allies in the region in hopes of de-escalating an otherwise inevitable and unwinnable military conflict.

Two ICBM-class missiles have been demonstrated, both probably capable of carrying a thermonuclear warhead available to Pyongyang. However, with only three known tests of these systems, although apparently successful, we do not consider it a *proven capability*, rather a *demonstrated one*. More concretely, these missiles *may be able to strike the US mainland*, but it is quite far from proven. On the other hand, strategic decision-makers in the US would have a hard time excluding the possibility of the missiles working in a major crisis. The missiles are vulnerable to preemption, however, and are probably still few in numbers by late 2018. Thus, we cannot consider them as second-strike capabilities on intercontinental ranges, but they probably represent an already dreaded first-strike uncertainty from a US perspective. To the US, it would be a complete disaster to have only one of these missiles striking one of its most populous cities with a thermonuclear payload, potentially killing hundreds of thousands. Such considerations probably already influence planning.

The diplomatic thaw in 2018, accompanied by statements that emphasize that the nuclear weapons are only meant to deter the US, and held together with the paucity in statements about regional first strikes, may indicate that Pyongyang has started a pivot towards a doctrine more reliant upon retaliation than preemption, even though the necessary capabilities are far from ripe. In case Pyongyang abandons the missile test moratorium imposed in 2018, we may expect to see new solid-fueled missiles, both land-based and submarine-based, and with increasing ranges. However, unless Kim Jong-un has retained even more surprises than he unveiled in the unprecedented year 2017, we do not expect to see solid-fueled missiles with true intercontinental ranges flight-tested in the next couple of years. Such missiles are the key to assured retaliation against the US mainland, especially when launched from a silent submarine.

In the advent of an assured retaliatory capability against the US mainland, which may be several years away, Pyongyang may enjoy what we earlier in the report described (in the words of Wu Riqiang) as first-strike uncertainty. The fear that they are unable to take out all long-range nuclear assets in North Korea with conventional precision-strikes or a nuclear first strike, may very well dissuade the US from entering into hostilities with the DPRK altogether, the reasoning goes.

Pyongyang seems to have a two-tiered doctrine of deterrence. The first tier is deterrence against US military buildup and other forms of aggression in the region, by threats of asymmetric escalation targeting regional, military targets with nuclear-tipped MRBMs (Japan and South Korea) and IRBMs (Guam). The second tier is the almost notional possibility of the DPRK retaliating against soft targets on the continental US with thermonuclear weapons. The latter is meant to deter either a US follow-up of Pyongyang's nuclear first strike in the region, or any other US attack on North Korea. Even the slightest possibility of a successful North Korean thermonuclear strike on the US mainland may already have shifted the strategic balance between Pyongyang and Washington D.C.

Alliance decoupling is a desired feature of the two-tiered doctrine from Pyongyang's perspective, if not a main driver for the nuclear program itself. Even the slightest increased doubt of the US' alliance commitments to Japan and South Korea means that Pyongyang has already increased its strategic leverage, even if lots of testing and further development remains on its intercontinental deterrent. On the positive side, by including the possibility of North Korean nuclear retaliation on the continental US (realistic or not) in the strategic calculations in Pyongyang and Washington D.C., the escalation pressure in the case of a regional crisis may actually decrease. The big question is whether North Korea and the US can succeed in establishing a stable, mutual deterrent relation, or if that is too big a concession to swallow for current and future US leaders. If the latter is the case, we should not expect North Korea to abandon its strategic equalizer without addressing its deeper security challenges, without which there would have been no nuclear program at all.

A Appendix – Terms and Abbreviations

BM	Ballistic Missile.	A guided missile with a significant part of its trajectory in free fall.
Byungjin	Policy of simultaneous development of nuclear weapons and the economy.	
C2	Command and Control.	
DPRK	Democratic People's Republic of Korea.	Formal name of North Korea.
INS	Inertial Navigation System.	A navigation system based on inertial sensors such as gyroscopes and accelerometers.
ICBM	Intercontinental Ballistic Missile.	A more than 5500 km range BM.
IRBM	Intermediate-Range Ballistic Missile.	A 3000 – 5500 km range BM.
ISR	Intelligence, Surveillance, and Reconnaissance.	
KWP	Korean Workers' Party.	
MEL	Mobile Erector Launcher.	A vehicle with a towed launcher for BMs.
MRBM	Medium-Range Ballistic Missile.	A 1000 – 3000 km range BM.
PAC-3	Patriot Advanced Capability-3.	A US ballistic missile and air defense system.
ROK	Republic of Korea.	Formal name of South Korea.
SAFF	Safing, Arming, Fuzing, and Firing (Unit).	A device preventing inadvertent initiation, and that arms and sets off a nuclear weapon at the proper time.
SLV	Space-Launch Vehicle.	Rocket that places objects in space.
Songun	Policy of "military first."	

