



THE ROLE OF MISSILE DEFENSE IN NORTH-EAST ASIA



Recommended Citation

David Wright, "THE ROLE OF MISSILE DEFENSE IN NORTH-EAST ASIA", Special Reports, January 13, 2022, <https://nautilus.org/napsnet/napsnet-special-reports/the-role-of-missile-defense--n-north-east-asia/>

DAVID WRIGHT

JANUARY 13 2022

I. INTRODUCTION

In this essay, David Wright analyzes the effectiveness of current missile defense systems in intercepting missile attacks and what could happen if the DPRK attacks the ROK, Japan, or the United States.

David Wright is a research affiliate in the MIT Department of Nuclear Science and Engineering's Laboratory for Nuclear Security and Policy and formerly researcher with the Global Security Program at the Union of Concerned Scientists.

This report is a part of a joint project on [Reducing the Risk of Nuclear Weapon Use in Northeast Asia \(NU-NEA\)](#) and has been cross-posted by the Asia Pacific Leadership Network [here](#), and the Research Center for Nuclear Weapons Abolition (RECNA), and the Panel on Peace and Security of North East Asia (PSNA) [here](#).

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Banner image: US PACOM deploys THAAD to Korea, March 6 2017, from [here](#)

NAPSNET SPECIAL REPORT BY DAVID WRIGHT

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Summary

This paper discusses specific types of missile attacks the Democratic People's Republic of Korea (DPRK) might launch in a conflict and identifies the key sources of uncertainty that US and allied political and military leaders must take into account in assessing how effective defense systems might be in stopping these attacks. A key finding is that while missile defenses might be able to blunt some kinds of attacks, the DPRK will have options for retaliatory missile attacks that can reach their targets despite the presence of defenses, and Pyongyang will know which options those are. The existence of this second set of cases is crucial for US and allied leaders to recognize if they are considering taking actions under the assumption that defenses will be effective in protecting US and allied populations.

Introduction

What role might missile defense play in the event of the use of nuclear weapons in Northeast Asia?

Advocates discuss various possible missions for missile defense. Some of those missions, like reassuring allies that the United States will not be deterred from coming to their aid by the threat of a missile strike, are largely political and depend heavily on the perception of how well the defenses might work.

Other missions, such as allowing “freedom of action”—that is, enabling a country to decide to take aggressive military actions in a situation under the assumption it can blunt possible retaliatory missile strikes—depend instead on the actual level of demonstrated capability of the defense in tests under realistic conditions. Similarly, if deterrence fails and an adversary launches a missile attack, the ability to reduce the damage from such an attack will depend on the actual effectiveness of the defenses under the particular conditions of the attack.

Because of the limits of testing programs, and because the defender is not likely to know the specific

characteristics of a missile attack before it is launched, the actual effectiveness of a defense against that attack will be highly uncertain, or largely unknown, prior to the attack.

If a significant discrepancy exists between (1) the capability leaders believe a defense system has and (2) its actual capability against a real-world attack, that discrepancy can be a recipe for disaster. If political and military leaders believe defenses have greater capability than they in fact have, those leaders might take actions that precipitate retaliatory missile strikes that the defense is unable to stop.

The main conclusion of this article is that the DPRK will have options for missile attacks against the Republic of Korea (ROK), Japan, and the United States that have a high probability of success, despite the deployment of missile defenses (at least of the kinds currently deployed). Defenses may be able to stop some types of attacks, but North Korean leaders will know which attacks are most likely to succeed and can shape their launch strategy around those.

In particular, this article does not assume that missile defenses would be incapable of stopping some missiles fired at the United States and its allies in a conflict, or that there is no rationale for deploying certain types of missile defenses. What it instead shows is that current defenses will not be able to provide US leaders with enough confidence that they can stop a retaliatory strike to allow them to decide to take military actions that they would not take in the absence of missile defense. In other words, missile defenses will not be able to provide “freedom of action” if that freedom is not believed to exist in the absence of missile defenses.

US and allied military leaders must be clear about the effectiveness that missile defense may realistically be able to provide against a determined adversary based on the demonstrated capability of the defense systems in realistic test programs. While posturing and exaggerating the capability of missile defense may be a tactic that leaders use to shape the context of a crisis, deciding to take aggressive military action assuming an unrealistic or undemonstrated effectiveness for missile defenses can have catastrophic consequences.

The analysis in this article assumes that over the next decade there will be evolutionary modifications of current defense systems, with testing continuing at roughly the same pace as in recent years; possible development of a ship- or drone-based boost-phase missile defense system applicable to the DPRK, but no deployment of a mature, tested system; and evolutionary modifications of the DPRK’s missiles and nuclear weapons.

The Political Role of Missile Defense

As noted above, there are two general roles that missile defenses are likely to play in cases related to possible nuclear use in northeast Asia.

The first is a political role that could influence the context of a crisis and might therefore affect the probability that certain cases occur. This role depends largely on perceptions of how effective defenses might be, rather than on their actual ability to defend areas against attacks. The second is the role missile defense might play in actually intercepting missiles and reducing the effects of an attack during a conflict. How effective defenses might be at this role will be highly uncertain, and may be largely unknown, since it will depend both on the maturity and level of testing of the defenses but also on the details of the attacking missiles and any countermeasures the attacker may take, which the defender is unlikely to know in advance.

This paper will focus on the second of these two roles but will start with a brief discussion of the first.[\[1\]](#)

US political and military leaders have repeatedly made exaggerated claims about the capabilities of US missile defense systems.[2] In the context of a crisis in Northeast Asia, the United States will certainly continue to exaggerate the potential effectiveness of its Ground-based Midcourse Defense (GMD) system against the DPRK's long-range missiles, which it has been doing despite GMD's mixed records in tests and the lack of tests in realistic scenarios. Such exaggeration is seen in part as important for reassuring Japanese and Korean policy makers. These leaders have expressed concerns that although their countries are under the US nuclear umbrella, the United States might be deterred from using nuclear weapons to defend them by the prospect that such use would lead to a retaliatory nuclear attack against the US homeland. Overstating confidence in the ability of missile defense to stop such retaliation is an attempt by the United States to reduce such fears of "decoupling."

Concerns about decoupling similarly led to uncertainties about the credibility of the US nuclear umbrella for NATO during the Cold War once the Soviet Union gained the ability to attack US territory with its nuclear missiles. To increase the credibility that nuclear weapons would be used in the theater, NATO took several steps, including forward-deploying tactical nuclear weapons on the battlefield to increase pressure for NATO commanders to use them if enemy advances threatened to overrun them, and by having a "two-key" system that effectively allowed the United States to turn over launch control of some theater nuclear weapons to West Germany in a crisis. Some Japanese bureaucrats have privately expressed the desire for a similar two-key system with nuclear weapons the United States might use in the Asian theater, as a way of increasing the credibility that these weapons would be used in a crisis, although they acknowledge that such an arrangement is very unlikely.[3]

Another political use of missile defenses is to help leaders in various countries build support for military engagements by reducing public fears about the effects of retaliation that might result from such engagements. For example, some years ago a Taiwanese official told me that while he did not have confidence that US Patriot missiles in Taiwan would be effective at stopping possible Chinese missile attacks on the island, he thought deploying Patriots was an important step to reassure the public, which he believed had an inflated sense of the missile threat. His concern was that such fears by the public might constrain Taiwanese military options in a crisis.