TEL	Transporter Erector Launcher.	Truck or tank with an integrated launcher for BMs.
THAAD	Terminal High Altitude Area Defense.	US ballistic missile defense system designed to intercept up to IRBMs in their terminal phases.

B Appendix – List of relevant North Korean missiles and space-launch vehicles

North Korean designation	Other designation[10]	Soviet ancestor	Category	Approximate range (km)[11]
Hwasong-5	Scud-A	R-11	SRBM	300
Hwasong-6	Scud-B	R-17	SRBM	500
Hwasong-7	No-dong	(Enlarged R-17)	MRBM	900 – 1300
(Hwasong-9?)	Scud-ER	R-17	SRBM	700 – 1000
Hwasong-10	Musudan	R-27	MRBM or IRBM	2500 – 3000
Hwasong-11	KN-02 Toksa	9K79 Tochka	Solid-fuel SRBM	120 – 220
Hwasong-12	KN-17		IRBM	3700 – 4500
Hwasong-13	KN-08		ICBM	*11000*
(Two-stage Hwasong-13?)	KN-14		ICBM	*8000 – 10000*
Hwasong-14	KN-20		ICBM	7500 – 10500
Hwasong-15	KN-22		ICBM	9000 – 13000
Paektusan	Taepodong-1		SLV	N/A
Unha	Taepodong-2		SLV	N/A
Pukguksong-1	Polaris-1		Solid-fuel SLBM	1000 – 1200
Pukguksong-2	Polaris-2		Solid-fuel MRBM	1000 – 1200

[10] Typically from official US and other Western sources. The DPRK itself uses Scud designations in export contexts.
[11] Assumed maximum range with a likely payload mass and a standard trajectory. The Earth's rotation contributes increasingly with the range, and variably with the launch direction relative to the rotational axis. Italic numbers are for missiles with no known flight-tests, and are thus mean estimates based on open-source models of the missiles with known engine types and propellants, and visible features such as dimensions, number of stages, and control surfaces.

References

[1] V. Narang, *Nuclear Strategy in the Modern Era - Regional Powers and International Conflict* (Princeton Studies in International History and Politics). Princeton, New Jersey, USA: Princeton University Press, 2014, p. 341.

[2] S. Harris, 23 January 2018, "Gaps remain in CIA's understanding of North Korean nukes, spy chief says." *The Washington Post*. Available: https://www.washingtonpost.com/world/national-security/gaps-remain-in-cias-understanding-of-north-korean-nukes-spy-chief-says/2018/01/23/9eb4cd62-006f-11e8-93f5-53a3a47824e8_story.html?utm_term=.d588266cfc9b

[3] J. S. Bermudez Jr., "North Korea's Development of a Nuclear Weapons Strategy," in "North Korea's Nuclear Futures Series," US-Korea Institute at SAIS, Available: https://www.38north.org/wp-content/uploads/2015/08/NKNF_Nuclear-Weapons-Strategy_Bermudez.pdf.

[4] KCNA, 1 April 2013, "Law on Consolidating Position of Nuclear Weapons State Adopted." *Korean Central News Agency*. Available: http://kcna.co.jp/item/2013/201304/news01/20130401-25ee.html

[5] A. Y. Mansourov, "Kim Jong Un's Nuclear Doctrine and Strategy: What Everyone Needs to Know," in "NAPSNet Special Reports," Nautilus Institute, 16 December 2014, Available: https://nautilus.org/napsnet/napsnet-special-reports/kim-jong-uns-nuclear-doctrine-and-strategy-what-everyone-needs-to-know/.

[6] S.-Y. Park, "North Korea's military policy under the Kim Jong-un regime," *Journal of Asian Public Policy*, vol. 9, no. 1, 2016.

[7] R. Goldman, 24 December 2017, "North Korea Calls U.N. Sanctions an 'Act of War'." *The New York Times*. Available: https://www.nytimes.com/2017/12/24/world/asia/north-korea-un-sanctions.html

[8] The National Committee on North Korea, 1 January 2018, "Kim Jong Un's 2018 New Year's Address." Available: https://www.ncnk.org/node/1427

[9] J. C. Un, 18 December 2017, "DPRK Will Advance along Road of Victory." *Rodong Sinmun (via KCNA Watch)*. Available: https://kcnawatch.co/newstream/1530444956-222481551/dprk-will-advance-along-road-of-victory/

[10] KCNA, 23 April 2018, "WPK's Line of Simultaneously Developing Two Fronts Praised." *Korean Central News Agency*. Available: https://kcnawatch.co/newstream/1528185524-659681772/wpks-line-of-simultaneously-developing-two-fronts-praised/

[11] J. Dagyum and O. Hotham, 29 November 2017, "North Korea announces first test of Hwasong-15 ICBM," NK News. Available: https://www.nknews.org/2017/11/north-korea-announces-first-test-of-hwasong-15-icbm/?c=1512023166609

[12] W. Burr and A. Cohen, 6 December 2016, "The Vela Incident: South Atlantic Mystery Flash in September 1979 Raised Questions about Nuclear Test," in *Briefing Book #570*: National Security Archive. Available: https://nsarchive.gwu.edu/briefing-book/nuclear-vault/2016-12-06/vela-incident-south-atlantic-mystery-flash-september-1979

[13] K. J. Kwon, 31 May 2012, "North Korea proclaims itself a nuclear state in new constitution." *CNN*. Available: https://edition.cnn.com/2012/05/31/world/asia/north-korea-nuclear-constitution/index.html

[14] J. Lewis, 9 March 2017, "North Korea Is Practicing for Nuclear War." *Foreign Policy*. Available: https://foreignpolicy.com/2017/03/09/north-korea-is-practicing-for-nuclear-war/

[15] N. Bertrand, 11 August 2017, "Experts say Trump is giving North Korea the excuse it needs to cling to its nuclear weapons program." *Business Insider*. Available: https://nordic.businessinsider.com/trump-north-korea-kim-jong-un-2017-8?r=US&IR=T

[16] A. Panda, 2 May 2017, "Under Trump, A Looming North Korean ICBM Threat Brings Alliance 'Decoupling' Fears Back to East Asia." *The Diplomat*. Available: https://thediplomat.com/2017/05/under-trump-a-looming-north-korean-icbm-threat-brings-alliance-decoupling-fears-back-to-east-asia/

[17] E. Talmadge, 30 August 2017, "Analysis: Is North Korea winning deterrence war with US?." *AP News*. Available: https://apnews.com/2ec0730c32a94f8baeba6306310a7078

[18] M. Rapp-Hooper, 7 September 2017, "Decoupling Is Back in Asia: A 1960s Playbook Won't Solve These Problems." *War on the Rocks*. Available: https://warontherocks.com/2017/09/decoupling-is-back-in-asia-a-1960s-playbook-wont-solve-these-problems/

[19] Yonhap, 26 November 2017, "Senior N. Korean official says its nuke program targets no country but U.S.." *Yonhap News Agency*. Available: https://en.yna.co.kr/view/AEN20171126002100315

[20] K. Mizokami, 10 July 2017, "This Is How South Korea Plans to Stop a Nuclear Attack from North Korea." *The National Interest*. Available: https://nationalinterest.org/blog/the-buzz/how-south-korea-plans-stop-nuclear-attack-north-korea-21472

[21] R. Savelsberg and J. Kiessling, 20 December 2016, "North Korea's Musudan Missile: A Performance Assessment," 38North. Available: https://www.38north.org/2016/12/musudan122016/

[22] J. Kim, 23 June 2016, "North Korea leader says missile launch shows ability to attack U.S. in Pacific." *Reuters*. Available: https://www.reuters.com/article/us-northkorea-missile-kim-idUSKCN0Z82PB

[23] *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, United Nations Office for Disarmament Affairs, 1967. Available: http://disarmament.un.org/treaties/t/outer_space

[24] R. Dobbs, 10 July 2012, "What Was at Stake in 1962?" *Foreign Policy*. Available: https://foreignpolicy.com/2012/07/10/what-was-at-stake-in-1962/

[25] K. Subrahmanyam, "The Euromissile Crisis," *Strategic Analysis*, vol. 9, no. 7, pp. 718-730, 1983.

[26] *Treaty Between The United States Of America And The Union Of Soviet Socialist Republics On The Elimination Of Their Intermediate-Range And Shorter-Range Missiles (INF Treaty)*, 1987. Available: https://www.state.gov/t/avc/trty/102360.htm

[27] R. Wu, "Certainty of Uncertainty: Nuclear Strategy with Chinese Characteristics," *Journal of Strategic Studies*, vol. 36, no. 4, pp. 579-614, 2013.

[28] A. Goldstein, *Deterrence and Security in the 21st Century: China, Britain, France, and the Enduring Legacy of the Nuclear Revolution*. Stanford University Press, 2000.

[29] Federation of American Scientists, "Ballistic Missile Basics." Available: https://fas.org/nuke/intro/missile/basics.htm

[30] Jane's World Air Forces, 26 June 2018, "Japan – Air Force." Available: https://janes.ihs.com/Janes/Display/jwafa143-jwaf

[31] Jane’s World Air Forces, 30 November 2018, "Korea, North – Air Force." Available: https://janes.ihs.com/Janes/Display/jwafa150-jwaf

[32] C. Hansen, 1995, "Swords of Armageddon: U.S. Nuclear Weapons Development since 1945."