A related example occurred during the 1991 Gulf War, when erroneous US claims that Patriot missile defenses were successfully intercepting Iraqi Scud missiles were used to reduce pressure on the Israeli government to launch retaliatory attacks. The United States was concerned that such attacks by Israel would fracture the coalition of countries the United States had put together to oppose Iraq. Analysis after the war showed that in fact the Patriots were ineffective at intercepting missiles, and that the Israeli military was aware of this fact during the war.[4]

At the same time, the existence of defenses has also been used by political leaders to reduce the pressure to launch a preemptive attack on the DPRK in response to perceived threats.

An additional political effect of the US focus on developing and deploying missile defenses has been to reduce the pressure to try to resolve the underlying security issues with the DPRK using diplomacy. Despite evidence late in the Clinton administration that DPRK leaders were open to accepting intrusive measures that would significantly limit, if not end, its development of nuclear weapons and long-range missiles, the incoming Bush administration instead pulled back from the negotiations and ramped up development of missile defenses. By exaggerating their confidence in the ability of missile defenses to stop a DPRK missile attack, US leaders have been able to reduce public fears about such attacks that might otherwise create strong pressure to engage the DPRK diplomatically to reduce the nuclear and missile threat.

The Effectiveness of Missile Defenses in Intercepting Missile Attacks

In differentiating the roles that missile defenses might play, it is important to distinguish between (1) the subjective “confidence” a military or political leader might express in the effectiveness of a certain defense system, and (2) the objectively defined “confidence level” that is mathematically determined from the results of actual tests of the system. The latter is a concept in probability theory that expresses what expectations one can logically draw, based on test data, about the kill probability of the defense system under the conditions of the tests.^[5] It is this rigorously derived confidence level in a given probability of intercepting incoming missiles that matters for assessing the ability of missile defenses to stop or reduce the damage from an actual attack.^[6]

Mathematics requires that, in order for a test series to provide a defender with high confidence in the level of effectiveness the defense system is likely to demonstrate in a particular scenario, the test series must consist of an adequately large number of tests.^[7] Such a test series must be repeated for those attack scenarios that differ in important ways, which further increases the total number of tests required.

One important consequence of this fact is that the number of tests required to establish high confidence is typically much larger than the number of tests that are actually performed for a defense system. As a result, the defender will have only a general sense of the actual effectiveness that can be expected of the system.

Moreover, it is critical to recognize that the test record only gives information about the performance of the defense system under the conditions of the tests. For example, care has been taken in past US missile defense tests for the target warhead to be spin-stabilized and travel on a well-behaved trajectory, and to be easily distinguished from other objects, such as missile stages and balloon decoys—all of which increases the likelihood of a successful intercept. These defenses have still not been tested, for example, against tumbling or significantly spiraling (cork-screwing) warheads, which can pose particularly difficult targets for interceptors to hit.^[8] As a result, the existing test records of these defenses gives little information about how well they would work against such targets.

Even more importantly, there are attacks that simply fall outside the conditions under which a defense is designed to operate. In those cases, one can say with high confidence that the defense will not be effective against such an attack. For example, the US Ground-based Midcourse Defense (GMD) and Aegis SM-3 defenses can only operate above the atmosphere—higher than about 100 km altitude—because at lower altitudes the combination of their speed and the atmospheric density heats and blinds their sensors. They cannot even attempt to intercept warheads at lower altitudes (technically, a “firing solution” does not exist).

It is therefore useful to distinguish between (1) cases in which an interceptor is unable to engage a warhead, meaning that it cannot even attempt to intercept under the scenario of the attack, and (2) cases in which an interceptor is able to engage the warhead but may not actually succeed in intercepting it due to details of the homing process, the presence of countermeasures the missile may release, etc. In case (1), in which the attacker denies the defense the ability to engage the warhead, it also denies it the ability to intercept.

What the analysis below shows is that there certainly exist attack cases in which US and allied defenses are able to engage the attacking warheads. Because of the limits of testing, the existence of countermeasures, etc., even in those cases US and allied leaders may have little confidence in the effectiveness of the defense.^[9] But beyond that, in many cases the DPRK would have attack options that can prevent some defenses from even engaging the warheads, while presenting the remaining

defenses with targets they are not designed to intercept. Those cases must clearly be recognized and considered by US and allied leaders.

Summary of Missile Defense Systems

Before considering possible conflict cases, this section summarizes the missile defense systems the United States and its allies have that might come into play in a Northeast Asian conflict. It describes their operation, how they have fared in tests, and what factors limit the confidence one could reasonably have in their effectiveness.

Appendix A gives a brief summary of the DPRK's missile program.

There are several general points to start with:

- Midcourse defenses, like the US GMD and Aegis Standard Missile 3 (SM-3) systems, attempt to intercept missile warheads at high altitudes and cannot engage a warhead below about 100 km altitude. At those lower altitudes, heating of the kill vehicle's infrared sensors by the atmosphere prevents it from homing on the target. Such exo-atmospheric kill vehicles maneuver using rocket thrusters, and the kill probability depends on the relative speed of the kill vehicle and the warhead (called the "closing speed"). These defenses are vulnerable to a range of countermeasures, such as light-weight decoys, that can prevent the interceptor from identifying the real target.[\[10\]](#)
- Terminal defenses, like Patriot, attempt to intercept as the warhead is re-entering the atmosphere above its target. These interceptors typically rely on radar sensors and maneuver using atmospheric forces. In this case the kill probability depends on the relative maneuverability of the interceptor and the warhead, which in turn depends in large part on the absolute speed of each object. To be effective, an interceptor must be able to generate lateral accelerations two to three times that of warhead.[\[11\]](#) Since maneuvering forces of an object in the atmosphere increase with the square of its speed, the interceptor is unlikely to be able to hit targets moving significantly faster than the interceptor since it will not be able to match the target's maneuvers, whether those are intentional or not (for example, due to tumbling or spiraling).
- Dividing chemical or biological weapons into large numbers of small submunitions that are released shortly after the missile booster burns out is not only the most effective way to deliver these agents by missile, it also creates too many lethal objects for midcourse or terminal defenses to stop. Developing submunitions is within the DPRK's technical capability, and, if its goal is to be able to retaliate by attacking population centers, it seems likely to have developed this capability to deliver these agents, which it is believed to stockpile.[\[12\]](#)
- Boost-phase defenses are intended to destroy missiles early in flight during their boost phase, before the missile releases its warhead(s). The advantage of this defense is that, if successful, it would stop a missile before it could release either a cloud of submunitions or countermeasures to accompany a warhead. The main disadvantage is that because the boost phase is very short—typically one to a few minutes—the interceptor must be based very close to the launch site of the missile to reach it in time. The United States does not currently deploy boost-phase defenses. However, such a defense against a country like the DPRK, which is geographically small, may be possible using interceptors based either on drones or ships stationed near the borders, and such systems have been proposed.[\[13\]](#) One potential countermeasure to boost phase defenses is for the attacker to fire several missiles closely spaced in time and location, some of which can be decoys without live warheads, as a way of creating more targets than there are interceptors that can reach them.

The defense systems considered are below:

- US GMD
- Aegis SM-3: Ship-based and Aegis Ashore
- Terminal High-Altitude Area Defense (THAAD)
- Patriot PAC-3 and PAC-3 MSE
- Aegis SM-2 and SM-6

US Ground-based Midcourse Defense (GMD)

The United States currently deploys 44 GMD interceptors, with 40 located in Alaska and four at Vandenberg Air Force Base in California. The interceptors boost an Exo-atmospheric Kill Vehicle (EKV) into space, which uses information from ground-based radars and on-board infrared sensors to attempt to physically collide with a warhead in flight (called “hit-to-kill”).