[33] W. Broad, 12 December 1989, "From Cold War to Nuclear Nostalgia." *The New York Times*. Available: https://www.nytimes.com/1989/12/12/science/from-cold-war-to-nuclear-nostalgia.html

[34] C. Sublette, "Nuclear Weapons Frequently Asked Questions." Available: http://nuclearweaponarchive.org/

[35] Nuclear Suppliers Group, "Guidelines for Transfers of Nuclear-Related Dual-Use Equipment, Materials, Software, and Related Technology," in *IAEA/INFCIRC/254/Rev.10/Part 2a (Corrected)*. Available: https://www.iaea.org/sites/default/files/publications/documents/infcircs/1978/infcirc254r10p2c.pdf

[36] D. Albright and K. O’Neill, *Solving the North Korean Nuclear Puzzle*. Washington, D.C.: ISIS Press, 2000.

[37] D. Albright, 13 February 2013, "North Korean Miniaturization," 38North. Available: https://www.38north.org/2013/02/albright021313/

[38] L.-E. De Geer, "Radionuclide Evidence for Low-Yield Nuclear Testing in North Korea in April/May 2010," *Science & Global Security*, vol. 20, no. 1, pp. 1-29, 2012.

[39] NORSAR, 2017, "Summing Up the Nuclear Test in North Korea on 3 September 2017." Available: https://www.norsar.no/in-focus/summing-up-the-nuclear-test-in-north-korea-on-3-september-2017-article1554-863.html

[40] R. L. Garwin and F. N. von Hippel, November 2006, "A Technical Analysis of North Korea’s Oct. 9 Nuclear Test." *Arms Control Today*.

[41] J. R. Murphy, B. C. Kohl, J. L. Stevens, T. J. Bennett, and H. G. Israelsson, "Exploitation of the IMS and Other Data for a Comprehensive, Advanced Analysis of the North Korean Nuclear Tests," in "2010 Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies, Science Applications International Corporation."

[42] Kyodo, 28 June 2008, "N. Korea says used 2 kg of plutonium in 2006 nuke test: source." *Kyodo News*.

[43] T. B. Cochran and C. E. Paine, "The Amount of Plutonium and Highly Enriched Uranium Needed for Pure Fission Weapons," Natural Resources Defense Council, Inc., 13 April 1995.

[44] D. Albright, 28 April 2017, "North Korea’s Nuclear Capabilities: A Fresh Look," in *PowerPoint slides from a series of talks in Washington, D.C., in 2017*: Institute for Science and International Security. Available: https://isis-online.org/uploads/isis-reports/documents/North_Korea_Talk_April_28_2017_Final.pdf

[45] G. Corera, *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A.Q. Khan Network*. Oxford University Press, 2009.

[46] S. S. Hecker, "A Return Trip to North Korea’s Yongbyon Nuclear Complex," in "NAPSNet Special Reports," 22 November 2010, Available: https://nautilus.org/napsnet/napsnet-special-reports/a-return-trip-to-north-koreas-yongbyon-nuclear-complex/.

[47] A. Panda, 13 July 2018, "Exclusive: Revealing Kangson, North Korea's First Covert Uranium Enrichment Site." *The Diplomat*. Available: https://thediplomat.com/2018/07/exclusive-revealing-kangson-north-koreas-first-covert-uranium-enrichment-site/