Despite repeated claims of high confidence by US officials that the GMD system could intercept long-range DPRK missiles,[\[14\]](#) there is no physical justification for that assertion based on the testing record. There have been only nineteen intercept tests since the testing program began in 1999—about one per year—and only four tests in the past decade. Currently the GMD system has successfully intercepted its target in about half of its intercept attempts, even though the tests have not been designed to be stressing.[\[15\]](#)

In these tests the target warhead has followed a well-behaved trajectory and has been easily distinguished from other objects, such as missile stages and balloon decoys. The system has still not been tested against tumbling or spiraling warheads, which are stressing for the kill vehicle and may in fact be likely targets the defense would encounter in a DPRK attack. Moreover, only two of the GMD tests have included intercontinental ballistic missiles (ICBM, with ranges greater than 5,500 km).

More generally, the details of an actual attack may differ in important ways from those of the tests, in part because the attacker can take steps to make the situation as difficult as possible for the defense. It is likely that these actual engagements would be the first time the defenses are used against missiles from these attackers, giving the attacker the element of surprise.

Exo-atmospheric defenses like GMD are inherently vulnerable to a range of countermeasures that are well within the capability of a country that is able to build a ballistic missile and a nuclear warhead to put on it.[\[16\]](#) Many countermeasures have the property that they represent a common-mode failure for interceptors, meaning if they evade one kill vehicle, they will evade all the kill vehicles engaging the target. That means that launching multiple interceptors at a target may not increase the kill probability.

To try to address the problem of countermeasures, the United States announced that it would build a set of large Long-Range Discrimination Radars (LRDRs), with the first one reportedly completed in Alaska in late 2021.[\[17\]](#) However, rather than using radar waves in the X-band the LRDR was designed instead to use S-band, which reduces the spatial resolution of the radar and undercuts its ability to discriminate warheads from decoys.[\[18\]](#) More recently, there are signs that the remaining LRDRs will not be built due to a new focus on building space-based sensors to track hypersonic weapons.

It is illogical to assume the DPRK would be building nuclear missiles with the intention of using them if necessary and yet would not equip them with countermeasures that would increase their effectiveness against known missile defenses the United States is building. Russia and China are

both believed to have developed and likely deployed such countermeasures on their long-range missiles.

For all of these reasons, US confidence that its GMD system would be effective in stopping an actual attack by North Korean long-range missiles (as well as an attack by Chinese or Russian missiles) is low today and will remain low in the coming decade. The data simply does not exist—and will not exist by the end of the decade—to provide a high confidence level of high effectiveness under real-world attack conditions.^[19]

Aegis SM-3 Defense

The Aegis missile defense system based on the Standard Missile 3 (SM-3) was developed initially to intercept missiles with ranges up to a few thousand kilometers, although the most recent version has been tested once against an “ICBM-representative target.”^[20] Like the GMD system, the SM-3 kill vehicle also is a hit-to-kill system that works above the atmosphere, and is unable to engage missiles at altitudes below about 100 km.

This system has been tested forty-five times since 2002 (about 2.5 tests/year) and has reportedly been successful in 80 percent of these tests.^[21] In the twenty-four tests against medium or intermediate range targets (1,000 to 5,500 km range), the success rate appears to have been about 86 percent, but even these successes provide only 50 percent confidence that the kill probability is as high as 82 percent.^[22] Assuming the kill probability for a single interceptor against a target is 82 percent, then targeting two interceptors on each target could give an effective kill probability of 97 percent, assuming the probabilities are independent of one another (which may not be true in practice).

However, as with the GMD system, these tests have not been conducted against stressing targets, such as tumbling warheads, and the tests appear to have been designed to minimize spiraling of the targets to provide a stable target. Moreover, because it is an exo-atmospheric defense it is also vulnerable to countermeasure issues similar to the GMD system. The tests conducted to date have not included realistic countermeasures.

As a result, while political and military leaders may be led to believe the system would have a high effectiveness against an attack, there are uncertainties and unknowns that keep one from assigning high confidence to the system’s performance.

People have occasionally suggested that Aegis SM-3 might be used to intercept ballistic missiles during the missile’s boost phase, but it is not designed to engage an accelerating target—which is what a booster would be—and does not have the divert capability to do this reliably.

Terminal High-Altitude Area Defense (THAAD)

THAAD is a hit-to-kill interceptor designed to engage short- and medium-range missiles (less than 3,500 km), although it has had one test against an intermediate-range missile (3,500 to 5,500 km).

It is designed to intercept targets between roughly 40 and 150 km altitude, so it operates in the high endo-atmosphere and low exo-atmosphere. It is believed to have a top speed of 2.6-2.8 km/s (Mach 8.7-9.3), and a maximum operational range of about 200 km.^[23]

The Pentagon lists the THAAD system as having sixteen successes in sixteen intercept tests since 2005.^[24] However, because of the relatively small number of tests conducted under similar scenarios, the test record implies lower confidence levels than it might at first appear. For example, ten of these tests were conducted against short-range targets, and half of those cases were “unitary”

targets, meaning the warhead did not separate from the missile body, which presented a very large target to the interceptor. Only five of the sixteen tests have been against medium-range targets. Five successful tests provide only 50 percent confidence that the kill probability against a single missile is as high as 87 percent. Alternately, these results mean that the United States could have high confidence (95 percent) that the kill probability is only greater than 47 percent.^[25] Even for a kill probability of 87 percent, there is a greater than 50 percent chance that at least one missile in an attack by five missiles would evade the defense. Firing more than one interceptor at each target might improve the total kill probability if the individual kill probabilities are independent, but countermeasures could cause what is called a “common mode failure,” in which case firing multiple interceptors would not help.

For endo-atmospheric engagements, THAAD should be able to engage some medium-range missiles if they are on a smooth, stable trajectory. However, it is unlikely to be successful at intercepting maneuvering or weaving targets that have speeds much greater than about 3 km/s, which corresponds to a range of about 1,000 km. It would have to engage intermediate-range missiles above the atmosphere. If it is engaging targets at altitudes above about 100 km, THAAD would be vulnerable to the countermeasures described above designed for use against midcourse defenses.

Patriot

The Patriot Advanced Capability (PAC)-2 defense system used in the 1991 Gulf War relied on a proximity fuse to trigger a blast fragmentation warhead that attempted to destroy incoming missiles low in the atmosphere. This system was followed by development of the PAC-3 defense, which also operates in the atmosphere using aerodynamic forces to maneuver but is designed as a hit-to-kill system.

The PAC-3 interceptor (now called the PAC-3 CRI (Cost Reduction Initiative)) has a speed of about 1.4 km/s (Mach 4.1) and is able to engage targets below about 24 km altitude. The maximum operational range of the interceptor is reported to be 15 to 20 km.^[26] A newer version of the system, called PAC-3 Missile Segment Enhancement (PAC-3 MSE), was fielded in 2016.^[27] The PAC-3 MSE includes an additional booster segment, so the interceptor is believed to have a top speed of 1.7-1.8 km/s (Mach 5.7-6), is able to engage targets below about 36 km altitude, and has an operational range of about 35 km.^[28]

Patriot is said to be designed to intercept short-range missiles. While that designation includes missiles up to ranges of 1,000 km, actual testing appears to have been against missiles with much shorter range. As discussed above, the interceptor is unlikely to be able to hit targets moving significantly faster than the interceptor, which may limit its ability to reliably intercept maneuvering or weaving warheads from missiles with ranges longer than 500 to 600 km.

Because of the short range of the interceptors, Patriot can defend areas within a few tens of kilometers around the location where the interceptor is deployed.

Aegis SM-2 and SM-6

Aegis ships also carry shorter range interceptors than the SM-3 missile. These systems use fragmentation warheads and are intended primarily to defend against aircraft and cruise missiles but may have some capability against short-range missiles.

Possible Nuclear-Use Cases

This section discusses the following possible cases for DPRK missile attacks:

- Attacks against the ROK
- Attacks against Japan
- Attacks against Guam
- Attacks against Hawaii
- Attacks against the continental United States
- Attacks against ships
- ASAT or EMP shots (high altitude nuclear explosions)
- Test/warning/demonstration shots (low altitude nuclear explosions)

The DPRK's goal for such an attack—for example, whether it was intended to have a counterforce effect or was simply retaliation targeted against population centers—affects the options Pyongyang would have for launching such an attack.

Attacks against the ROK

Because all of the ROK's territory lies within 500 km of the border with the DPRK, the entire country is within range of many DPRK missiles.

Seoul is located less than 50 km from the border with the DPRK, and as a result it is within range of the DPRK's artillery attacks. Because it is a very large population center it is vulnerable to missiles with low accuracy. The ROK has deployed US Patriot PAC-2 defenses for some time, and it recently received and deployed PAC-3 units.[\[29\]](#) These systems can be used for air defense as well as defense against short-range ballistic missiles and are assumed to be deployed around Seoul.

However, if the DPRK decided to attack this area with missiles, it could penetrate the defense in several ways. It has a number of different missiles with ranges greater than 1,000 km,[\[30\]](#) which could be launched to shorter ranges on depressed trajectories[\[31\]](#) that would fly too low to be attacked by Aegis SM-3 and might have reentry speeds that are too high for Patriot to intercept reliably. The United States deploys a THAAD battery in the ROK, which for political reasons is located nearly 200 km south of Seoul.[\[32\]](#) Because of its location, THAAD is unlikely to be able to reach and engage missiles targeted on Seoul.

In addition, since attacking Seoul does not require high accuracy, the DPRK could cause the incoming warheads to tumble or spiral, which would make them more difficult to intercept. It might also deliver chemical or biological weapons using submunitions that were released early in the missile's flight, creating too many targets for the defenses to stop.

Another potential target near Seoul is Camp Humphreys, which is the US army base that houses the 28,000 US soldiers that are stationed in the country. Nearby is Osan Air Base, one of two major US Air Force bases in the country. Both are within about 100 km of the border and are therefore likely out of the range of most DPRK artillery but easily reachable by ballistic missiles. As with Seoul and other targets throughout this small country, the DPRK could attack with missiles on trajectories that underfly SM-3 but might approach the targets at speeds faster than Patriot could reliably intercept. As above, THAAD is far enough south to make it unlikely that it would be effective at intercepting missiles fired at Camp Humphreys if the attack used missiles flown on depressed trajectories.

In principle, THAAD could engage missiles aimed at targets further south, such as bases at Busan and Kunsan, and the industrial center of Ulsan, if those missiles flew on standard trajectories.

However, the DPRK could launch a medium-range missile to these targets on a depressed trajectory that would fly too low for THAAD to engage. It could also cause its warheads to tumble, which would reduce the effectiveness of the interceptors, or it could launch submunitions carrying chemical or biological weapons.

In addition, the DPRK has been testing two new missiles—the KN-23 and 24—that are designed to reach ranges of several hundred kilometers by flying on non-ballistic trajectories, using fins to allow them to travel at about 50 km altitude. Flying them at somewhat lower altitudes would reduce their range somewhat but could place them at an altitude throughout their trajectory that was too low for THAAD to engage. While these missiles might approach their targets at low enough speeds to be engaged by Patriot interceptors in areas where Patriots were deployed, they would be able to attack targets throughout most of the country that were not within a few tens of kilometers of a Patriot deployment.

The DPRK is developing the Pukguksong missile to be launched from submarines in the future, and there have been some statements suggesting that the KN-23 could be launched from submarines. Both missiles would allow the DPRK to be able to attack targets in the ROK over short distances from unexpected directions if launched from submarines. However, North Korean submarines would likely be noisy enough in the foreseeable future to make them vulnerable to US anti-submarine forces if the submarines traveled very far from the DPRK coast. Similarly, North Korean surface ships carrying missiles would likely be detected by allied forces and could be destroyed early in a conflict, so these options might not appear attractive to Pyongyang.

The conclusion is that the ROK would need to rely on Patriot for missile defense. Although it may be able to protect some targets, albeit with uncertain effectiveness, it could not cover all of the ROK. The country would therefore be vulnerable to attack despite the deployment of missile defenses expected to operate in the next decade. Development of drone- or ship-based boost phase defenses to cover the DPRK could affect this conclusion, if shown to be effective and reliable.

Attacks against Japan

Unlike the ROK, Japan is far enough from the DPRK that if Pyongyang attacked using medium-range missiles launched from its territory on standard trajectories they would have to travel to high enough altitudes that they could be engaged by either THAAD or Aegis SM-3 above the atmosphere. For example, a 1,300 km range Nodong missile, which could reach Tokyo, would have an apogee on a standard trajectory of about 300 km.

Patriot would have little or no capability against these missiles; unless the DPRK launched short-range missiles from ships or submarines, the reentry speeds of the missiles would likely exceed what Patriot could engage. But either surface ships or submarines operating within a couple hundred kilometers of Japan during a crisis would be at high risk of being detected and sunk once a conflict started.

As above, if the DPRK were targeting population centers or other relatively large soft targets with nuclear weapons, it could release warheads that tumbled or spiraled during flight, which would reduce the effectiveness of interception by THAAD or Aegis.

The DPRK could also launch long-range missiles on depressed trajectories that would reduce or eliminate the amount of time they were high enough for an exo-atmospheric defense like Aegis to engage and would have a speed well above what THAAD has been reliably tested against and is likely be able to intercept during terminal phase. US and Japanese leaders would have little or no confidence that they could intercept such missiles.[\[33\]](#)

For example, a long-range missile like the Hwasong-14 with a speed of about 7 km/s when its engines stop burning—giving it a range of about 10,000 km on a standard trajectory—could be flown on a depressed trajectory to a range of 1,300 km with an apogee of about 100 km, which is likely too low for Aegis to intercept. The flight time of such an attack would be about six minutes, giving very little warning time; the flight time of a Nodong missile over that range would be ten to eleven minutes.

A warhead on this trajectory would be traveling too fast for THAAD to intercept while it was at high enough altitudes for THAAD to engage (above 40 km). Because of its relatively long path through the atmosphere on this trajectory, if the ballistic coefficient of the reentry vehicle was low enough it might slow to speeds that would allow Patriot to engage it. However, the defense would not know this in advance and would therefore not be able to count on Patriot. Even if effective, Patriot would defend a small area compared to a large population center like Tokyo, so many batteries would be needed. If the DPRK monitored where these defenses were deployed, it could direct attacks at undefended population centers throughout Japan.

Although so far the DPRK has only launched its long-range missiles on highly lofted trajectories, there does not seem to be a technical barrier to flying them on depressed trajectories.[\[34\]](#) While flying on this trajectory would reduce the accuracy of the missile, these attacks would presumably be used against large population centers and this decrease would not matter.

If the DPRK's goal was primarily to create terror and complicate military operations, it could also use chemical or biological weapons against population centers and military bases in Japan. Delivering these agents using submunitions released from ballistic missiles shortly after burnout would not only optimize the distribution and release of these agents but would also present too many objects for a defense to engage.

Drone- or ship-based boost phase interceptors off the DPRK coast could potentially play a role if they were successfully tested and deployed in the coming decade.