[48] The New York Times, 9 September 2016, "Decoding North Korea's Claim of a Successful Nuclear Test." *The New York Times*. Available: https://www.nytimes.com/2016/09/10/world/asia/north-korea-nuclear-test-statement.html
[49] D. Albright and P. Brannan, 26 June 2006, "The North Korean Plutonium Stock Mid-2006," Institute for Science and International Security. Available: http://isis-online.org/uploads/isis-reports/documents/dprkplutonium.pdf
[50] D. Albright, "Swiss Smugglers Had Advanced Nuclear Weapons Designs," in "ISIS Report," Institute for Science and International Security, 16 June 2008, Available: https://isis-online.org/uploads/isis-reports/documents/Advanced_Bomb_16June2008.pdf.
[51] D. Sanger, 15 June 2008, "Nuclear Ring Reportedly Had Advanced Design." *The New York Times*. Available: https://www.nytimes.com/2008/06/15/world/asia/15nuke.html?_r=1&hp=&pagewanted=all
[52] *United Nations Security Council Resolution 1172 (1998),* United Nations Security Council, 6 June 1998. Available: http://dag.un.org/bitstream/handle/11176/46551/S_RES_1172%281998%29-EN.pdf?sequence=3&isAllowed=y
[53] The Guardian, 23 September 2017, "China to enforce UN sanctions against North Korea." *The Guardian*. Available: https://www.theguardian.com/world/2017/sep/23/china-to-enforce-un-sanctions-against-north-korea
[54] C. Sublette, 14 October 2006, "The Nuclear Weapon Archive – A Guide to Nuclear Weapons." Available: http://nuclearweaponarchive.org/Usa/Weapons/Allbombs.html
[55] D. Albright and S. Kelleher-Vergantini, "Update on North Korea's Yongbyon Nuclear Site," in "ISIS Imagery Brief," Institute for Science and International Security, 15 September 2015, Available: http://isis-online.org/uploads/isis-reports/documents/Update_on_North_Koreas_Yongbyon_Nuclear_Site_September15_2015_Final.pdf.
[56] N. Hansen and R. Kelley, 9 August 2016, "North Korea H-bomb claims examined." *Jane's Intelligence Review*.
[57] J. V. Hastings, H. Lee, and R. Kelley, "North Korea's Lithium Research Networks and its Quest for a Hydrogen Bomb," *The Korean Journal of Defense Analysis*, vol. 30, no. 3, pp. 337–352, September 2018.
[58] D. Albright, S. Burkhard, M. Gorwitz, and A. Lach, "North Korea's Lithium 6 Production for Nuclear Weapons," in "ISIS Report," Institute for Science and International Security, 17 March 2017, Available: http://isis-online.org/uploads/isis-reports/documents/North_Korea_Lithium_6_17Mar2017_Final.pdf.
[59] D. E. Sanger and W. J. Broad, 3 April 2017, "North Korea's Nuclear Strength, Encapsulated in an Online Ad for Lithium." *The New York Times*. Available: https://www.nytimes.com/2017/04/03/us/politics/north-korea-nuclear-trump-china.html
[60] J. Pearson, 9 September 2016, "North Korea's bomb is more powerful, but worry is miniaturization." *Reuters*. Available: https://www.reuters.com/article/us-northkorea-nuclear-science-idUSKCN11F19W
[61] J. Lewis, 11 March 2016, "Five Things You Need to Know about Kim Jong Un's Photo Op with the Bomb," 38North. Available: https://www.38north.org/2016/03/jlewis031116/

[62] Federation of American Scientists, "R-11 / SS-1B SCUD-A R-300 9K72 Elbrus / SS-1C SCUD-B." Available: https://fas.org/nuke/guide/russia/theater/r-11.htm
[63] S. Engelberg and M. R. Gordon, 26 December 1993, "Intelligence Study Says North Korea Has Nuclear Bomb." *The New York Times*. Available: https://www.nytimes.com/1993/12/26/world/asia/intelligence-study-says-north-korea-has-nuclear-bomb.html
[64] J. Lewis, 5 September 2016, "DPRK Missile Designations," ArmsControlWonk. Available: https://www.armscontrolwonk.com/archive/1201889/dprk-missile-designations/
[65] National Air and Space Intelligence Center, "Ballistic and Cruise Missile Threat," 21 July 2017, Available: https://www.nasic.af.mil/Portals/19/images/Fact%20Sheet%20Images/2017%20Ballistic%20and%20Cruise%20Missile%20Threat_Final_small.pdf?ver=2017-07-21-083234-343.
[66] M. Korda, 31 July 2017, "The More You KN-0W About North Korean Missiles," ArmsControlWonk. Available: https://www.armscontrolwonk.com/archive/1203680/the-more-you-kn-0w-about-north-korean-missiles/
[67] M. Schiller, "Characterizing the North Korean Nuclear Missile Threat," in "Technical Report," RAND Corporation, Available: https://www.rand.org/content/dam/rand/pubs/technical_reports/2012/RAND_TR1268.pdf.
[68] Missile Defense Project, "Hwasong-5 ('Scud B' Variant)," in "Missile Threat," Center for Strategic and International Studies, 15 June 2018, Available: https://missilethreat.csis.org/missile/hwasong-5/.
[69] Missile Defense Project, "Hwasong-6 ('Scud C' Variant)," in "Missile Threat," Center for Strategic and International Studies, 15 June 2018, Available: https://missilethreat.csis.org/missile/hwasong-6/.
[70] Missile Defense Project, "No Dong 1," in "Missile Threat," Center for Strategic and International Studies, 15 June 2018, Available: https://missilethreat.csis.org/missile/no-dong/.
[71] D. Wright, 7 December 2017, "Reentry of North Korea's Hwasong-15 Missile," in *All Things Nuclear*: Union of Concerned Scientists. Available: https://allthingsnuclear.org/dwright/reentry-of-hwasong-15
[72] United States General Accounting Office, "Ballistic Missile Defense – Information on Theater High Altitude Area Defense (THAAD) System," in "Briefing Report to the Chairman, Committee on Foreign Relations, U.S. Senate," January 1994, Available: https://www.gao.gov/assets/80/78797.pdf.
[73] T. A. Postol, 3 March 2018, "North Korean Ballistic Missiles and US Missile Defense," in *APS Physics, Forum on Physics and Society*. Available: https://www.aps.org/units/fps/newsletters/201804/north-korea.cfm
[74] J. Bermudez, V. Cha, and L. Collins, 12 November 2018, "Undeclared North Korea: The Sakkanmol Missile Operating Base," in *Beyond Parallel*: Center for Strategic & International Studies. Available: https://beyondparallel.csis.org/undeclared-north-korea-sakkanmol-missile-operating-base/
[75] Arms Control Association, "U.S. and Allied Ballistic Missile Defenses in the Asia-Pacific Region," in *Fact Sheets & Briefs*. Available: https://www.armscontrol.org/factsheets/us-allied-ballistic-missile-defenses-asia-pacific-region

[76] A. Wellerstein, "Nukemap." Available: https://nuclearsecrecy.com/nukemap/

[77] E. Nakashima and J. Warrick, 30 July 2018, "U.S. spy agencies: North Korea is working on new missiles." *The Washington Post*. Available: https://www.washingtonpost.com/world/national-security/us-spy-agencies-north-korea-is-working-on-new-missiles/2018/07/30/b3542696-940d-11e8-a679-b09212fb69c2_story.html?utm_term=.a8a5cffdadab

[78] S. Wudunn, 1 September 1998, "North Korea Fires Missile Over Japanese Territory." *The New York Times*. Available: https://www.nytimes.com/1998/09/01/world/north-korea-fires-missile-over-japanese-territory.html

[79] J. S. Bermudez Jr., November 1999, "A History of Ballistic Missile Development in the DPRK," in *Occasional Paper No. 2*: Center for Nonproliferation Studies, Monterey Institute of International Studies.

[80] The New York Times, 4 July 2006, "North Korea Test-Fires Several Missiles." *The New York Times*. Available: https://www.nytimes.com/2006/07/04/world/asia/04cnd-korea.html

[81] *United Nations Security Council Resolution 1874 (2009)*, United Nations Security Council, 12 June 2009. Available: https://www.un.org/sc/suborg/en/s/res/1874-%282009%29

[82] T. A. Postol and M. Schiller, "The North Korean Ballistic Missile Program," *Korea Observer*, vol. 47, no. 4, pp. 751-805, Winter 2016.

[83] D. Fickling, 27 April 2006, "Iran has bought long-range missiles, says Israel." *The Guardian*. Available: https://www.theguardian.com/world/2006/apr/27/iran.israel

[84] J. Schilling, "A Revised Assessment of the North Korean KN-08 ICBM," *Science & Global Security*, vol. 21, no. 1.

[85] James Martin Center for Nonproliferation Studies at the Middlebury Institute of International Studies. The CNS North Korea Missile Test Database [Online]. Available: https://www.nti.org/analysis/articles/cns-north-korea-missile-test-database/

[86] N. Hansen and M. Schiller, 9 February 2018, "North Korean ICBM design shows external influence." *Jane's Intelligence Review*. Available: https://janes.ihs.com/IntelligenceReview/Display/FG_735058-JIR

[87] M. Elleman, 14 August 2017, "The secret to North Korea’s ICBM success," in *IISS Analysis*: International Institute for Strategic Studies. Available: https://www.iiss.org/blogs/analysis/2017/08/north-korea-icbm-success

[88] A. Panda, 16 August 2017, "North Korea's New High-Performance Missile Engines Likely Weren't Made in Russia or Ukraine," The Diplomat. Available: https://thediplomat.com/2017/08/north-koreas-new-high-performance-missile-engines-likely-werent-made-in-russia-or-ukraine/

[89] Press Center, 17 January 2016, "Treasury Sanctions Those Involved in Ballistic Missile Procurement for Iran," U.S. Department of the Treasury. Available: https://www.treasury.gov/press-center/press-releases/Pages/jl0322.aspx

[90] A. Fifield, 26 October 2016, "Did North Korea just test missiles capable of hitting the U.S.? Maybe." *The Washington Post*. Available: https://www.washingtonpost.com/world/asia_pacific/did-north-korea-just-test-missiles-capable-of-hitting-the-us-maybe/2016/10/26/984e8a21-e6a7-4689-81e0-21d7d25c302f_story.html?utm_term=.a8417b962585