The bottom line is that the DPRK appears to have ways to evade missile defenses if it decided to attack Japan, and that Japan would therefore have no confidence that it could be protected from such an attack in a conflict.

Attacks against Guam

Beyond Japan, the next closest land target that the DPRK is likely to attack is Guam, which is 3,300 km away and houses a major regional US military presence at a number of bases. Guam is also a potential symbolic target because it is US territory. However, the goal of an attack on Guam would likely be a counterforce mission to disrupt the operation of the bases, rather than a terror attack against a population center, given the small population of the island (fewer than 200,000).

Because of the distance, any missile attack launched from DPRK territory would reach high enough altitudes that it could be engaged by Aegis or possibly by THAAD. Moreover, because Guam is physically small—roughly 10 km across in most places—Pyongyang might have little confidence that it could target Guam effectively without firing a large number of missiles. It currently has little or no information about the accuracy of its intermediate and long-range missiles, due to either systematic or random errors. The DPRK has conducted only two non-lofted tests of these missiles and there is no indication it was collecting telemetry from the missile during the tests. Such telemetry, as well as a number of additional tests, would be required for the DPRK to have confidence that the missile could have an accuracy as small as 10 km over these distances. The small size of the island suggests that the DPRK would not try to defeat Aegis defenses by tumbling or spiral the warhead in flight,

which could further reduce the accuracy.

For these reasons, attacking Guam does not seem like an attractive option for the DPRK.

An Aegis Ashore system might make sense rather than having an Aegis ship posted offshore and might be more effective than THAAD; this is the upper end of what THAAD has been tested against.^[35] A drone- or ship-based boost phase around the DPRK might add an additional layer of defense.

Attacks against Hawaii

Like Guam, Hawaii houses major US military bases, including the headquarters of the United States Pacific Command (USPACOM), which is made up of the Air Force, Army, Marine Corps and Navy, all of which have bases in Hawaii.

The most populated island is Oahu, with nearly a million people; it is roughly square, about 40 km across, and 7,300 km from the DPRK. The USPACOM headquarters is on Oahu, as is the base at Pearl Harbor.

The big island of Hawaii is 7,500 km from the DPRK. It is about 130 km across and houses 200,000 people.

Like Guam, Oahu is an inviting military target. But it is far enough away from the DPRK that nuclear warheads launched on ballistic missiles would travel high above the atmosphere and could be engaged by the US GMD system based in Alaska, assuming it had sufficient warning time. Such warheads could also potentially be engaged by Aegis SM-3, if it was in position and if tests over the next decade show it to be capable against long-range missiles.^[36] These warheads might also be engaged by an Aegis Ashore deployment in Hawaii, which has been discussed but is not currently planned. As noted above, however, because of the limits of testing, the existence of countermeasures, etc., even in cases in which engagement is possible US and allied leaders would have little confidence in the ability of the defense to actually kill the warhead.

Moreover, the DPRK might consider a missile attack against Oahu using chemical or biological submunitions because of the large population density there; such an attack could successfully evade defenses. While it might not significantly affect operation of the military bases on Oahu, it would demonstrate the vulnerability of a large number of US citizens to a missile attack.

Attacks against the Continental United States

Having successfully tested long-range missiles in 2017 (Hwasong-14 and 15), the DPRK appears to have the ability to reach the continental United States with nuclear weapons. Pyongyang presumably sees this fact as helping to deter US attacks on its territory.

The accuracy of its long-range missiles is not expected to be good enough to effectively attack military targets, and its goal would instead be to threaten large population centers. Because of the apparent range of the Hwasong-15, the DPRK would be able to target cities throughout the United States. Since the possibility of delivering such an attack appears to be what has motivated the DPRK to develop long-range missiles and nuclear weapons, one has to expect that it has also equipped these missiles with countermeasures that it has either developed or purchased.^[37] Although the United States may not have seen tests of countermeasures, as Donald Rumsfeld noted, “absence of evidence is not evidence of absence.”^[38] Russia, which appears to be the ultimate origin of much of the DPRK’s missile technology,^[39] is known to have had an active countermeasures program. As a result, while DPRK leaders might not have high confidence that they could successfully deliver an

attack, US leaders could have little confidence in the ability of its missile defense systems to stop such an attack.

If the DPRK's goal was terror attacks against the US public, it could also defeat midcourse and terminal missile defenses by using submunitions on its long-range missiles to deliver chemical or biological agents.

As noted above, boost phase defense against the DPRK—either from ships or drones—may be feasible due to the small geographic size of the country. Such systems have not been built but could likely be developed over the next decade.

Attacks against ships

A large component of US and allied forces in a conflict with the DPRK would be sea-based, including carrier groups, and these would present tempting targets for Pyongyang to attack if possible. Since the DPRK air force would be no match for US and allied aircraft protecting the fleet, the DPRK would likely be limited to launching missile attacks against the ships, assuming it had the ability to locate them, which is not a given.

Because ships are relatively small and mobile targets, the DPRK may lack confidence in its ability to use high-accuracy or homing missile warheads to attack them effectively using conventional missile warheads in the foreseeable future. The DPRK might consider using a nuclear weapon instead, which could have a relatively large destructive radius against a relatively soft target like a ship.

Since such an attack would clearly be against a military target and take place at sea far from population centers, Pyongyang might see it as more justified and less provocative than an attack on cities. And, if successful, such an attack could potentially have a significant—although certainly not decisive—military effect.

The effectiveness of such an anti-ship attack would depend on the range to the ships, as discussed below, and the accuracy of the missile used in the attack. For example, a 20 kiloton airburst would lead to a destructive radius on the sea below it of roughly one to two kilometers. A 150 kiloton airburst, comparable to the largest yield weapon the DPRK has tested, would have a destructive radius below it of roughly three to five kilometers.^[40] However, since the DPRK has not tested its longer range missiles enough to have an estimate of their accuracies, it would have little confidence that it could place a warhead close enough to a ship to destroy it.

Consider several cases:

If ships were within about 400 km of the DPRK, Pyongyang could use KN-23 and KN-24 missiles, which would fly too low to be engaged by Aegis SM-3 interceptors but might be engaged by Aegis SM-2 or SM-6 interceptors. However, the DPRK could also use longer range missiles on depressed trajectories, which could fly too low for SM-3 but could have too high a terminal speed to be engaged by SM-2 or SM-6. Flying its missiles on depressed trajectories could significantly reduce their accuracy.

If the ships were within about 2,000 km of the DPRK, Pyongyang could use a long-range missile like the Hwasong-14, with a burnout speed of about 7 km/s, on a depressed trajectory. As in the case of attacks on Japan discussed above, such a missile would likely fly too low for SM-3 to engage, and it would be too fast for SM-2 or SM-6 to intercept. However, at this range ships could be stationed with Japan between them and the Korean peninsula, and if THAAD interceptors were deployed in Japan they might be able to engage these missiles as they flew over Japan, since they would be at an

altitude of 60-80 km at that point in their trajectories (Figure 1).