[91] Yonhap News Agency, 2 December 2017, "Daily press “North, Hwaseong-13 type development stopped ... fuel injection time, output problem” (per Google Translate from Korean to English)." *Yonhap*. Available: https://m.yna.co.kr/view/AKR20171202040300073 (in Korean)

[92] A. Panda, 15 September 2017, "North Korea Overflies Japan With Another Intermediate-Range Ballistic Missile: Early Analysis," The Diplomat. Available: https://thediplomat.com/2017/09/north-korea-overflies-japan-with-another-intermediate-range-ballistic-missile-early-analysis/

[93] A. Panda, 15 April 2017, "North Korea's 2017 Military Parade Was a Big Deal. Here Are the Major Takeaways," The Diplomat. Available: https://thediplomat.com/2017/04/north-koreas-2017-military-parade-was-a-big-deal-here-are-the-major-takeaways/

[94] A. Panda, 17 July 2017, "North Korea's ICBM Celebration Concert Reveals Never-Before-Seen Missile Imagery," The Diplomat. Available: https://thediplomat.com/2017/07/north-koreas-icbm-celebration-concert-reveals-never-before-seen-missile-imagery/

[95] M. Elleman, 29 November 2018, "North Korea’s Hwasong-14 ICBM: New Data Indicates Shorter Range Than Many Thought," 38North. Available: https://www.38north.org/2018/11/melleman112918/

[96] D. Wright, 28 November 2017, "North Korea’s Longest Missile Test Yet," in *All Things Nuclear*: Union of Concerned Scientists. Available: https://allthingsnuclear.org/dwright/nk-longest-missile-test-yet

[97] M. Beljac, 2 December 2017, "North Korea’s Hwasong-15 ICBM and The Window of Vulnerability," in *Analysans – Analyses of Things Nuclear, Space, Philosophy, Anthropocene And Left Political Economy*. Available: http://analysans.net/north-koreas-hwasong-15-icbm-window-vulnerability/

[98] J. M. Acton, J. G. Lewis, and D. Wright, 9 November 2018, "Video Analysis of the Reentry of North Korea’s July 28, 2017 Missile Test," ArmsControlWonk. Available: https://www.armscontrolwonk.com/archive/1206084/dprk-rv-video-analysis/

[99] M. Hanham, 31 July 2012, "North Korea's Procurement Network Strikes Again: Examining How Chinese Missile Hardware Ended Up in Pyongyang," Nuclear Threat Initiative. Available: https://www.nti.org/analysis/articles/north-koreas-procurement-network-strikes-again-examining-how-chinese-missile-hardware-ended-pyongyang/

[100] J. Lewis, M. Hanham, and A. Lee, 3 February 2014, "That Ain’t My Truck: Where North Korea Assembled Its Chinese Transporter-Erector-Launchers," 38North. Available: https://www.38north.org/2014/02/jlewis020314/

[101] S. L. Persio, 21 December 2017, "Like Trump, Kim Jong Un Wants Trucks Made At Home – In His Case To Launch Missiles." *Newsweek*. Available: https://www.newsweek.com/trump-kim-jong-un-wants-trucks-made-home-his-case-launch-missiles-717945

[102] A. Panda, 6 December 2017, "The Hwasong-15: The Anatomy of North Korea's New ICBM," The Diplomat. Available: https://thediplomat.com/2017/12/the-hwasong-15-the-anatomy-of-north-koreas-new-icbm/

[103] J. Lewis and D. Schmerler, 6 December 2018, "North Korean Missile Base at Yeongjeo-Dong," ArmsControlWonk. Available: https://www.armscontrolwonk.com/archive/1206442/north-korean-missile-base-at-yeongjeo-dong/

[104] J. Cheng, 1 July 2018, "North Korea Expands Key Missile-Manufacturing Plant." *The Wall Street Journal*. Available: https://www.wsj.com/articles/north-korea-expands-key-missile-manufacturing-plant-1530486907

[105] Missile Defense Project, 15 June 2018, "KN-11 (Pukkuksong-1)," in *Missile Threat*: Center for Strategic and International Studies. Available: https://missilethreat.csis.org/missile/kn-11/