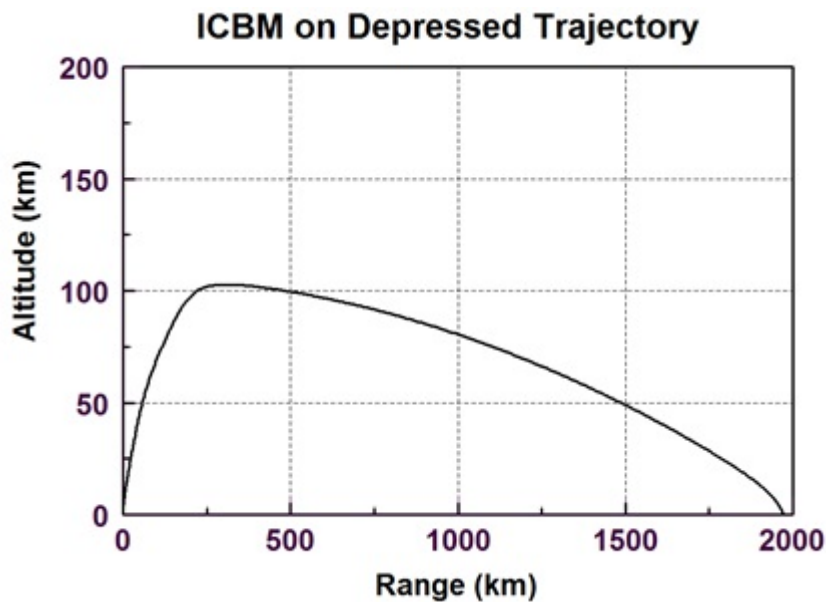


Figure 1: Potential depressed trajectory flown by a Hwasong-14 missile

If the ships were significantly farther from the DPRK, missiles attacking them would have to fly higher trajectories and would likely be vulnerable to attack by SM-3. The ability of SM-3 to actually intercept warheads from these missiles depends on the considerations discussed above, such as whether the missiles included countermeasures or the warheads were tumbling.

The conclusion is that the DPRK is unlikely to have high confidence in the success of such an attack and therefore may choose to attack other targets. At the same time, if such an attack occurred, the United States and its allies may not have high confidence in stopping the attack, since it would depend on the details of the attack.

High altitude nuclear explosion: An EMP or ASAT shot

By detonating a nuclear weapon at high altitude, the DPRK could create an electromagnetic pulse (EMP) to disrupt electronics over large areas of the Earth below the blast and disrupt or destroy large numbers of satellites in low Earth orbits (LEO).[\[41\]](#)

An airburst at an altitude of about 30 km would create EMP in a ground region with a radius of about 600 km; the radius would increase to 1,100 km for a blast at 100 km altitude.[\[42\]](#) Such an attack could significantly disrupt civil infrastructure in the affected region, but because most critical military equipment is hardened against EMP, it is unlikely to seriously affect US and allied military capabilities.

An airburst at an altitude of 100 km or higher could disable essentially all LEO satellites in line of sight of the blast very quickly due primarily to X-rays. Such an airburst would pump the Earth's radiation belts to a level that would cause many other LEO satellites to fail over weeks or months as they repeatedly passed through regions of high radiation.[\[43\]](#) Important military satellites could be radiation-hardened to reduce their vulnerability to this effect, and such an attack would not affect satellites in higher orbits, such as navigation satellites in semi-synchronous orbits or communication satellites in geo-synchronous orbits. As a result, such an attack would be highly disruptive, but its military effects are not likely to be significant.

In both cases, the DPRK would have to expect retaliation for launching such an attack, while not

significantly degrading military capabilities or destroying population centers. The DPRK is therefore likely to see such an attack as inviting retaliation for little gain.

Whether the booster carrying this warhead could be intercepted depends on where it was targeted. The DPRK seems unlikely to attempt an EMP attack against the ROK because it could also affect electronics in its own country. An EMP attack on Japan could be launched on an ICBM following a depressed trajectory that remains below 100 km as described above. Such a warhead would underfly SM-3 interceptors, detonate before reaching low enough altitudes to be engaged by Patriot, and would be traveling too fast for THAAD to intercept reliably.

An EMP attack against the United States would require delivery by long-range missile, which could be engaged by Aegis SM-3 or GMD interceptors. Estimates of how successful these defenses would be must take into account their demonstrated effectiveness in tests and the likely presence of countermeasures accompanying the warhead.

Low-altitude nuclear explosion: Test/warning/demonstration shot

The DPRK might also consider detonating a nuclear weapon at low altitude, say 10 km, over a remote location in the Pacific Ocean as a warning shot or a demonstration of its nuclear capability, with the intention of forestalling or stopping a conflict. A detonation at this altitude would be low enough to have little or no effect on satellites and would create little EMP on Earth. It would also be high enough not to place a large amount of irradiated water vapor into the atmosphere, thereby reducing the amount of fallout produced. The DPRK could portray such an explosion as a warning shot with minor enough physical consequences that it might believe the United States would not respond militarily; it is unclear, of course, how the United States might actually respond.

This warhead would be carried on a missile with a range of several thousand kilometers, in order to reach a remote part of the ocean. It could be launched in a direction that was clearly not aimed at US or allied territory, but it would need to overfly Japan early in flight, and Aegis SM-3 interceptors might be able to engage it. The DPRK might announce the test in advance to reduce the risks that it could lead to dangerous escalation, although doing so might allow the United States or Japan to position an Aegis cruiser to attempt an intercept. Depending on the location of the test, the US GMD system might or might not be able to engage it. In either case, the DPRK would presumably launch the warhead with countermeasures to attempt to defeat interceptors.

Conclusions

This paper discusses specific types of missile attacks the DPRK might launch in a conflict. It finds the DPRK will have options for missile attacks against the ROK, Japan, and the United States that have a high probability of success, despite the deployment of missile defenses (at least of the kinds currently deployed). Even if defenses are able to stop some types of attacks, DPRK leaders will know which attacks are most likely to succeed and can shape their launch strategy around those.

It is crucial for US and allied leaders to recognize this vulnerability if they are considering taking military action under the assumption that defenses will be effective in protecting US and allied populations. Current defenses will not be able to provide US leaders with enough confidence that they can stop a retaliatory strike to allow them to decide to take military actions that they would not take in the absence of missile defense.

In other words, missile defenses will not be able to provide “freedom of action” if that freedom is not believed to exist in the absence of missile defenses.

Appendix: the DPRK's Missile Programs

In the past five years, the DPRK has expanded its missile arsenal to cover ranges from short- to intercontinental. It is believed to be able to arm these missiles with conventional weapons, nuclear warheads, and chemical and biological weapons in submunitions.

Short range (< 1,000 km)

The DPRK has tested and deployed for many years a number of short-range missiles, including the KN-02, with an estimated range of 120-170 km range, and several variants of Scud missiles (Hwasong 5, 6, and 9). The latter are single-stage liquid-fueled missiles with ranges between 300 and 1,000 km.

More recently, the DPRK tested two new missiles, which the United States military calls the KN-23 and 24. These are one-stage solid-fueled missiles reportedly able to carry about 500 kg to a range of 400 to 450 km. These missiles do not follow standard ballistic trajectories but instead use fins in the atmosphere to keep their trajectories below 50 km altitude (a standard missile of this range would reach altitudes above 100 km).^[44] The KN-24 is reported to have been tested to a range of 230 km while staying below 30 km altitude.^[45]

All of these missiles can be launched from mobile launchers.

Medium range (1,000-3,000 km)

The DPRK has for many years deployed Hwasong-7 missiles, called Nodong in the West, which is believed to be able to carry about 700 kg to a range of 1,200 to 1,500 km, putting all of Japan within reach. This missile is essentially an enlarged Scud, with one-stage and liquid fuel, and an accuracy of probably a couple kilometers.

More recently, the DPRK has tested several versions of a one-stage solid-fueled missile called the Pukguksong, which is believed to have a range up to about 2,000 km. Different versions of this missile can be launched from mobile launchers on the ground or from submarines.^[46] Little is known about the status and accuracy of these missiles.

Intermediate range (3,000-5,500 km)

The DPRK's only known missile in this category is the Hwasong-12 (or KN-17), which has had only three known successful tests. The tests suggest the missile could reach a range of 3,700 to 4,800 km, but the payload of the missile in these tests is not known.^[47] The significance of this missile is that it was the first DPRK missile tested that demonstrated long enough range to reach US military bases in Guam.

Intercontinental range (> 5,500 km)

The DPRK has tested two missiles with maximum range greater than 5,500 km, the Hwasong-14 and 15. These missiles have only been tested on highly lofted trajectories over the Sea of Japan—twice for the Hwasong-14 and once for the Hwasong-15. The Hwasong-14 appears from its test to have a range of more than 10,000 km,^[48] and the Hwasong-15 of more than 13,000 km,^[49] although in neither case do we know the mass of the warhead carried in the tests.

These missiles are believed to use components produced and tested in the Soviet Union; it is also possible that the DPRK was able to acquire full missiles. This conclusion is supported by the fact that all three tests of these two missiles were successful despite the lack of a series of developmental

tests by the DPRK.^[50] If it acquired full missiles, Pyongyang might have information on the reliability and accuracy of these missile from the previous Soviet tests; if not, these three tests offer little information about either.

If the DPRK is reliant on importing key components for these missiles, that could significantly limit how many of these missiles it has in its arsenal.

There continue to be questions about whether the DPRK has adequate reentry vehicles for these missiles, since none of them were tested on standard, long-range trajectories. However, an analysis of the reentry environment during its lofted tests shows the DPRK could have proof-tested a reentry vehicle on those tests that would survive on a long-range flight.^[51] Moreover, there do not appear to be any technical barriers to the DPRK developing reentry vehicles that could withstand the heat and stress of reentry over these ranges.

The US Congressional Research Service analysis of these missiles in 2021 concludes:^[52]

North Korea improved its ability to strike the entire continental United States with an ICBM through a series of tests in 2017. The successful launches of the liquid-propellant, multistage Hwasong-14 (KN-20) and Hwasong-15 (KN-22) in July and November 2017 demonstrated significant advances in North Korean missile technology. Despite these improvements, the reliability of these systems remains uncertain. Without further testing, neither the North Koreans nor others can assess whether the missiles will function as designed in combat. The absence of ICBM tests since the only successful launch of the Hwasong-15 in November 2017 may also suggest that the North Korean missile force possesses only a small quantity of these weapons or that it is continuing its test moratorium for nontechnical reasons.

III. ENDNOTES

[1] For a discussion of the potential roles of missile defense in the strategic context, see Chapter 5 of L. Grego, D. Wright, and G. Lewis, "Shielded from Oversight," Union of Concerned Scientists, 2016, <https://www.ucsusa.org/sites/default/files/attach/2016/07/Shielded-from-Oversight-full-report.pdf>

[2] G. Lewis, "Updated List of Claims about GMD Effectiveness, Mostly Missile Defense blog, February 2020,

<https://mostlymissiledefense.com/2020/02/24/updated-list-of-claims-about-gmd-effectiveness-february-24-2020/>

[3] G. Kulacki, "Japan and America's Nuclear Posture," Union of Concerned Scientists, 2010,

<https://www.ucsusa.org/sites/default/files/2019-09/japan-american-nuclear-posture.pdf> These issues are considered in more detail in P.K. Davis, J. Kim, Y. Park, and P.A. Wilson, "Deterrence and Stability for the Korean Peninsula," *Korean Journal of Defense Analyses*, 28(1), 1-23, 2016, https://www.rand.org/pubs/external_publications/EP66368.html

[4] T. Weiner, "Patriot Missile's Success a Myth, Israeli Aides Say, *New York Times*, 21 November 1993, <https://www.nytimes.com/1993/11/21/world/patriot-missile-s-success-a-myth-israeli-aides-say.html> This ineffectiveness was caused by inadvertent countermeasures the Scud's employed as a result of the spiraling of the warheads during reentry after breaking off from the booster body, and the fact that the Iraqi "stretched Scuds" reentered at higher speeds than the fuse on the Patriots could handle.

[5] Grego et al., “Shielded from Oversight,” Appendix 8, “Confidence Levels and Probability,” <https://www.ucsusa.org/sites/default/files/attach/2016/07/Shielded-from-Oversight-appendix-8.pdf>

[6] Of course, if the testing conditions do not represent realistic conditions of an attack, then this assessment will overestimate the capability of the defense, as discussed below.

[7] For an example, see the discussion below of THAAD’s test program.

[8] P. Zarchan, “Tracking and Intercepting Spiraling Ballistic Missiles,” Proceedings of IEEE Position Location and Navigation Symposium, March 2000, pp. 277–284, <https://doi-org.libproxy.mit.edu/10.1109/PLANS.2000.838314>

[9] Even if a defense system was known with high confidence to have a very high probability of intercepting a missile—say 95 percent—there would still be a nearly one-in-four chance that at least one missile would penetrate the defense in an attack by five missiles. If the actual intercept probability was 80 percent, in such an attack at least one missile would penetrate the defense two-thirds of the time. When defending against nuclear-armed missiles, even these high intercept probabilities might be seen as offering inadequate protection to allow freedom of action.

[10] Note that launching multiple interceptors against each incoming warhead could increase the probability of kill, assuming the kill probability of each interceptor is independent of the others. However, the effective use of countermeasures by the attacker would likely mean that if one interceptor misses its target, all of the interceptors will do so.

[11] See, for example, P. Zarchan, *Tactical and Strategic Missile Guidance—An Introduction (7th Edition)*, American Institute of Aeronautics and Astronautics (AIAA), 2019.

[12] A. Sessler, J. Cornwall, B. Dietz, S. Fetter, S. Frankel, R. Garwin, K. Gottfried, L. Gronlund, G. Lewis, T. Postol, D. Wright, *Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned US National Missile Defense System*, April 2000, pp. 49-58 and Appendix F,

<https://www.ucsusa.org/sites/default/files/2019-09/countermeasures.pdf>

[13] R. Garwin and T. Postol, “Technical Refinements in Design Features of the Airborne Patrol Against North Korean ICBMs,” May 2018, <https://fas.org/rlg/refine.pdf> ; J. Sankaran and S. Fetter, “Reexamining Homeland Missile Defense against North Korea,” *The Washington Quarterly*, Volume 43, Issue 3, 2020, <https://doi-org.libproxy.mit.edu/10.1080/0163660X.2020.1813400>. Proposals for space-based defenses require very large systems that are both very expensive and vulnerable to attack.

[14] Lewis, “Updated List of Claims about GMD Effectiveness,” February 2020.