[106] D. Wright, 30 August 2016, "Range of the North Korean KN-11 Sub-Launched Missile," in *All Things Nuclear*: Union of Concerned Scientists. Available: https://allthingsnuclear.org/dwright/range-of-the-north-korean-kn-11-sub-launched-missile
[107] Jane's Strategic Weapon Systems, 19 March 2018, "Pukkuksong-1/Bukgeukseong-1," Jane's. Available: https://janes.ihs.com/Janes/Display/jswsa397-jsws
[108] J. S. Bermudez Jr. and D. Dueweke, 25 July 2018, "Expansion of North Korea's Solid Fuel Ballistic Missile Program: The Eight Year Old Case of the Chemical Materials Institute," 38North. Available: https://www.38north.org/2018/07/cmi072518/
[109] A. Panda, 24 August 2017, "Something New, Something Old: North Korea's Next Missiles," The Diplomat. Available: https://thediplomat.com/2017/08/something-new-something-old-north-koreas-next-missiles/
[110] J. S. Bermudez Jr., 16 November 2017, "North Korea's Submarine Ballistic Missile Program Moves Ahead: Indications of Shipbuilding and Missile Ejection Testing," 38North. Available: https://www.38north.org/2017/11/sinpo111617/
[111] J. Lewis, 28 August 2016, "KN-11 and THAAD," ArmsControlWonk. Available: https://www.armscontrolwonk.com/archive/1201857/kn-11-and-thaad/
[112] M. Elleman, 25 May 2017, "The Pukguksong-2: Lowering the Bar on Combat Readiness?," 38North. Available: https://www.38north.org/2017/05/pukguksong2_052517/
[113] J. Schilling, 24 May 2017, "The Pukguksong-2 Approaches Initial Operational Capability," 38North. Available: https://www.38north.org/2017/05/jschilling052417/

About FFI

The Norwegian Defence Research Establishment (FFI) was founded 11th of April 1946. It is organised as an administrative agency subordinate to the Ministry of Defence.

FFI's MISSION

FFI is the prime institution responsible for defence related research in Norway. Its principal mission is to carry out research and development to meet the requirements of the Armed Forces. FFI has the role of chief adviser to the political and military leadership. In particular, the institute shall focus on aspects of the development in science and technology that can influence our security policy or defence planning.

FFI's VISION

FFI turns knowledge and ideas into an efficient defence.

FFI's CHARACTERISTICS

Creative, daring, broad-minded and responsible.

Om FFI

Forsvarets forskningsinstitutt ble etablert 11. april 1946. Instituttet er organisert som et forvaltningsorgan med særskilte fullmakter underlagt Forsvarsdepartementet.

FFIs FORMÅL

Forsvarets forskningsinstitutt er Forsvarets sentrale forskningsinstitusjon og har som formål å drive forskning og utvikling for Forsvarets behov. Videre er FFI rådgiver overfor Forsvarets strategiske ledelse. Spesielt skal instituttet følge opp trekk ved vitenskapelig og militærteknisk utvikling som kan påvirke forutsetningene for sikkerhetspolitikken eller forsvarsplanleggingen.

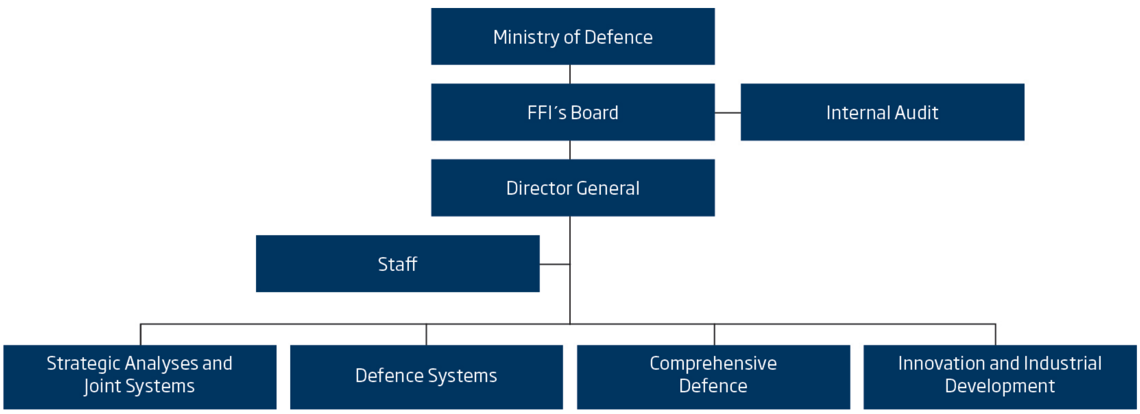
FFIs VISJON

FFI gjør kunnskap og ideer til et effektivt forsvar.

FFIs VERDIER

Skapende, drivende, vidsynt og ansvarlig.

FFI's organisation



Forsvarets forskningsinstitutt
Postboks 25
2027 Kjeller

Besøksadresse:
Instituttveien 20
2007 Kjeller

Telefon: 63 80 70 00
Telefaks: 63 80 71 15
Epost: ffi@ffi.no

Norwegian Defence Research Establishment (FFI)
P.O. Box 25
NO-2027 Kjeller

Office address:
Instituttveien 20
N-2007 Kjeller

Telephone: +47 63 80 70 00
Telefax: +47 63 80 71 15
Email: ffi@ffi.no