[15] G Lewis, “What Did FTG-11 Actually Prove?,” Mostly Missile Defense blog, April 2019, <https://mostlymissiledefense.com/2019/04/04/what-did-ftg-11-actually-prove-april-4-2019/>; Missile Defense Agency, “Ballistic Missile Defense Intercept Flight Test Record,” August 2021, <https://www.mda.mil/global/documents/pdf/testrecord.pdf>

[16] National Intelligence Council, *Foreign Missile Developments and the Ballistic Missile Threat to the United States Through 2015*, September 1999, https://www.dni.gov/files/documents/Foreign%20Missile%20Developments_1999.pdf; A. Sessler, J. Cornwall, B. Dietz, S. Fetter, S. Frankel, R. Garwin, K. Gottfried, L. Gronlund, G. Lewis, T. Postol, D. Wright, *Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned*

US National Missile Defense System, April 2000,

<https://www.ucsusa.org/sites/default/files/2019-09/countermeasures.pdf>; JASON, MDA Discrimination: Unclassified Summary, MITRE Corporation, 3 August 2010), <https://irp.fas.org/agency/dod/jason/mda-dis.pdf>

[17] J. Judson, "US Missile Defense Agency declares initial delivery of Long-Range Discrimination Radar in Alaska," *Defense News*, 6 December 2021, <https://www.defensenews.com/pentagon/2021/12/06/us-missile-defense-agency-declares-initial-delivery-of-long-range-discrimination-radar-in-alaska/>

[18] Grego et al., *Shielded from Oversight*, Appendix 3, "The Long-Range Discrimination Radar," <https://ucsusa.org/resources/disastrous-us-approach-strategic-missile-defense#ucs-report-downloads>

[19] For example, a goal for the development of the system that became the US GMD system reportedly was a design requirement of 95 percent effectiveness with 95 percent confidence against a small-scale missile attack (M. Dornheim, "Missile Defense Design Juggles Complex Factors," *Aviation Week and Space Technology*, 24 February 1997, p. 54).

[20] US Department of Defense press release, 17 November 2020, <https://www.defense.gov/Newsroom/Releases/Release/Article/2417334/us-successfully-conducts-sm-3-block-ii-a-intercept-test-against-an-intercontinent/>. Note that the closing speed of an SM-3 Block II-A interceptor, with a speed of about 4.5 km/s, against a 5,500 km-range ICBM (which has a speed of about 6 km/s) would at most be about 10% larger than the closing speed with a 3,500 km-range target (which has a speed of about 5 km/s) and could be less than that depending on the geometry of the engagement.

[21] Missile Defense Agency, "Ballistic Missile Defense Intercept Flight Test Record," August 2021, <https://www.mda.mil/global/documents/pdf/testrecord.pdf>; George Lewis, "Table of Aegis SM-3 Intercept Tests," Mostly Missile Defense blog, May 2013, <https://mostlymissiledefense.com/2013/04/27/table-of-aegis-sm-3-intercept-tests-april-27-2013/>

[22] Grego et al., "Shielded from Oversight," Appendix 8.

[23] Astronautics.com, "THAAD," <http://www.astronautix.com/t/thaad.html>

[24] Missile Defense Agency, "Ballistic Missile Defense Intercept Flight Test Record," August 2021, <https://www.mda.mil/global/documents/pdf/testrecord.pdf>; George Lewis, "THAAD Flight and Intercept Tests Since 2005," Mostly Missile Defense blog, July 10, 2016, <https://mostlymissiledefense.com/2016/07/10/thaad-flight-tests-since-2005-july-10-2016/>

[25] Grego et al., "Shielded from Oversight," Appendix 8.

[26] NATO, "Patriot Factsheet," 2012, https://www.nato.int/nato_static/assets/pdf/pdf_2012_12/20121204_121204-factsheet-patriot-en.pdf

[27] Lockheed Martin, "PAC-3," <https://www.lockheedmartin.com/en-us/products/pac3-mse.html>

[28] GlobalSecurity.org, "PAC-3 Missile Segment Enhancement (MSE)," nd, <https://www.globalsecurity.org/space/systems/patriot-ac-3-mse.htm>; Missile Defense Advocacy Alliance, "Patriot Advanced Capability-3 Missile," August 2020, <https://missiledefenseadvocacy.org/defense-systems/patriot-advanced-capability-3-missile/>

[29] Yonhap News, "S. Korea receives upgraded U.S. Patriot missile interceptor," 12 December 2020, <https://en.yna.co.kr/view/AEN20201212001000325>

[30] A 1,000 km range missile would be able to reach speeds of about 3 km/s.

[31] A missile on a depressed trajectory burns the full amount of fuel as on a standard trajectory but reaches a shorter range because it is launched at a lower angle. See L. Gronlund and D. Wright, "Depressed-Trajectory SLBMs: A Technical Assessment and Arms Control Possibilities," *Science and Global Security* 3, no. 1-2, pp. 101-159, 1992, <http://scienceandglobalsecurity.org/archive/sgs03gronlund.pdf>

[32] The current THAAD deployment is at the Lotte Skyhill Seongju Country Club (36° 3'N, 128° 13.5'E). This location was picked for political reasons and its rationale is to defend potential targets in the south of the country.

[33] Japan recently decided against deploying Aegis Ashore (See M. Dahlgren, "Japan Halts Aegis Ashore Deployment Plan," *Missile Threat*, Center for Strategic and International Studies, June 23, 2020, <https://missilethreat.csis.org/japan-halts-aegis-ashore-deployment-plan/>), but the basing mode of Aegis would not change these conclusions.

[34] Gronlund and Wright, "Depressed-Trajectory SLBMs." Calculations for this trajectory show that total heating of the reentry vehicle would be essentially the same on these two trajectories, and that the peak heating rate would be several times lower on the depressed trajectory compared to a standard trajectory.

[35] Deploying Aegis Ashore on Guam has been discussed, but there is no current plan to do so.

[36] To date, only one test against an "ICBM-class target" has taken place, but few details are known about this test. US Department of Defense Press Release, "U.S. Successfully Conducts SM-3 Block IIA Intercept Test Against an Intercontinental Ballistic Missile Target," 17 November 2020, <https://www.defense.gov/Newsroom/Releases/Release/Article/2417334/us-successfully-conducts-sm-3-block-ii-a-intercept-test-against-an-intercontinen/>

[37] National Intelligence Council, *Foreign Missile Developments*, 1999; Sessler et al., *Countermeasures*, 2000.

[38] R. Cohen, "Rumsfeld Is Correct—the Truth Will Get Out," *New York Times*, 7 June 2006, <https://archive.nytimes.com/www.nytimes.com/iht/2006/06/07/world/IHT-07globalist.html>

[39] M. Schiller, "The Scope of Foreign Assistance to North Korea's Missile Program," *Science & Global Security*, 27:1, July 2019, <https://scienceandglobalsecurity.org/archive/sgs27schiller.pdf>

[40] These calculations use Nukemap 2.7 (<https://nuclearsecrecy.com/nukemap/>). The distances are chosen to be somewhat smaller than the 5 psi and 3rd degree burn radii. The optimal heights of burst for these two cases (chosen to maximize the 5 psi radius) are 0.85 and 1.7 km, respectively, so the warhead would have to go through most of its terminal phase through the atmosphere, which would degrade its accuracy.

[41] Low Earth orbit includes satellites with orbital altitudes below 2,000 km.

[42] These distances include regions on Earth within line-of sight of the blast and may overestimate the size of the area where the EMP is significant. For a blast at altitude h , the ground radius is given by $r_e \cdot \arccos(r_e / (h + r_e))$, where r_e is the radius of Earth.

- [43] E. Conrad, G. Gurtman, G. Kweder, M. Mandell, and W. White, "Collateral Damage to Satellites from an EMP Attack." DTRA-IR-10-22, August 2010, <https://ntrl.ntis.gov/NTRL/dashboard/searchResults.xhtml?searchQuery=ADA531197>
- [44] M. Elleman, "North Korea's New Short-Range Missiles: A Technical Evaluation," *38North*, 9 October 2019, <https://www.38north.org/2019/10/melleman100919/>; M. Elleman, "Preliminary Assessment of the KN-24 Missile Launches," *38North*, 25 March 2020, <https://www.38north.org/2020/03/melleman032520/>
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IV. NAUTILUS INVITES YOUR RESPONSE

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Nautilus Institute

608 San Miguel Ave., Berkeley, CA 94707-1535 | Phone: (510) 423-0372 | Email:
nautilus@nautilus.org